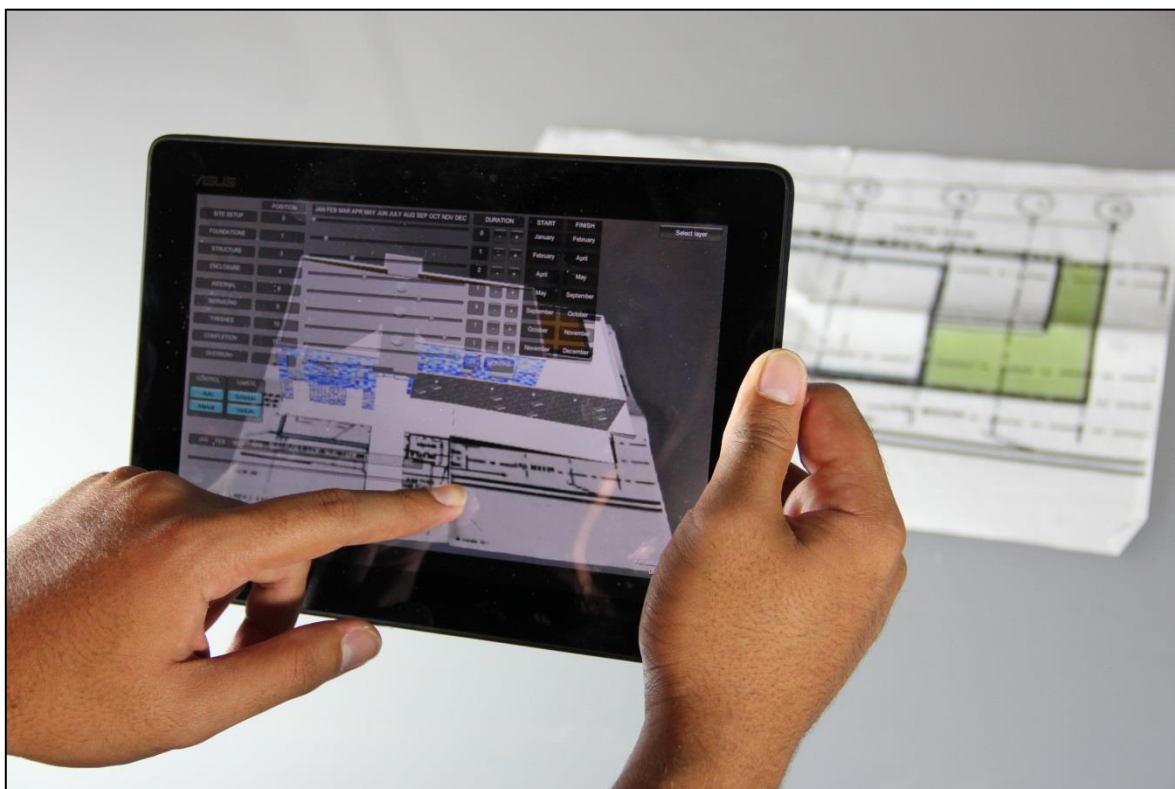


# 4D Building Information Modelling With Augmented Reality on Mobile Devices to Support Construction Management:

*Applications and key performance criteria from a stakeholder perspective*



By

Jay Vaai

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## 1. ABSTRACT

This research addresses the gap between construction project management and the 3D visualization of construction sequence. Typically project managers use software that presents construction stages as 2D Gantt charts, where the X axis represents time and the Y axis represents the construction activity. These are then typically cross referenced to either 2D or 3D construction drawings. The potential of linking construction sequencing charts and critical paths to Building Information Models is well established. So called '4D BIM' applications such as *Synchro* enable the linking of three dimensional information and Gantt charts. There is also precedent in virtual reality simulations, such as the AR4BC project by (Woodward, Hakkarainen, & Rainio, 2010) and the desktop VR simulation applications for teaching construction management (Nikolic, 2006).

From these and other precedents it is observed that 4D BIM is orientated towards the final stages of design where models are complex and not optimized, while full VR applications are typically not available in practice. Moreover, recent availability of augmented reality applications for mobile devices opens up new ways to integrate 4D BIM into project management. As part of initial discussions with consultants, a mock-up of an AR application running on a tablet that would enable on - site visualization was demonstrated. Given positive feedback, prototype applications were developed using the *Unity* interactive 3D authoring platform, which provides real time interaction between a Gantt chart and a 3D model. The final AR application uses a plan drawing as the marker and the user can switch between isometric and first person cameras to review construction sequencing, with the aim of identifying potential sequencing issues and / or clashes in the design while on site.

The prototype interface and functionality have been evaluated through a series of structured interviews with building industry professionals. The results of these interviews have been analysed and from this, key performance criteria and guidelines for further development have been identified. This thesis illustrates the potential of AR on mobile devices for construction management, documents the design and implementation of a prototype application and articulates issues for further research from the perspective of key building industry stakeholders.

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## 2. INTRODUCTION

### AIM

This research aims to evaluate the potential of augmented reality (AR) on mobile devices to enable the use of 4D Building Information Modelling (BIM) in order to support construction management. The objective is to develop prototype applications and through a methodology of structured interviews with key stake holders, identify key performance criteria and guidelines for further development. The term key stakeholders in the scope of this research refer to the construction practitioners directly involved in the process such as project managers, architects, and engineers.

The following sections present a review of 4D BIM with a focus on applications developed for mobile devices and precedent for augmented reality is undertaken. This review identifies a gap in current knowledge and subsequently research questions are identified and a research methodology articulated.

### 4D BUILDING INFORMATION MODELLING (4D BIM)

The on-going research and development of software that merges schedule based information such as Gantt charts with 3D construction models is referred to as 4D Building Information Modelling or 4D BIM. 4D is a reference given to the 4<sup>th</sup> dimension of time in Computer Aided Design (CAD) modelling after the 3<sup>rd</sup> dimension of space or 3D (Vicosoftware, 2014). There are higher dimensions/levels of BIM such as 5D BIM which addresses cost information and 6D BIM which addresses sustainable design (Holzer). BIM is an emerging technology that is increasing dramatically in usage today for the development of complex 3D buildings, where architectural and engineering teams work synchronously to develop one shared building model (Wammen, 2010).

3D and 4D applications/software have distinct differences for visualization. 3D BIM enables the user to visualize a building model. 4D BIM advances this by combining schedule related information with the 3D model and enables the user to visualize the process in which the building model will progress (Khanzode, Fischer, & Reed, 2005). 4D BIM applications today are well established and are widely used for enabling construction practitioners to make informed decisions that induce a reduction in time delays and enable identification of clashes early in the project life cycle (Staub-French & Khanzode, 2007). This occurs more often in large scale commercial projects where both the 3D model and 2D management schedule grow very large as a result of increased complexities and people involved in the construction process.

Today there are a variety of desktop computer programs that are engineered for 4D BIM simulation. Figure 1 below lists some of the more common 4D BIM tools that currently have a wide use in the Architecture, Engineering and Construction (AEC) industry today. Software such as Synchro and Autodesk Navisworks both allow the fusion of Gantt chart information from Microsoft Project (MS

Project) and 3D models from Autodesk Revit. Both software types have diverse and complex functions that enable 2D Gantt charts to be cross referenced to respective components in a 3D Model at different stages in construction. A Gantt chart or bar chart is a project management technique that lists a series of tasks for an activity and is represented as a series of bars along a timeline (Gantt.com, 2012). Although these BIM platforms have been designed and programmed to address the bridge between schedules and 3D models. They contain complexities that require a background experience in BIM software which some lack in some construction management practitioners. Project managers who are accustomed to opening up CAD files and finalising changes will find BIM programs more challenging to implement similar workflows (Holzer, p. 467).

Product Name	Manufacturer	BIM Use
Navisworks Manage Navisworks Scheduling	Autodesk	Clash Detection Scheduling
ProjectWise	Bentley	Clash Detection Scheduling
Digital Project Designer	Gehry Technologies	Model Coordination
Visual Simulation	Innovaya	Scheduling
Solibri Model Checker	Solibri	Spatial Coordination
Synchro	Synchro Ltd.	Planning & Scheduling
Tekla Structures	Tekla	Structure-centric Model Schedule driven link
Vico Office	Vico Software	Coordinate Scheduling Estimating

Figure 1: Common software programs for 4D BIM simulation (Reinhardt, 2009)

### BIM and Mobile Technology

With the improvement of smart mobile technology and the constant development trend of so called mobile applications (apps), the construction industry is considering the potential of mobile BIM. Not only are apps portable, but through improved visualization software and sensory features these mobile platforms have become relatively easy to use (Woodward, Hakkarainen, & Rainio, 2010).

Applications such as Autodesk 360, Autodesk Sketchbook, Magicplan are just a few recent mobile applications that have been specifically developed for use in the AEC industry and are currently used in practice today. Autodesk 360 provides a full stereoscopic view of a 3D BIM simulation and is operational on both smart phone and tablet platforms (Autodesk, BIM 360, 2013). Autodesk Sketchbook provides drawing tools for Architectural concept development and is suitable for when the architect requires an en suite of sketch tools to draw out ideas on site (Quirk, 2012). Magic plan has gained a lot of attention in the apple marketplace as being a leading tool for architectural design for its use in quickly dimensioning interiors and developing 2D Plans using mobile sensory

information. These are three of several applications that are currently on the smart device market and more are in development (Quirk, 2012).

**AUGMENTED REALITY**

Mixed reality is a sub-class within virtual simulation technology, where digitized objects are merged with real world objects to create a hybrid physical and virtual world (Milgram & Kishino, 1994). Mixed reality has been an on-going research field that has progressed throughout the past 20 years. The field of research can be considered in terms of a continuum that spans from full simulation (virtual reality) to the simple reproduction of reality through video recording; with augmented reality (AR) and augmented virtuality (AV) being hybrids of the two (Milgram & Kishino, 1994).

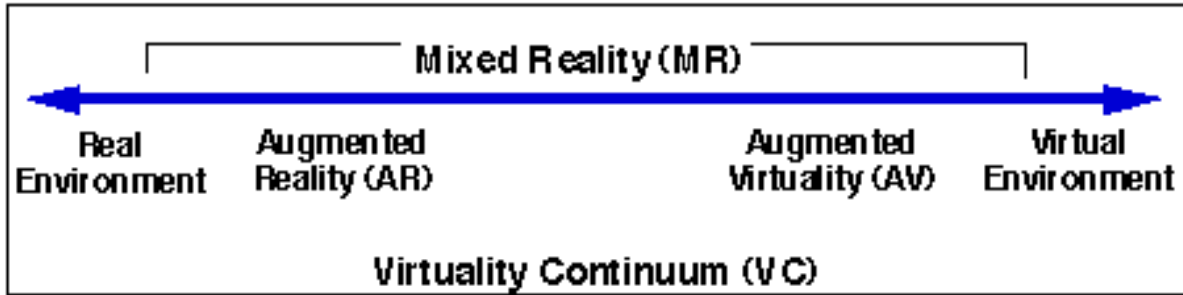


Figure 2: Simplified representation of a "virtuality continuum" (Milgram & Kishino, 1994).

There was initially a heavy focus in research on virtual reality and this is now common practice in 3D video games and film. Computer aided design has also now progressed to the point where high quality 3D visualization of design and construction processes are now common place. Research with augmented reality had been hindered by availability of technology. Early AR simulations relied on bulky back pack worn computers and were controlled using custom built hardware as shown in figure 3 below (Haller, Billinghamurst, & Thomas, 2007, p. 106).



Figure 3: Outdoor augmented reality environment backpack system/Information on screen (Haller, Billinghamurst, & Thomas, 2007, p. 133)

However recent advances in the power of mobile technology and the availability of simple tracking software based on scene markers, has enabled much new research. By mid-2009 augmented reality had surpassed virtual reality as an internet search term as seen in the figure 4 below (Schonfeld, 2010), indicating the impact of these new technologies.



Figure 4: Augmented Reality vs. Virtual Reality Google analytics (Schonfeld, 2010)

Augmented reality superimposes virtual information onto the physical world, typically using real time video capture. Either through the use of 2D image markers or through GPS tracking, 3D models can be aligned with the perspective of the real time video. This can be displayed on a video screen or projection, or through a head mounted display (HMD). Much recent activity has focused on the use of 2D markers and mobile screens such as tablets and smart phones.





Figure 5: Augmented Reality in Architecture (DesignBoom, 2012)

Augmented reality can also be defined as a medium that is experienced, as explored by Alan B. Craig in his book *Understanding Augmented Reality* (Craig, 2013). This is different from Milgram and Kishinos definition that portray augmented reality as a technique in mixed realities technology. The emphasis is on the interactive and experiential aspects of the technology, in contrast to previous traditions of text and film making.

*“One reads a book. One watches a movie. One experiences augmented reality” (Craig, 2013)*

Figure 6 is an example of one early augmented reality application for hand held devices, called the invisible train. By manoeuvring physically in the real world around the 2D markers set on the table; the user is able to view a virtual train simulation from different angles in AR. Touching the screen with a stylus enabled the user to interact with the 3D models and re arranges the train tracks in different formats (Haller, Billingham, & Thomas, 2007, p. 108).



Figure 6: Early augmented reality tests: Invisible Train demonstrates collaborative hand-held augmented reality gaming (Wagner, Pinatric, Ledermann, & Schmalstieg, 2005, p. 108)

Augmented reality today is widespread and it has visualization applications for advertising, gaming, social networking and many more (Jang & Hudson - Smith, 2012). The potential for augmented reality has moved to tracking and recognizing not only flat image markers but also markers on shaped objects such as cylinders and special frames (Qualcomm, Resources - Cylinder targets, 2012). This is particularly useful for advertising company messages using augmented reality. An example of taking advantage of this advertising power was the development of an AR game in Christchurch NZ called "*Zombies from Hell*" (Strecker, 2013). The only way to play the game was to obtain the marker that was on the advertiser's pizza box. Activating the application and focussing it onto the 2D marker on the pizza box simulated a small 3D game world, where the advertiser's premises took centre stage. (HellsPizza, 2013). This example demonstrates the contemporary robustness and accessibility of AR based on marker technology.





Figure 7: Zombies from Hell AR Game (HellsPizza, 2013)

An alternative to tracking technologies, now also available on mobile devices, is the use of Global Positioning Systems (GPS) and Geographic Information System (GIS) shown on the next page. This technique allows the user to geo locate a 3D model in a particular location in the world using google mapping and wireless technologies. This method does not require a 2D target marker but relies on integrated wireless internet in order to identify the mobile devices position to be located.



Figure 8: GPS Located Architectural 3D Models using GPS and Wi-Fi (Cronin, 2011)

Further parallel developments to this improvement in hardware are evolving software applications for achieving augmented reality. There are now several authoring platforms that enable non-specialists to create content and applications using streamlined workflows that reduce programmatic complexities. The Unity 3D development engine for example is capable of achieving augmented reality by integrating an extension plugin called Vuforia. This plugin is a software development kit created by mobile developers Qualcomm focussed on the integration of tools, which removed complex work flows that were common within previous software development. Once the plugin is installed, a variety of options are available to aid the user in producing an augmented reality simulation powered on a mobile device (Qualcomm, Augmented Reality (Vuforia) , 2012). Vuforia is one of many methods available today that can author and develop augmented reality.

## RESEARCH QUESTION AND SCOPE

The overview of 4D BIM, the porting of applications to mobile devices and the precedent for AR on mobile devices identifies a gap in current research that this thesis addresses. In particular, in the field of visualization for construction project management, there is an opportunity to provide access to 3D visualization. As is documented in the early stages of this research, there is interest within this sector for the on-site 3D visualization of construction assemblies and construction sequence. The proposition that underpins this research is that 'AR BIM' applications on mobile devices may provide new ways to support construction project management. In order to explore this proposition, the research is structured around the following research questions.

- *From a stakeholder perspective, what aspects of project management could AR BIM on a mobile device best address?*
- *What are the key performance criteria and guidelines for development of AR BIM on a mobile device?*

In order to address these questions the following methodology is used.

- **Precedent review:** key precedents and issues from previous research are identified; these enable the 'mock up' of a potential AR application.
- **Stake holder consultation:** initial ideas for the AR application and its potential use in project management are tabled with key stakeholders; a real world project is obtained to provide a realistic scenario to evaluate the prototype.
- **Iterative development of a prototype AR application:** the prototype is developed in a series of stages; with each stage subject to internal review and feedback from academics and industry stakeholders.
- **Structured interviews:** a working prototype is demonstrated to representatives from key stakeholders; feedback is documented through structured interviews based on the two research questions.
- **Analysis of interviews:** Each conversation is documented; consistent themes are established; subjected to analysis, discussion and graphic documentation; and from this the two research questions are addressed.

## SIGNIFICANCE OF RESEARCH

As described above, there are many available and growing technologies that enable linkages with Gantt charts and a rising amount of mobile/non - mobile applications available for architectural use. However, there are only a handful of applications that are currently in development for 4D information visualization using augmented reality.

Project managers are among the few practitioners that lack the training and tools to effectively visualize the construction process. Current Computer Aided Design (CAD) software focuses on providing 3D visualization of the end product of a construction project (Ibrahim, 2006). The use of Augmented Reality is one method that has much potential to enable project managers with little experience of 3D BIM software to exploit the advantages of construction visualization. Project managers are known for their versatility and constant movement on and off building sites, hence they are a key group who might benefit from mobile BIM (Danko, 2012).

The significance of this project is to address a growing area in research for mobile augmented reality. It focuses on simulating 4D information on site using AR. This is to enhance the understanding and to aid the project manager in identifying potential issues before and during the project life cycle. Literature identifies that 4D BIM is standard practice on a desktop computer and is widely used today. Mobile 4D BIM on site is a growing area of research and 4D AR BIM is also at its early stages of development. This research looks into transporting 4D BIM onto a mobile platform so that common tasks that a project manager undertakes on site are directly linked to the 3D model. The 3D essentially supplements the manager in making informed decisions and identifying possible issues.

The focus is to explore another communication channel that enables the project manager to visualize 3D models using mobile augmented reality. It is unclear what features are needed by stakeholders and the restricted scale of a tablet screen presents a challenge for developing an effective user interface. Initial research is needed to evaluate the key tasks that an AR application would address and how these can be embedded within an effective user interface. Through the implementation of a prototype application and subsequent feedback from a range of stakeholders, the objective of the thesis is to generate recommendations and guidelines that can underpin further research and application development.

### 3. PRECEDENT REVIEW

Given the scope and focus of the research is on application development the strategy is to focus on precedent for applications and discussion around these. A full precedent review of building information modelling and graphic user interfaces is beyond the time constraints available. Through close analysis of state of the art commercial applications, precedent from academia and other precedent from mobile technologies; direct precedent that addresses the research objectives will be obtained. The objectives of this chapter discuss in detail the examples that have influenced and inspired the design process in chapter 4. It discusses areas of research which inform the design process and identifies the extent of current knowledge as evident in application precedent. The importance of researching 4D applications is because this research is directed at merging management information and 3D models. Therefore precedent must be drawn from areas of research that have addressed this link and the tools they use.

The precedent review is divided into 2 portions. The first section - computer applications - discusses precedents such as mainstream software and research applications that are used to simulate and practice 4D BIM. The precedents for this review are assessed in terms of:

- **4D BIM Industry Standard practice**  
Identifying BIM mainstream products that are used for 4D BIM in industry.
- **Capacity to handle 3D content**  
This was important for all mobile application precedents as the case 3D model for the application would be industry standard and have very high precision detail in 3D content.
- **Special functions/Significant features**  
Analysing for what makes each precedent different from the other and the aspects that could inform the design of the Graphical User Interface (GUI)
- **Approach to displaying information on screen**  
How does the application operate and display certain types of information about a 3D model, and how does it tie task related information to a 3D model visually.

The second section examines mobile applications and discusses precedents of mainstream smart device apps that are being used for construction related simulations. This was undertaken to ascertain functional aspects that could inspire and inform the design of the prototype applications – in particular the graphic user interface (GUI) and covers these areas:

- 4D & 3D BIM on mobile devices
- AR 3D BIM for visualization
- 4D AR BIM for visualization
- 4D BIM research projects

The scope of the precedent review has also in part, been set by the authoring platforms available. As discussed below, these enable a decision to be made on the platform that will be used for developing the prototype. This narrows the scope of the subsequent application review to examine the capacity of Unity 3D in relation to the research aims.



## AUTHORING PLATFORMS FOR AUGMENTED REALITY

Within the book *Emerging technologies of Augmented Reality*; Haller, Billinghurst, & Thomas identify distinct development platforms that are available for creating and authoring AR simulations. These platforms include the AR toolkit, Studierstube and DWARF. These are particularly important authoring precedents as they are popular for their ease of use. They do not need extensive programming and emphasise AR technology for non-programming users (Haller, Billinghurst, & Thomas, 2007, p. 162). There are numerous software platforms that are capable of authoring augmented reality simulations. However the focus here is to analyse platforms that have construction/architectural based examples. Two established platforms are available in this context – AR Toolkit and Unity 3D.

### AR TOOLKIT

The AR Toolkit developed by Dr Hirokazu Kato is a popular authoring platform for augmented reality today. Currently it is available freely as a downloadable package online and improvement of its features is a work in progress at the University of Washington, HIT Lab NZ at the University of Canterbury in New Zealand, and ARToolworks Inc. in Seattle (ARToolkit, 2013). AR Tool Kit uses computer vision algorithms to track 2D target markers and uses C or C++ programming languages to create interfaces and add functionality. It also supports both video and optical see through augmented reality. AR is supported through direct video feed of the real world with a 3D object overlain or alternatively can support designing environments for AR on Head Mounted Displays. The toolkit has a few limitations that are common for most AR authoring tools, such as the influence of 2D marker size and pattern. The more distinct the pattern is with colour/shape the easier the camera will register it from a distance. If parts of the 2D marker are covered the 3D model will not superimpose (ARToolkit, 2013). Figure 9 shows how the AR Toolkit camera technology tracks a 2D target and how a 3D object is superimposed over video stream of the real world.

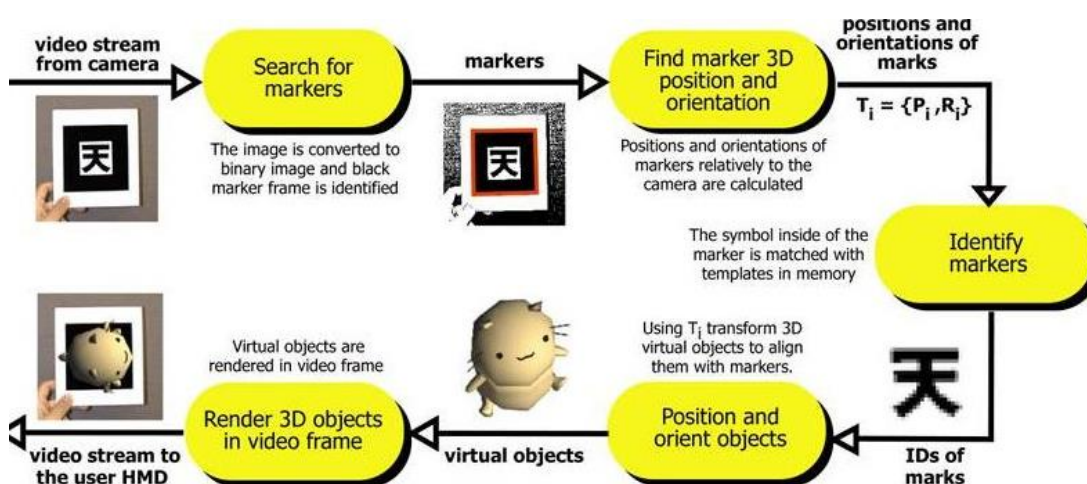


Figure 9: AR Toolkit workflow (ARToolkit, 2013)

There are a few construction CAD related projects that have used the AR toolkit to simulate augmented reality of a 3D building model onto a target 2D marker as shown in figure 10 below. Furthermore there is also precedents that suggest the AR Toolkit has extendable features that allow AR applications to be ported onto mobile devices for android (ARToolworks, 2014).

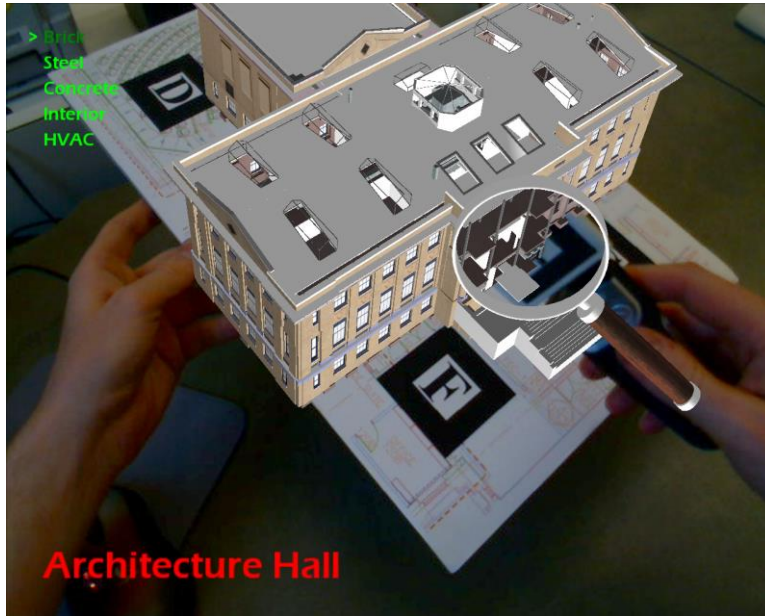


Figure 10: Project ARchitectureView (Belcher & Brian , 2008 )

## UNITY 3D

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Unlike AR Toolkit, Unity 3D is not an authoring platform that is solely focused on creating augmented reality applications. It is a development engine for the production of primarily video games and to some extents entertainment simulations (What is Unity and what can I do with it?, 2013). Unity 3D is also a common platform for the development of serious games, which are simulated environments for training and learning. These include simulations such as army personnel training, construction safety situations and lifesaving real time environments developed with Unity 3D. A serious game precedent where employers are trained to visualize life on an oil rig environment will be discussed further in the precedent review chapter. Unity 3D would appear to be the ideal platform for this project, primarily because of the capacity to build sophisticated user interfaces. Unity 3D also has well-documented dictionaries of scripting commands that are available online on the main Unity 3D website and also on a variety of independent developer websites. In addition all scripting commands can be written in either C# or JavaScript (Unity3D, Welcome to the Unity Scripting Reference!, 2013).

Unity 3D is one of the easiest authoring platforms to use since it has such a diverse range of precedents and uses in gaming and entertainment (Fear, 2009). It was important to find research precedents that demonstrated application development for construction uses and could simulate a vast amount of 3D content whilst maintaining performance. Unity 3D among all authoring platforms, delivered this with its numerous online precedents of 3D modelling simulations and training examples. Documented resources show the limitations of scripting and key performance criteria for 3D performance and content. Many tutorial resources generated by the creators of Unity 3D are available online alongside hundreds of other avid developers who have posted free resources and training. Most importantly within these resources are scripting samples that contain C# and JavaScript which can be easily manipulated to serve a different function. In addition Unity 3D has a diverse community of developers that share knowledge on forums. This ability to access various development forums allows any user to analyse methods that other developers have used to achieve similar goals/functions.

A separate extension package called Vuforia enables augmented reality to be integrated with Unity 3D. The extension is easy to install and has a simplified set of tools. Porting an application for a mobile smart device is relatively straightforward and there are not many programmatic complexities to deal with (Qualcomm, Augmented Reality (Vuforia) , 2012). The complexity of AR controls within Unity 3D are limited compared with AR specific platforms such as the AR toolkit. Developing an AR application with Unity 3D also requires added software development kits (SDKs) and mobile platform licenses which are not free. Despite this added complexity, Unity 3D provides a sophisticated platform, is well supported in terms of documentation and examples. For these reasons, and given the authors limited programming experience Unity 3D was chosen to undertake the application development.

## COMPUTER SOFTWARE APPLICATIONS

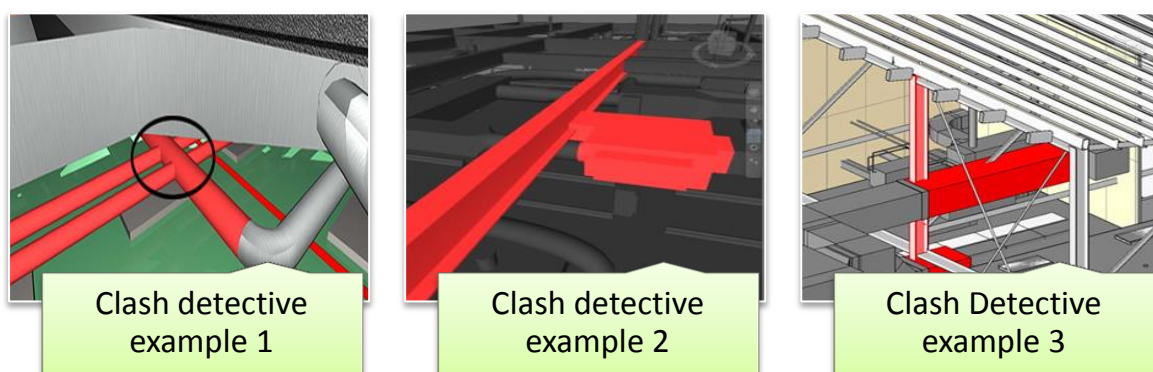
In order to begin development of the prototype, precedent from common 4D BIM applications and other precedent in academia will be examined. The aim is to identify functions/aspects from these examples that can inform the design of the prototype application. The chosen software platforms are well established desktop computers applications that are capable of 4D BIM integration. Also discussed are recent mobile platform precedents such as smart reality and BIM 360 which are lightweight mobile versions of two desktop computer applications. Applications such as Navisworks and Synchro both have abilities that enable users to integrate a Gantt chart with 3D building models from BIM platforms such as Revit. This section also discusses desktop computer research projects such as the VCS project in which a different development path was used to integrate MS project with a 3D model. From this review of 4D BIM, a final section examines an oil rig simulation that illustrates the interaction and visualization capabilities of Unity 3D called the Oil rig simulation. These areas of precedent – commercial 4D BIM, examples from academia and a large scale simulation – will inform the subsequent development of the prototype applications.

## NAVISWORKS

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Developed by Autodesk; Navisworks enables the integration of common scheduling software Microsoft project (MS Project) with a range of trade specific 3D models from mainstream Autodesk BIM programs. Navisworks also has integrated file size reduction tools making it a well-established tool for multi sized BIM projects and is also valued for its ease in filtering and grouping objects with similar object properties (Morkos, Macedo, Fischer, & Somu, 2012). Navisworks can also integrate with other scheduling tools such as Asta and Oracle Primavera (AutodeskNavisworksHelp, 2014). It operates by cross referencing components in a 3D model back to tasks listed within the respective Schedule/Gantt chart. This link can then enable the user to control the project visually using tools that graphically identify clashes and 3D timelines. (Autodesk, Navisworks, 2013). These clash detection tools identify conflicts not only in the schedule but also components that are in the 3D model as shown in figure 11 below. Therefore any Autodesk native 3D models such as Revit, which are integrated into navisworks can be analysed for modelling clashes using the clash detective.

Navisworks is an important precedent among other 4D BIM precedents since it is the industry standard program used in practice. Navisworks has the capacity to simulate projects with relatively large file sizes and has a well-established system for identifying project clashes using the clash detective function. The clash detective function is very useful for identifying and resolving potential convergences between various servicing components such as structural beams and piping in a 3D model as seen below in Figure 11. By identifying these clashes early the risk of cost overruns and potential conflicts is reduced hence improving the coordination amongst key stakeholders (Autodesk, Navisworks, 2013).



**Figure 11: Navisworks clash detection systems identifying intersections in servicing components**

**Left:** (Logiseek, 2012), **Middle:** (MrAsBuilt, 2014), **Right:** (Architecture, 2012)

## BIM 360 GLUE

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Navisworks is today is not yet able to simulate augmented reality but there is precedent that validates developers are slowly shifting into making it a portable mobile application. This comes as a result from the development and incorporation of some of its features with a recent Autodesk mobile application product called BIM 360. Similar to Navisworks it gives the user a 360 degree view of the project in 3D on a tablet computer. It can identify clashes with a variety of tools on screen whilst on the move. This is particularly useful for practitioners that want to take a portable version of a 3D model on site and access it virtually with any other key stakeholders (Autodesk, BIM 360, 2013).

BIM 360 is important not just for being an extension of Navisworks for mobile devices but also an application that can simulate the complexities of large 3D model content. This is important in this precedent review as this will be a challenge during development to simulate large amounts of 3D content on devices with lesser computing power. This is a challenge in many mobile application platforms that intend to simulate complex 3D content, as optimization plays a key role during development (Jie, Yang, & Haihui, 2011). BIM 360 also enables online collaboration of a singular 3D model on a cloud based system increasing the practice of teamwork and partnership between project participants. A variety of tools enable users to pinpoint issues and save the view they were in in order for different users to find. Comments and arrows can be drawn and saved on the 3D model and the application is able to communicate this information with a main Navisworks desktop computer program (Schwaiger, 2013).

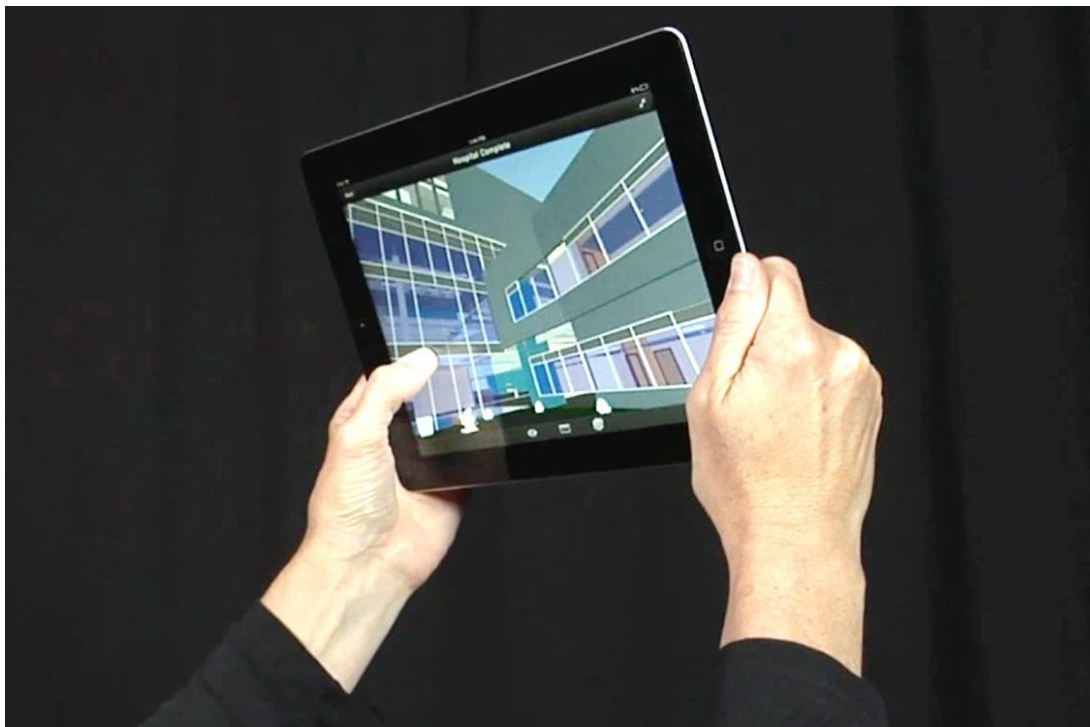


Figure 12: BIM 360 virtual simulation view on an apple iPad tablet computer (Autodesk, BIM 360, 2013)

## SYNCHRO

Synchro is relatively similar in function to Navisworks in the ability to merge project management information from MS project and provide virtual simulation tools that graphically show clashes in both schedule and 3D model. Apart from interface design, navigation methods and selection tools both Navisworks and Synchro have clash detection tools that highlight 3D components that are conflicting (SynchroSoftware, 2012). Both applications have different workflows but both strive for the same objective of integrating task based information and 3D components in simulation. Small differences such as methods of selecting objects and navigating the interface using the mouse and keyboard set these applications apart. Synchro and Navisworks integrate and import similar 3D model files from Autodesk products.

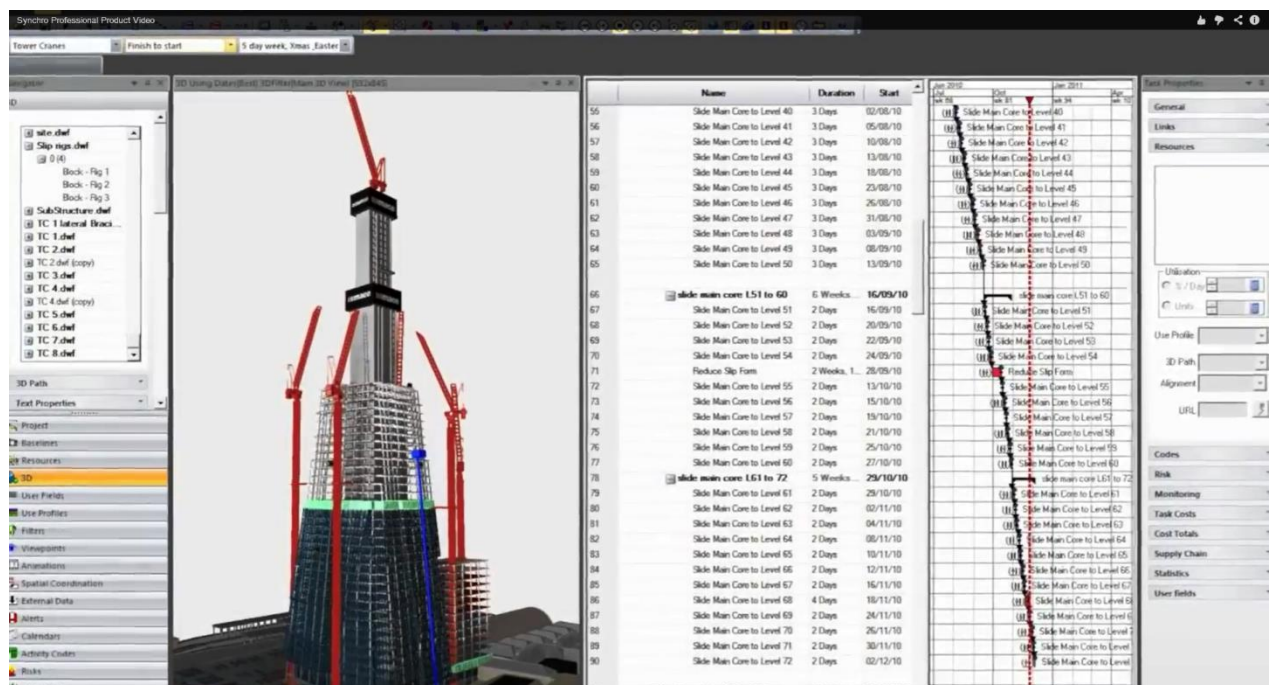
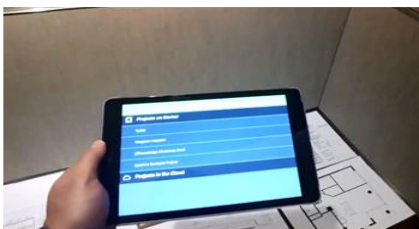


Figure 13: Synchro integrating with MS project Gantt chart (SynchroSoftware, 2012)

## SMART REALITY

Synchro through collaboration with software developers JBKnowledge have also released an application for smart devices which is simulated using augmented reality. This precedent is the most important of all examples that have been discussed in this chapter as it is one of the few precedents that display construction management information using augmented reality. Smart Reality is a 4D AR (augmented reality) BIM application which simulates a Revit based 3D model in AR using the 2D building plan as a target marker. The application smart reality is by far the closest example of mobile 4D AR BIM that has been found through research at this stage in time. Smart reality is a particularly important precedent since it is one of the few applications that is operating on an android device and has a video demonstration of functions. Although developers have released a Beta version for testing they also stress that it is still a work in progress among many other research projects that are carrying out 4D AR BIM. The application has features that allow the user to simulate an augmented reality 4D model of a Revit model onto a 2D plan acting as the target marker (Benham, 2014). Shown in figure 14 below are a number of features after activating the application that gives users added perspective on a 3D model.

a) Application active



b) Model Activated in AR on 2D Plan



c) 3X scaling 3D model up



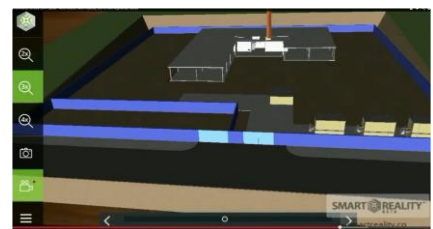
d) Floor plan example



e) Timeline 1



f) Timeline 2



g) Timeline 3

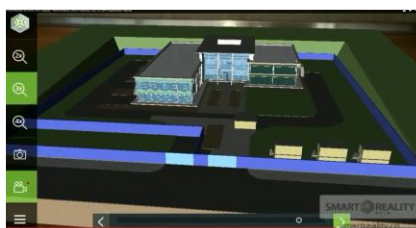
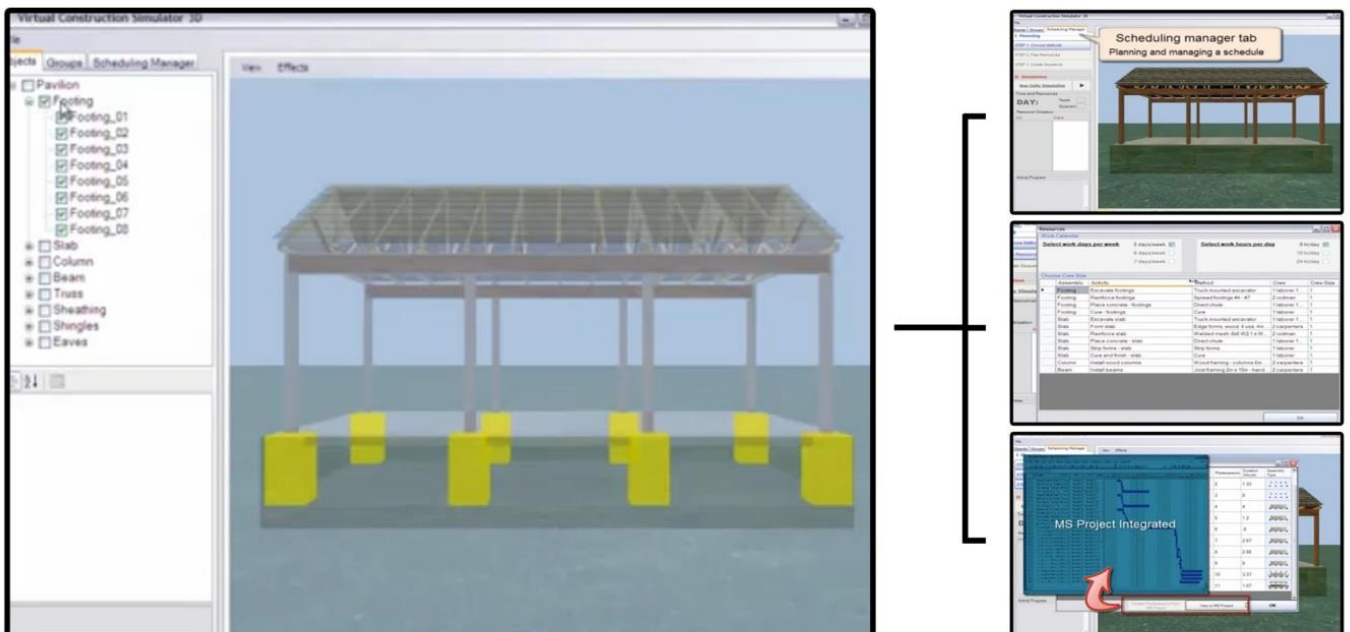


Figure 14: Smart Reality application (Benham, 2014)



## VIRTUAL CONSTRUCTION SIMULATOR

The virtual construction simulator is a research project which aimed to integrate a MS project Gantt chart with a 3D building model as shown in figure 15 below. The Gantt chart reacted to changes made in the schedule and was further referenced on the 3D model in visual representation. The goal of creating this project was for improving engineering education in planning and construction management amongst students at Penn State University. This was done by exposing them to playing the simulation as a type of game where players had to test different construction scenarios. (Messner, et al., 2011).



**Figure 15: VCS Project interface enabling MS Project cross referencing (Nikolic, 2006)**

This project was significant as a research precedent as it recorded a workflow showing an attempt at the same concept for this research through developing 4D BIM integration with a development engine called irrlicht (Nikolic, 2006). The complexity of this project was sufficiently larger, since the programme MS project was fully integrated into standalone platform and there were multiple developers. The aspects from this precedent were significant with the method in which the application uses colour coordinated changes that were triggered by changes in the schedule. Although the 3D content simulates a simple building model it is simple enough to display the idea that the Gantt chart has a direct link with the 3D model and any changes made to it is registered in the 3D model via colour highlights.

## OIL RIG SERIOUS GAME

This precedent was important for showcasing a complex 3D project created using Unity 3D. Aspects such as detail of 3D content and textural quality will be important in the design of the prototype. Most importantly for this precedent was assessing how the user interface functions. With the authors limited programming experience it was important to observe the extents of the user interface and to ascertain an idea of functions that can be designed with Unity 3D.

The Oil rig simulation created by Real Visual 3D is a serious game application for standalone aimed to enable potential employees for an oil rig to visualize how operations occur on an oil rig. These include samples of daily tasks, common objects found around the site and emergency procedures. Figure 16 below shows the application in operation and a few of the features that help train participating users in understanding information. Image 2 clarifies where the user is able to explore the entire oil rig using a walkthrough mode. Image 3 shows the enhanced user experience through animated 3D content such as co-workers and sophisticated vehicles such as cranes and helicopters. Images 4/5 are unique on screen features that help the user ascertain information about a particular object which in this image is manufacturing information on an oil barrel. If there are areas of concern that pose a potential risk to the personnel on the rig. The user can virtually create a virtual hotspot on the area of concern as shown in image 6. This allows another user in the simulation to enter and view what has been labelled as a potential risk from the previous participant enhancing the sense of collaboration amongst employees (RealVisual, 2011).

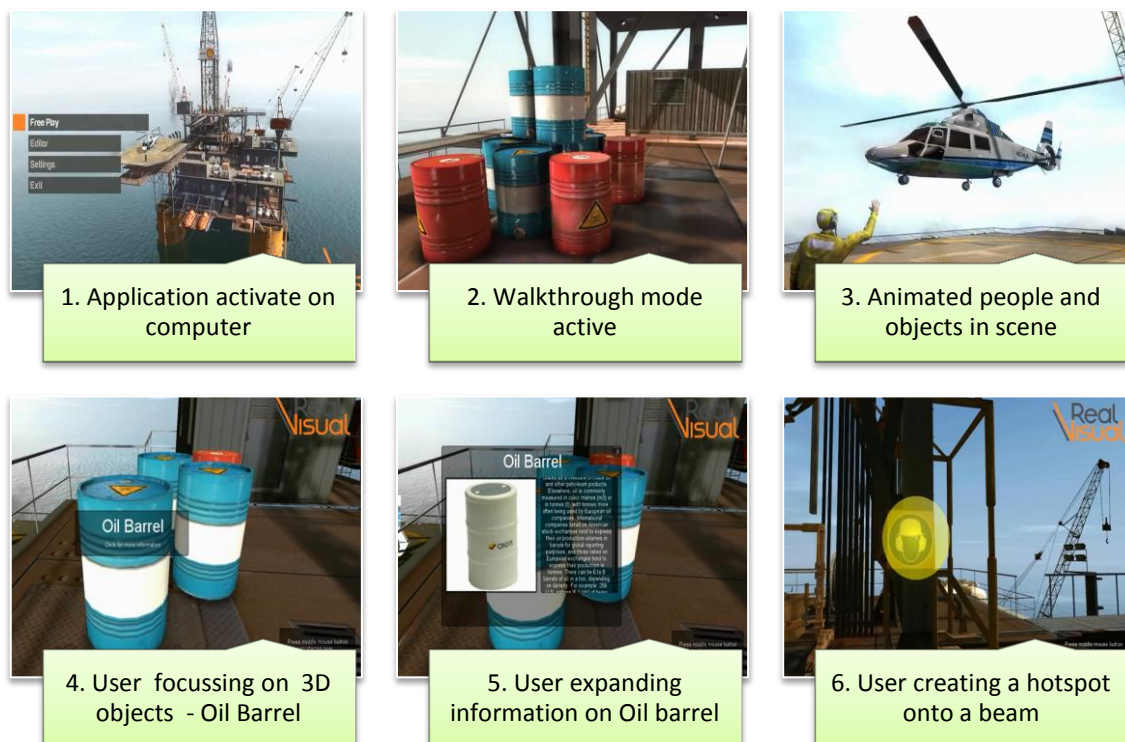


Figure 16: Oil rig simulation (RealVisual, 2011)

## MOBILE APPLICATIONS

This section discusses precedents of mobile applications that are important precedents for informing the design of the prototype. There are numerous applications for Architectural, Engineering and Construction (AEC) use. Applications such as such as AutoCAD 360 and Magic Plan are rated as one of the top ten performing applications for Architectural practitioners in the world (Quirk, 2012). The focus of this review is to analyse functions and special features of applications aligned to construction management or augmented reality. In this context, three applications have been selected for analysis: AutoCAD360; BIM Anywhere; and 3Don Architecture.

## AUTOCAD 360

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This application is relatively similar to BIM 360 in that it was also made by Autodesk and enables online 3D model collaboration. As opposed to integrating Revit based drawings/3D models AutoCAD 360 enables users to turn the drawings/3D models made with AutoCAD into portable resources that can be viewed on a tablet computer as shown in the demonstration Figure 17. Traditional methods of checking 2D building plans against a real building on site involved printing them out and taking them on site as seen in image 1. With AutoCAD 360 the user views a 2D plan on site without the hassle of unrolling large A1 sized rolls of paper as seen in image 2. In image 3 the user can present findings from on-site visits to virtually any audience with ease since the application ties information found on site with the tablet computer back to the original AutoCAD desktop computer program (Autodesk, AutoCAD 360 Spotlights, 2013). AutoCAD 360 has received a lot of attention on both social networks and in general practice as an application that has been used extensively amongst Architects (Quirk, 2012).



Figure 17: AutoCAD 360 demonstration (Autodesk, AutoCAD 360 Spotlights, 2013)

## BIM ANYWHERE

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This application has relatively identical features to the last 2 by enabling the user to visualize 3D models. This application however is different in that it utilizes a form of augmented simulation by using QR codes that are glued to surfaces within the building. This method along Milgram and Kishinos virtual continuum is referred to as augmented virtuality. Although a QR code is used the 3D environment simulated on the tablet is mostly 100% virtual and relies on sensors such as the gyroscope and accelerometer within the tablet to guide the user. This is different from augmented reality which is a mixture of both real and virtual objects on screen. By activating this application the tablet computer camera is switched on and directs the user to focus the tablet onto the QR code. Once the camera has focused onto the QR code the BIM model is superimposed virtually into position on screen which can be in front or anywhere around the user (BIManywherePro, 2013). This application contains similar functions to Autodesk 360 and BIM 360 in its ability to share files online using cloud sharing services where office personnel can communicate with on-site personnel using a singular digitized 3D model.

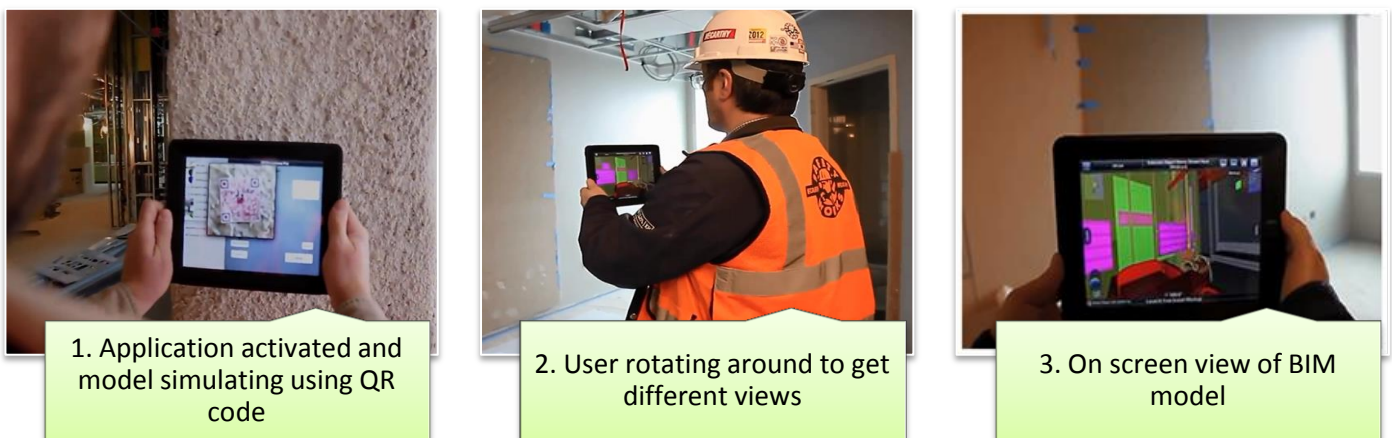


Figure 18: BIM Anywhere demonstration (BIManywherePro, 2013)

## 3DON ARCHITECTURE

The mobile application 3DOn is unique in that it utilizes both virtual and augmented reality for on-site simulation of 3D models created using Google sketch up. Google sketch up is a 3D modelling program which is commonly used amongst a large range of design related disciplines for its ease of use. 3DOn contains 3 different modes that change the user perspective for visualizing a 3D Model. Preview mode enables the user to examine the model using virtual reality on the tablet screen. Walkthrough mode is relatively identical to any other virtual game application where the user can examine both inside and outside the building. On site mode is a special mode that enables the user to superimpose the 3D model using augmented reality. This application however does not use a 2D target marker but instead uses GPS and wireless internet systems that are installed within the mobile device. This application from these demonstrations only superimposes the building in augmented reality on site but has limited interaction functionality.

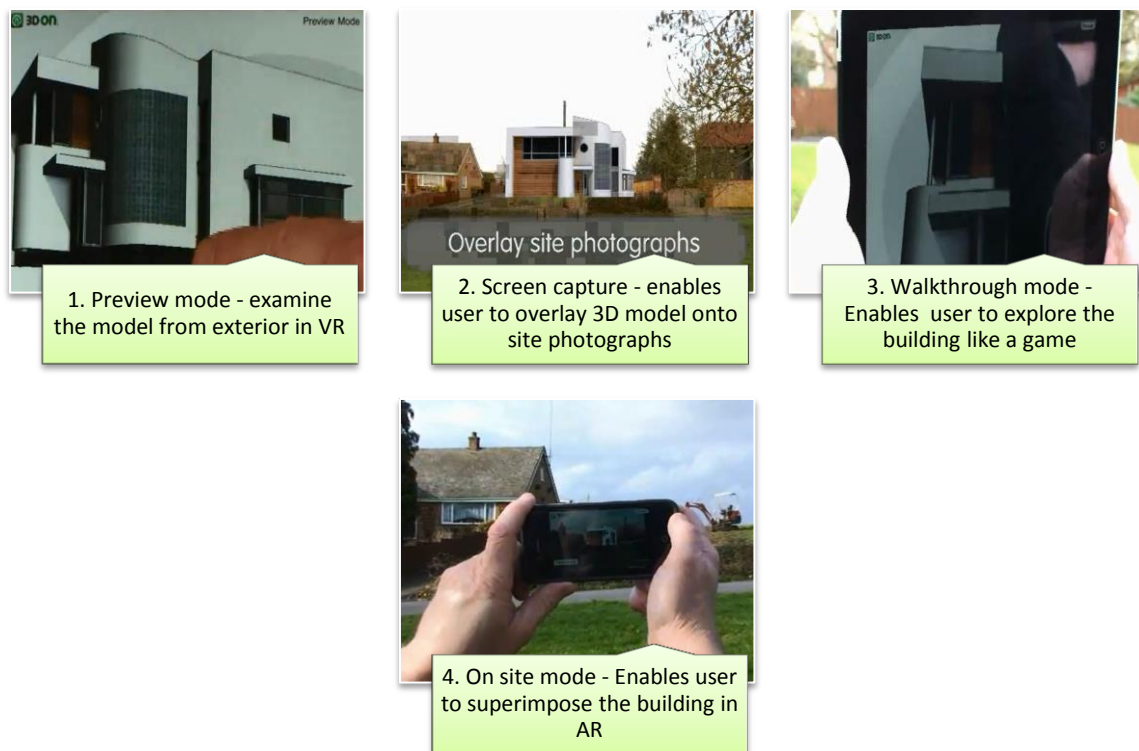


Figure 19: 3DOn Architecture demonstration (3DOn, 2014)

## ASPECTS THAT MAY INFORM THE INITIAL PROTOTYPE DEVELOPMENT

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The intent of the both the review of computer applications (commercial BIM, examples from academia and an exemplar Unity 3D application) and the examination of three relevant mobile applications ( AutoCAD 360, BIM Everywhere and 3DOn Architecture) was to identify precedent for the development of the prototype. Each precedent was assessed in terms of:

- **4D BIM Industry Standard practice**  
Identifying BIM products that are used for 4D BIM in industry and how information is displayed using the interface
- **Capacity to handle 3D content**  
This was important for all mobile application precedents as the case 3D model for the application would be industry standard and have a very high 3D content.
- **Special functions/Significant features**  
Analysing for what makes each precedent different from the other and the aspects that could inform the design of the Graphical User Interface (GUI)
- **Approach to displaying information on screen**  
How does the application operate and display certain types of information about a 3D model, and how does it tie task related information to a 3D model visually.

Shown below is a compendium of the aspects from the precedent review that have been identified as potentially useful, and that may inform the prototype application. In conclusion these are collated as a table that draws together the precedent review and the significance of these for the prototype development.

- **Clash Detection**  
This feature was present in both Synchro and Navisworks and would be useful functions to be implemented on a mobile platform. The ability to identify clashes on site using clash detection tools is the aspect that could inform the design of the application. Identifying clashes using augmented reality on site would benefit any user from the AEC industry.
- **Timeline Animation**  
Navisworks had the ability to visualize the building construction using animation. The animation had very complex mechanisms and showed virtually all construction phases in a project.
- **Colour coded changes**  
Colour coding and the ability to register changes to a schedule by applying colours to a particular 3D model component. This would be important on site or in the context of 4D BIM on a tablet

- **GPS Augmented reality**  
3Don had precedents of GPS located 3D models which would be the ideal setting for using the prototypes 3D model.
- **3D Tagging**  
Most mobile applications had the ability to make notes on the 3D model by clicking on different areas on the 3D model.
- **Animation**  
The Oil Rig simulation included animated people and machines in order to enhance the user experience.
- **Information pop ups**  
The Oil rig demonstration had ability to view information about a particular 3D object by focussing the camera reticule on the object.
- **Cloud sharing**  
BIM 360, BIM Anywhere and AutoCAD 360 had cloud sharing capabilities. This could be useful for the prototype design in the context of taking pictures on site and sending back to a design office. The ability to share a 3D model from site to office via cloud sharing.
- **Scale up tool**  
Seen in the smart reality application were tools that enabled the 3D model to expand by using a series of scale – up buttons. This aspect could be applied to the application if AR is superimposed on a 2D marker. It would be useful to enhance the user perspective to have buttons that scale up the 3D model.
- **Deactivating 3D layers**  
For almost all mobile applications there was always a function that enabled the user to essentially view 3D content hidden between layers. The ability to dissect the model using deactivation buttons which remove layers of the 3D model to reveal hidden components could be useful.
- **Colour coded triggers**  
Computer applications Synchro and Navisworks were important for informing the design in the sense of how they highlight changes in the 3D model from the Gantt chart.



### Summary of precedent review

The review of literature and key aspects of each software research precedent is summarised in Figure 20

<b>Precedent review Summary/Significance of precedents to research</b>					
<b>Application/Program</b>	<b>Type of application</b>	<b>3D content</b>	<b>Special functions</b>	<b>What aspects inform the scope of design</b>	<b>Significance in literature</b>
<b>Navisworks</b>	Desktop Computer	High	Clash Detection, Timeline	The ability for a 3D Timeline, Managerial tasks Highlighted 3D model	An application that can simulate complex BIM standard 3D models
<b>Synchro</b>	Desktop Computer	High	Clash Detection, Timeline	The ability for a 3D Timeline, Managerial tasks Highlighted 3D model	An application that can simulate complex BIM standard 3D models
<b>VCS</b>	Desktop Computer	Low	Colour coding Task in 3D	The visual representation from linking Gantt tasks with 3D model	An research application that merges MS Project
<b>Real Visual 3D Oil Rig Simulation</b>	Desktop Computer	High	Displaying text based information	Ability and Complexity of Unity 3D for 3D Models and GUI	A research application that provides training simulation using Unity 3D
<b>BIM 360 Glue</b>	Mobile Application extension	High	Cloud sharing, Augmented Virtuality	Ability to simulate Complexity of 3D models on iPad/Sensory input	An application that merges Navisworks for mobile device compatibility
<b>AutoCAD 360</b>	Mobile Application extension	High	AutoCAD models visualization	Ability to simulate for high complexity 3D models	An application that merges AutoCAD for mobile device compatibility
<b>3DOn Architecture</b>	Mobile Application	Low	Augmented Reality/GPS	Ability to simulate to GPS located 3D models	AR Mobile application supporting Architectural visualization
<b>Smart Reality</b>	Mobile Application extension	Moderate	Augmented Reality/4D BIM	Ability to simulate for 4D AR BIM usage on mobile device	An application that supports construction management using augmented reality
<b>BIM Anywhere</b>	Mobile Application extension	High	Augmented Virtuality/Clash Detection	Ability to simulate Complexity of 3D models on iPad/Sensory input	An application that merges Navisworks for mobile device compatibility

Figure 20: Significance of literature precedents

## 4. RESEARCH METHODOLOGY

This chapter discusses the key stages in which this research progressed from the precedent review. By way of introduction these are illustrated in Figure 21 below.

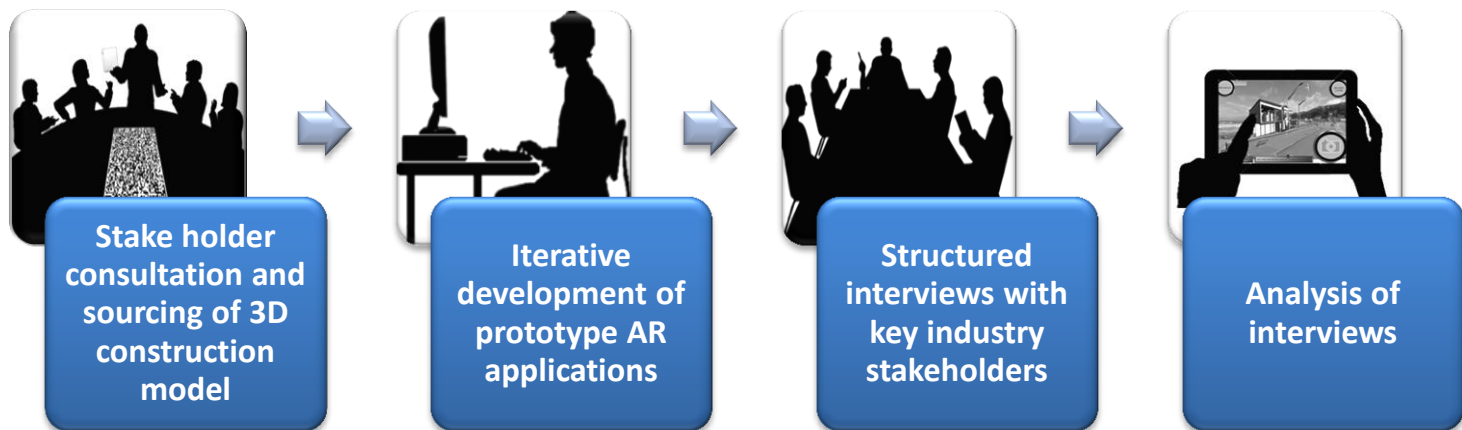


Figure 21: Research Methods

## 1. INTERVIEWS AND REQUEST FOR 3D BUILDING MODEL

One of the early drivers for scoping the project alongside the precedent review was a series of interviews with practicing project managers and architects. This was done by simply sending out an email requesting a visit to the member of each firm and to discuss the intentions of the research and whether they could provide 3D Building Information Model to act as the case study. At this point early in the project only a series of conceptual edited diagrams, photos and drawings were presented on what the research project was targeting to achieve and to define augmented reality. The format for each presentation was structured to give the interviewee an idea of how this research was proposing to use mixed realities to enhance 3D visualization. It was made clear in the very first interview that many 3D building models would have restrictions on sharing since 3D building models are legal entities that belong to clients. This constrained every interviewee from sharing these models for research. Therefore the presentation was not only a driver for providing an overview on the research project, but also to entice the interviewee and encourage them to provide a model.

## 2. REQUEST FOR BUILDING INFORMATION MODEL

The second aim of the interviews and visits to architectural firms was to request use of a Building Information Model (BIM) which had high geometrical 3D content and had been tendered for construction. ArcHaus Architects in Wellington provided this with their 2013 Lyall Bay Surf Club project which has model complexities that were important for increasing the viability of this research. These model complexities within the model were particularly extensive in components such as servicing layouts, structure, enclosure and internal walls. The importance of these complexities was due to their nature in having very high precision in design detail and hence resulting in an immense amount of 3D content. This presents a challenge during the stages in which the 3D model is ported as a 3D application to a tablet computer.



Figure 22: Lyall Bay Surf Club (LBSC) in its traditional Autodesk Revit format

PRESENTATION TO INTERVIEWEES

These presentation slides essentially were designed to show the interviewees the knowledge that the author has on the subject and the gap in knowledge that was being addressed using AR. These slides presented:

- **The Authors experience using mixed reality technology**

These slides were important to showcase to the interviewee that the author has experience with using technology capable of creating mixed realities. I.e. Unity 3D



Figure 23: 4th year visualization project - simulating a 3D model of Wellington city

- **The authors knowledge of mixed realities in the context of construction**

Theses slides consisted of all precedents from research and were important to showcase advanced design precedents that have been used for construction visualization. These precedents shown in figure 24 below were particularly important as they also showcased the capabilities of Unity 3D.

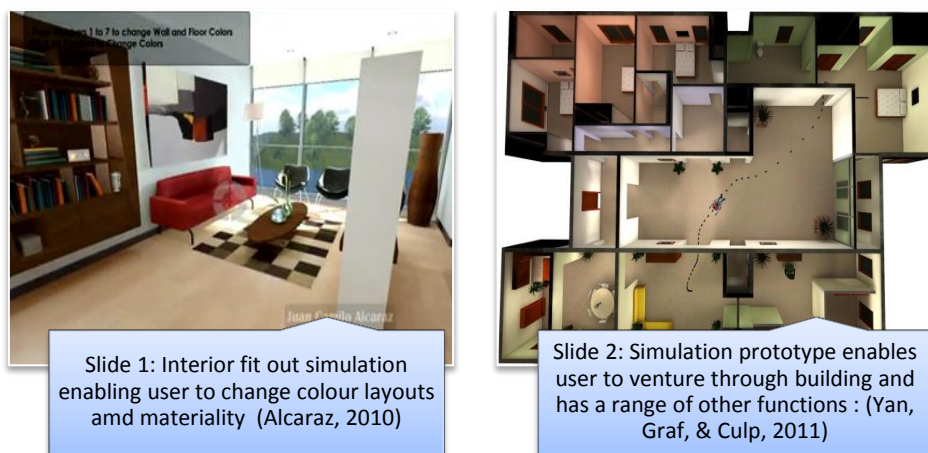
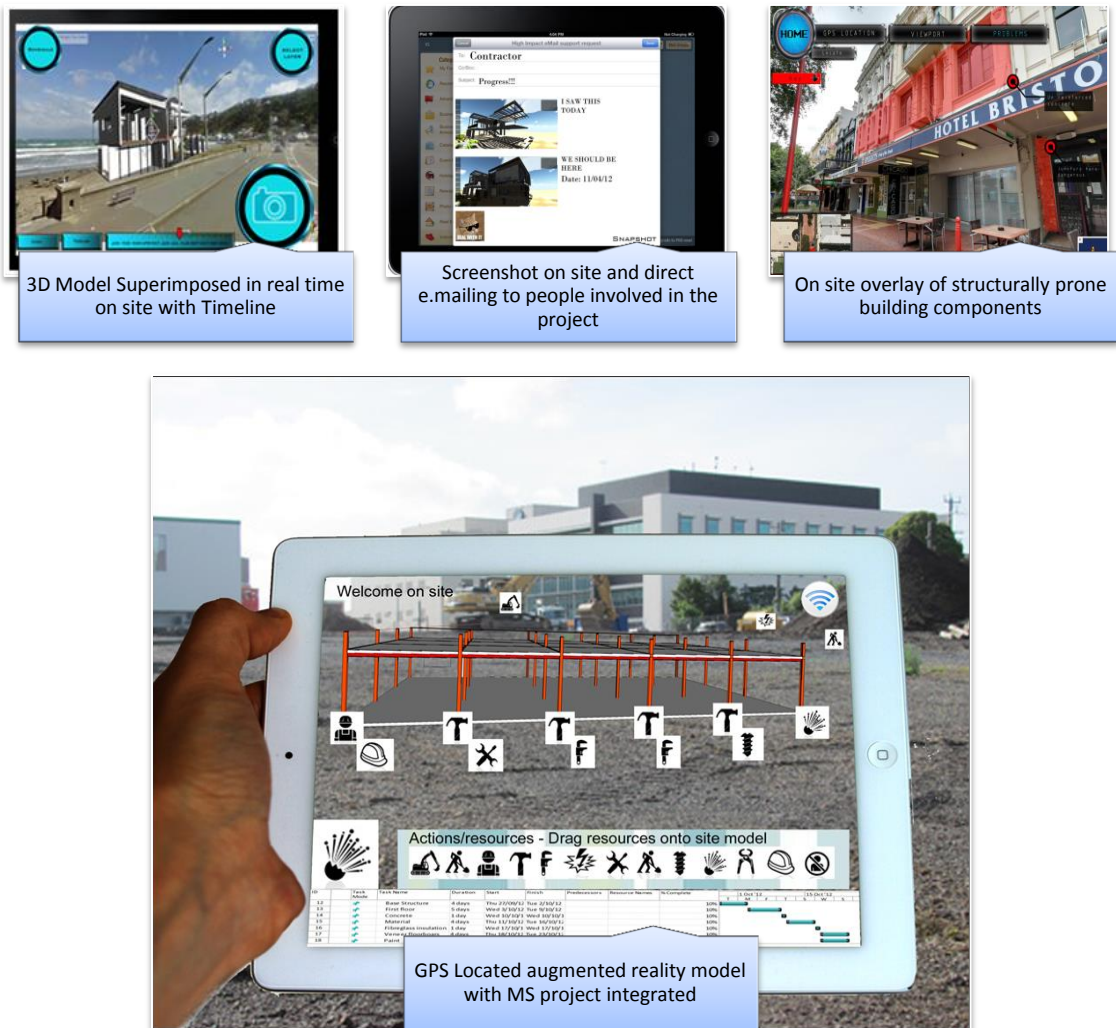


Figure 24: Unity 3D Precedents

- **The proposed outcome for the research**

These slides were important to show the interviewee that the application was designed for a mobile device such as a smart phone or tablet computer. These images were also directed at engaging each interviewee in providing the Building Information Model to act as the case model for the research. It was vital to ascertain an industry standard 3D model and avoid prefabricating one to increase the practicability of the research.



## SUMMARY/DESIGN SCOPE

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### Interviews

The interviews with industry practitioners were aimed to:

- Give an overview of the possibilities with augmented and virtual reality
- Give an overview on the background literature researched of 4D BIM & AR BIM
- To identify where practitioners see value in using 4D AR BIM

Feedback from these interviews refined the scope of aspects that were identified from the precedent review. This stage of the research enabled these aspects to be clarified and refined in relation to real world scenarios, by questioning practitioners on what functions they would value as outcomes from the precedent review were presented. Practitioners were invited to describe a variety of scenarios from their personal experience and consider how mobile augmented reality could aid project management.

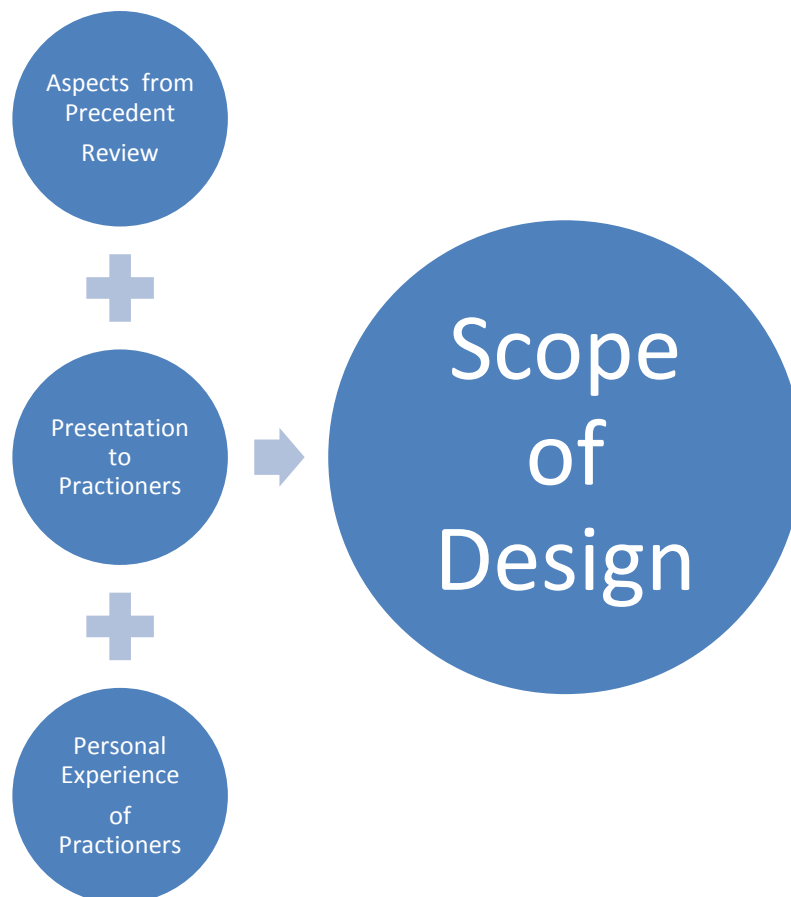


Figure 26: Achieving scope of research focus/GUI design

## Aspects of Construction management

- **3D Gantt chart visualization**

Project management firms stressed the importance of a visual Gantt chart into the application. Similar to how Synchro and Navisworks have integrated Gantt charts that communicate with the 3D model. However the difference of this Gantt chart with any other is that all tasks within the Gantt chart visually connect with the 3D model components. They stressed that they need a sort of colour ID on each 3D component in order to identify where the task sits in terms of completion and this needs to link back to the Gantt chart.

- **Critical Path Visualization**

Visualization of critical path was a large aspect that most project management firms would value using augmented reality. They expressed that; it is easy to identify and calculate tasks that were on the critical path but identifying which of these tasks link to construction elements on site is difficult. In MS project; tasks on the critical path are highlighted in red but have no corresponding 3D element unless it is exported to a 4D BIM program. Therefore the application not only a Gantt chart, but a Gantt chart that can also calculate critical path and visually connect that information back to the 3D model. This paired with augmented reality in a site context would provide a very powerful control tool.

- **Access to different layers on a 3D model**

If this application was going to deal with 3D information on a building model it is imperative that access to different layers of the construction 3D model are flexible. This is standard for most 3D Modelling packages and since the application proposal was targeting on site use. For example is the ability to view hidden 3D details such as plumbing underneath the floor or electrical wiring behind the wall. These are all standard BIM tools and it would have an even greater impact in the augmented reality context.

- **Using a timeline to construct building sequence**

In this scenario practitioners wanted a function that could essentially cross reference a real life construct with an augmented reality 3D model. In the sense that if practitioners were on a building site; they could use a mobile device to superimpose an augmented reality 3D model onto the building in construction and further use a slider to cross reference where the construction has progressed physically and where it should have progressed digitally. Practitioners that stressed this idea were all experienced with using Navisworks and noted that this was the animated timeline feature is the key feature which makes Navisworks understandable.

- **Visualizing resources, costs and responsible peoples to particular 3D objects**

In the scenario where a practitioner is on site and a construction model is simulated through augmented reality. Practitioners stress that a function that could '3D tag' construction components and display information about it would be very useful. Examples such as the cost to build that wall (5D/6D BIM) or the material costs of the wall are important for visualization. If the application targets mobile communication devices it would be very valuable if the phone book connected responsible stakeholders of a components to the actual component in 3D. This solves a lot of coordination problems and allows faster identification of people.

### **Focus on Augmented Reality**

Initially the proposal aimed at providing both a virtual and augmented reality simulations as end products. However practitioners mentioned that most virtual reality simulations such as 3D walkthroughs were well established with mainstream CAD programmes and encouraged that the research focuses on augmented reality as the research agenda.



## SCOPE OF FUNCTIONS

The idea here was to establish aspects of construction management that practitioners supported. This way aspects that were common in literature paired with aspects that practitioners valued. It was also important to assess each aspect in respect of what could be incorporated within the time available for the research.

Each interview discussed 6 key aspects of construction management that can be supported with augmented reality. Although this was reduced from the scope of 10 aspects that were chosen from precedent review; the scope was still too large for the time available. Therefore, from the review of precedent and feedback from practitioners the scope of design was refined down to these 4 aspects of construction management for GUI development.

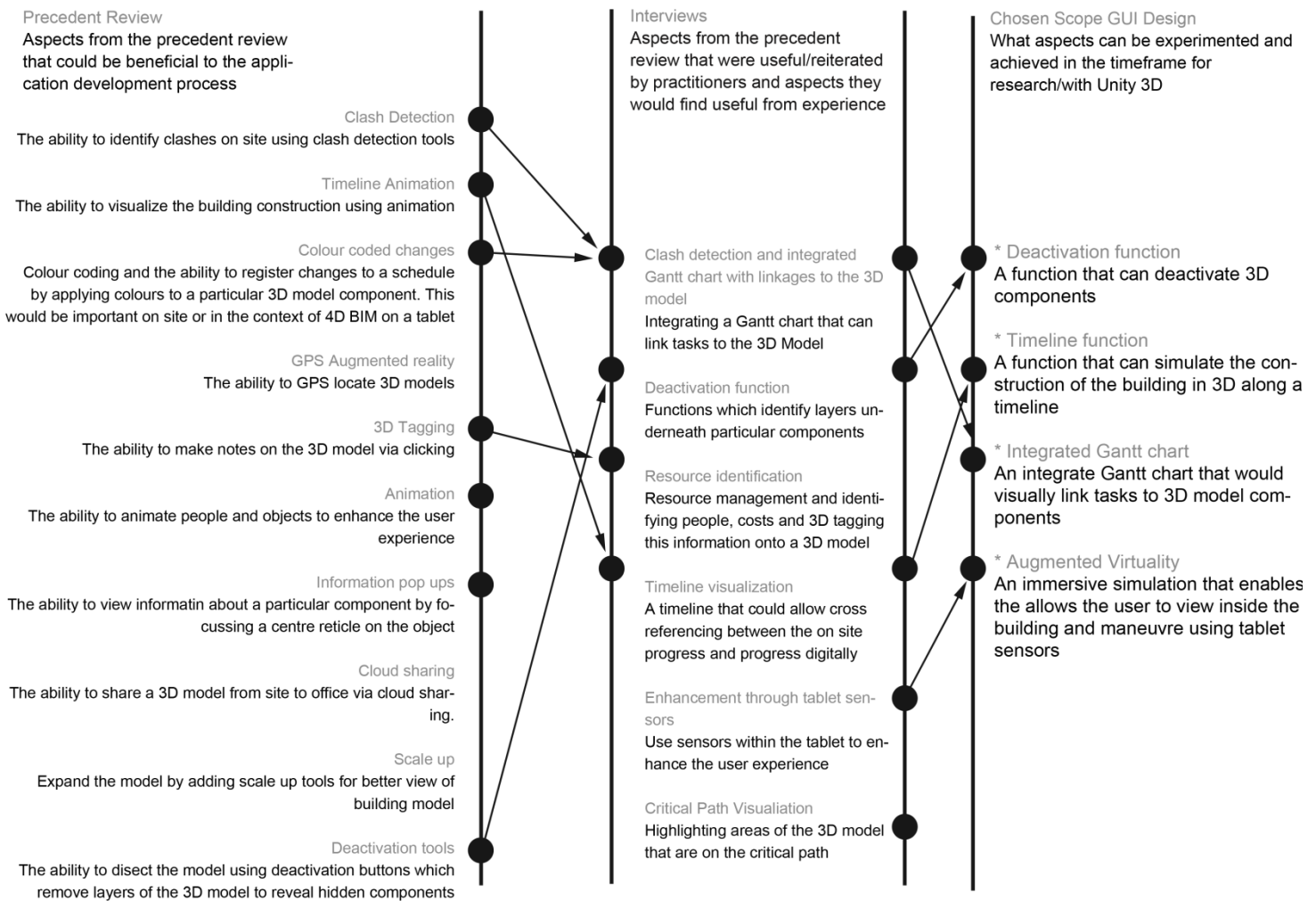


Figure 27: Scope refinement - Identifying the scope of functions that will be designed

**Research scope for aspects of construction management for design of prototype****- Gantt chart visualization function**

This research aspect will focus on a function within the User Interface that will essentially be a Gantt chart compressed onto a mobile tablet screen. However based off the importance of connecting the Gantt chart back to the 3D model; The design of this function will aim to add features that enable the 3D model to react to any changes made in the schedule.

**- Deactivation function**

This function will enable the user to deactivate 3D layers in order to reveal hidden 3D content underneath various layers. This will be important function given the 3D model has sufficient detail.

**- Timeline**

This function will enable the user to build the construction model from the ground up in 3D. The sequence of each 3D component appearing will be referenced from a Gantt chart of listed tasks.

**- Immersive Walkthrough using Augmented virtuality**

This function will enable the user to view the building from inside and use tablet sensors to manoeuvre the building using augmented virtuality methods.

### 3. APPLICATION DEVELOPMENT THROUGH ITERATIVE DESIGN

Following the interviews and attainment of a 3D building information model and scope of functions, the next stage was to begin the actual creation of the application in Unity 3D. The 5 stages of iterative design are listed below.

#### 1. Polygon Optimization & Unity 3D performance testing

The optimization iteration focuses on analysing and implementing techniques to reduce the geometry of the 3D case model and simulating to analyse for performance.

#### 2. Texture Mapping

Texture Mapping focuses on applying realism and atmosphere to the 3D model following optimization by applying and testing 3 methods of applying textures.

#### 3. Graphical User Interface Design (GUI)

The third iteration is the largest portion of the development process and focuses on the development of the Graphical User Interface or GUI which enables the user to interact with the model with 3 distinct functions. The GUI is driven from the scope of design that was achieved from the precedent review and interviews.

#### 4. Augmented reality Plugin and Mobile platform testing

The fourth iteration analyses the tests of using augmented reality using both a desktop computer and mobile tablet computer.

#### 5. Final Interface Redevelopment and Gyroscope

The final iteration integrates a unique tablet sensor that requires certain gestures from the user to explore inside the building.

#### 6. Final Interface Redevelopment and Gyroscope

The final stage is a redevelopment phase in which the interface will be optimized for demonstrations with selected practitioners in industry.

#### 4. INTERVIEWS FOR FEEDBACK

The final stage of the research demonstrates the use of the application in front of selected AEC professionals in Wellington, New Zealand. The interviews are structured to showcase the intended workflow of the application and to generate discussion on useful functions that could be developed with mobile augmented reality technology. Questions were asked at each interview to encourage a discussion and critique on the interface. Feedback from interviews will then provide guidelines for future development.

The two key questions that are asked are listed below:

- How can mobile augmented reality be utilized in your firm?
- How can the graphical user interface (GUI) be improved?

## 5. ITERATIVE DEVELOPMENT OF PROTOTYPE APPLICATION

This chapter expands and discusses the 6 stages of iterative design that took place in order to formulate a final developed design prototype. By the end of the design phase; programmes ranging from Unity 3D, Autodesk 3DS Max, Adobe Photoshop and scripting language JavaScript, all contributed to the assembly the final application. As a result of the excess amount of polygons that form the LBSC Revit model, an immense amount of optimization was required in order to enable efficient simulation. With the completion of optimization; the model is then imported into Unity 3D. This enabled the application of textures for improved realism and for the development of the Graphical User Interface (GUI).

The GUI section discusses the creation of the interface and 3 functions that were scoped earlier from literature. Tests are carried out during each iteration phase to analyse the performance of the simulation within Unity 3D. Numerous performance tests were simulated on both a desktop and tablet computer as standalone applications. However the tablet computer was only obtained later in the design stage and many preliminary iteration tests to analyse impacts of optimization were mainly done as desktop computer and web player applications. The final iteration focuses on preparing the application for demonstrations and integrating the final function which used a Gyroscope sensor within the tablet computer. Integrating the gyroscope was a method of conceptually showing the possibilities of manoeuvring within the building using augmented virtuality.

This chapter is divided into 6 main iterative design stages:

- |   |  |
|---|--|
| <p><b>1. Polygon optimization &amp; Unity 3D performance testing</b><br/>Discusses the breakdown and optimization of the 3D Revit model components and testing it within Unity 3D for simulation.</p> | <p><b>4. Augmented reality and Mobile platform testing</b><br/>Discusses porting the application for augmented reality on a tablet computer.</p>   |
| <p><b>2. Texture Mapping</b><br/>Is the application of customized textures along with special maps and light mapping.</p>   | <p><b>5. Final interface development &amp; Gyroscope</b><br/>Discusses optimizing and repositioning the interface and the integration of a tablet sensor that demonstrates augmented virtuality.</p> |
| <p><b>3. Graphical User Interface</b><br/>This section discusses the development of interactive controls that enable the user to visualize different aspects of the 3D model.</p>                     | <p><b>6. Developed design</b><br/>Is a summary of the final design which will be used for demonstrations.</p>  |

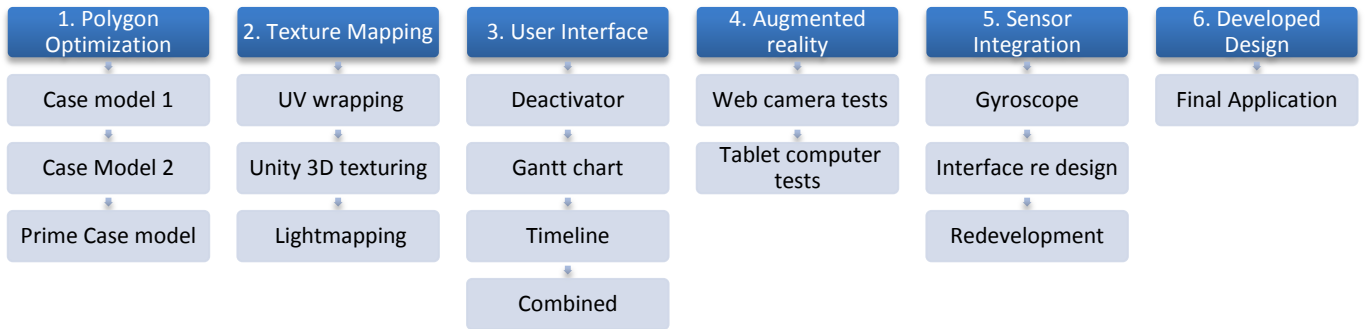


Figure 28: Development process breakdown

## 1. POLYGON OPTIMIZATION & UNITY 3D PERFORMANCE TESTING

### INTRODUCTION

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This iteration focuses on optimizing and preparing the 3D model for the next stage which would be to texturize and give realism to the 3D model. This is done through optimizing all the 3D components that form the entire 3D model and combine pieces in order to reduce the complexities before any GUI development may begin. Optimization is a reduction in the detail of components in the Building Information Model. It is a process which is found in almost any computer simulated technology workflow such as computer generated imagery (CGI) for films, gaming and even in this case computer aided design (CAD). An effective simulation within Unity 3D is dependent on the optimization of the 3D model(s) to ensure the simulation renders all objects in scene efficiently and there is no strain on the computers graphical processing unit (Optimizing Graphics Performance, 2012). The 3 main factors of the 3D model that influence the computing performance of the simulation within Unity 3D consist of the polygon count, textural properties and the number of 3D objects within the scene. These can be manipulated to become more lightweight within 3D editing software which in this case is Autodesk 3DS Max design (Jie, Yang, & Haihui, 2011). This stage is important for when the application is installed on a mobile platform which has much lesser computing power compared to the desktop computer. The importance of optimization is to reduce the polygon count without compromising the detail and realism of the 3D model and therefore requires attention to detail in order for 3D components to be optimized efficiently.

#### **Unity 3D Performance testing**

Analysing the impacts of optimizing 3D models was done by constantly exporting different versions of a 3D model from 3Ds Max into Unity 3D and running a walkthrough simulation. This enabled the author to establish benchmarks for efficient simulation and to analyse the performance of the Graphics Processing Unit (GPU) using in built tools within Unity 3D. Iterations 1.1 and 1.2 aimed to gather techniques for optimization during the period in which the LBSC prime case model had not yet been obtained. Iteration 1.3 discusses the results of applying of these techniques to the LBSC model. These sub experimentes listed below all contribute to analyzing techniques to enable optimization of the LBSC 3D model in iteration 1.3.

- **1.1 Library case model**
- **1.2 Commercial build model**
- **1.3 Lyall Bay Surf Club**

## ITERATION 1.1 CASE MODEL: ST. PAULS CATHEDRAL WALKTHROUGH

---

This experiment essentially introduces the key tools that were used for assessing performance of an application scene level within Unity 3D before building it as a standalone application. This experiment was primarily an initiation test to experiment with different features of Unity 3D and to identify tools that can monitor optimization efforts. The St. Pauls cathedral experiment was a preliminary test in creating a virtual simulation walkthrough of a 3D model made with Google Sketchup. In addition an interactive menu was also created to enable a user to activate and deactivate specific portions of the 3D model as to reveal different types of information. The objectives of this experiment were part of a 2 week design intensive exercise in which the author was tasked with creating a conceptual presentation of what the author proposed to create at the end of this thesis. At this early stage only a general idea of the end product could be conceptualised.

The key steps in assessing performance are listed in succession below:

### 1. First person controller (FPC)

Following the creation of the 3D model using Google Sketchup and importing it into Unity 3D a first person controller is added into the interior of the building 3D model. This enables the user to venture through the building as a walkthrough as shown figure 29. The first person controller is a pre-built asset available within Unity 3D that allows the user during run time to essentially explore a building. The FPC consists of a camera which is the view in which the user will look from, and a surrounding collider which registers 3D objects that are solid i.e. walls/floors. Controlling the FPC during run time is done using key bindings **W**, **A** and **D** to move and the mouse is used to orbit the camera view around the 3D model. There are several settings that are addressed before the walkthrough can be initiated such as sensitivity, speed and collision.



Figure 29: Adding a first person controller to the scene



## 2. Rendering Statistics and Run time profiler

Assessing optimization and identifying bottlenecks is done by using in built tools within Unity 3D that profile the overall performance of hardware during run time. During run time within the Unity 3D editor the statistics box can be brought up on the top right hand corner of the screen as shown in the image below. This statistics box is a summary of how hard the computer is working to render each frame per second in the simulation. This is a lightweight method of analysing efficiency of the simulation before building the scene into an application. The target frame rate for efficient simulation during run time is roughly 40 – 60 frames per second (fps).



Figure 30: Performance statistics

A more complex method of assessing hardware performance during run time is by using another in built profiling system tool within Unity 3D called the profiler. This is a much more mathematical method of assessing hardware performance such as the central processing unit. The profiler is only used on occasions when bottlenecks become difficult to detect using the statistics box.

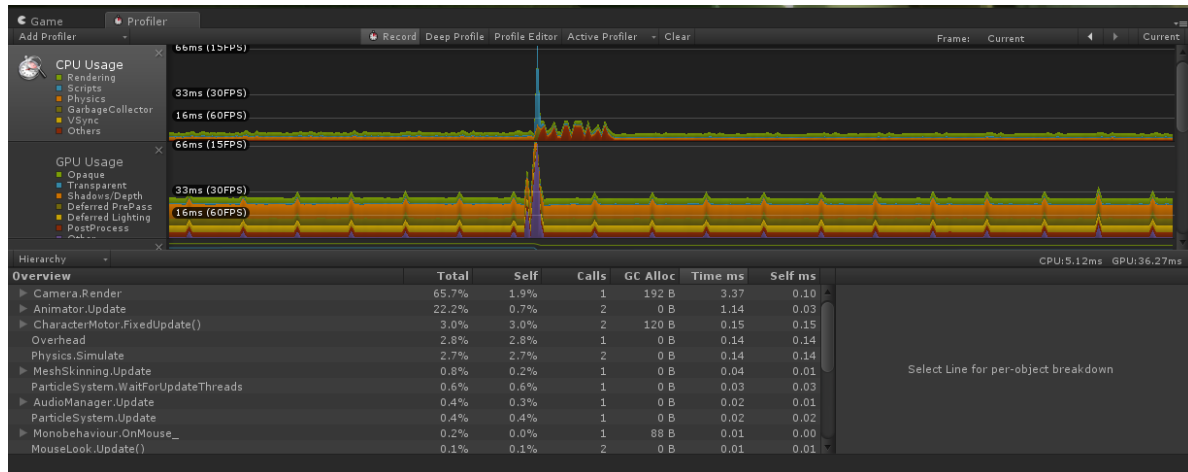


Figure 31: Unity 3D profiler

### 3. Building the application

With the simulation running smoothly in Unity 3D and the frame rate optimal, the final step is to build the actual application. Unity 3D provides a range of platforms to build and in this case for the St. Pauls model a web playable application was built. The web player application allows users to essentially access the application online on a web page after downloading the Unity 3D web player plugin.

The results of the final build are shown below in succession. **1)** The application loads within a new tab in internet explorer **2)** Once the application is active a menu on the left can be used to select five different viewpoints which essentially transport the user to different views around the 3D model. **3)** By activating the button 'walkthrough' the user is transported to a fixed view outside the building **4)** Visualization mode transports the user outside the building and can activate different layers of the building. **5)** When the user activates the Gantt chart mode a MS project Gantt chart pops up next to a 3D model. The Gantt chart is a fixed image within the simulation and does not have any functionality as the author is attempting to showcase a concept of the end product of this thesis. The concept essentially communicates a method of visualizing 3D models together with Gantt chart schedules through Unity 3D.

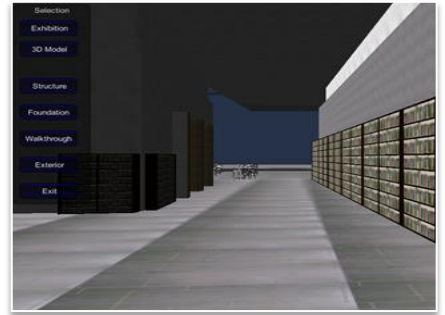
1. App Loading



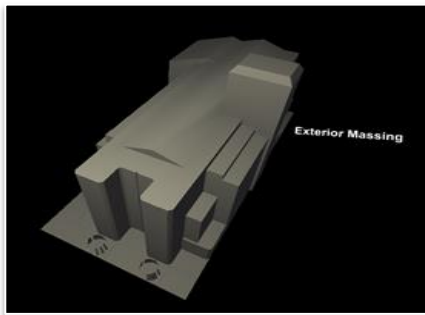
2. Application Active



3. Walkthrough mode



4. Visualization mode



5. Gantt chart mode

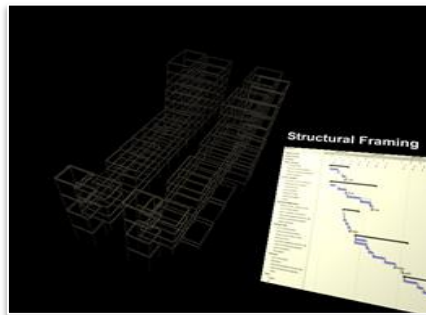


Figure 32: St. Paul's Cathedral simulation using the Unity web player plugin

## ITERATION 1.2 CASE MODEL: REVIT COMMERCIAL BUILDING MODEL

The second preliminary test similarly aimed to create a first person walkthrough of a much more complex 3D Revit model of a prefab commercial building. This 3D model is particularly important for gaining insight into optimizing an actual building information model since the prime case model will be in a similar format. Similarly to the St. Pauls simulation; optimization is assessed by exporting the model to 3DS Max and improving the polygon count using a variety of editing and modification techniques. Testing each reduction is done by exporting the 3D model into Unity 3D to analyze impacts of optimization. This model is much more dynamic in that it has four sets of servicing construction groups as shown in figure 33 below. 3D components such as; structural beams, plumbing, lighting fixtures plus heating and ventilation ducts. These components have a very high polygon count and require special optimization within 3DS Max to reduce with compromising detail.

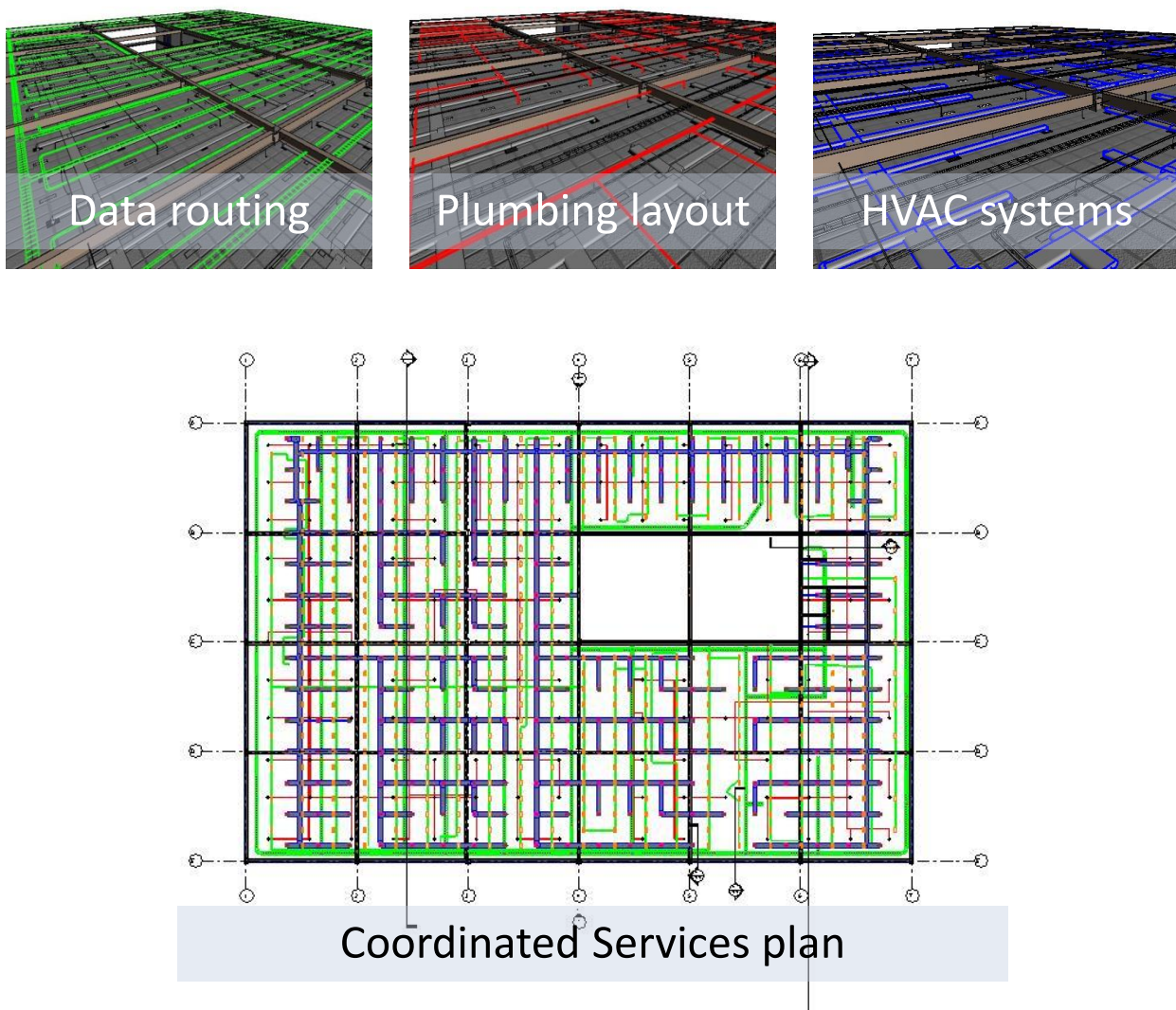


Figure 33: Commercial Building project in traditional Revit format

## Polygon count

Once the model was imported into 3DS Max the total polygon count of the model was estimated at 200,000 polygons. According to literature the baseline polygon count in which Unity 3D would ideally simulate efficient web player applications is 65,000 polygons (Jie, Yang, & Haihui, 2011). However hardware performance is subject to a range of factors including texture sizes and special maps therefore the polygon count is not the only issue that addresses performance. The overall goal here was to continually reduce the polygon count incrementally and build multiple applications for testing. The overall objective was to achieve the most efficient frame rate with minimal reductions to the 3D model.

## Optimization

Exporting the 3D model from Revit to 3DS Max is relatively straightforward and has a variety of file options for exportation. In this case the model was imported into 3DS Max in .FBX format. Optimization is done within 3DS Max using these main methods to optimize high detail components:

- Deleting portions of the 3D component/model that are unseen such as screws, light switches and small furniture
- For curved surfaces such as lamps shades and other light fixtures that had a very high polygon count modifiers such as the *Optimize* and *ProOptimizer* were applied. These modifiers essentially calculate the amount of polygons on the component and reduce detail based on mathematical algorithms.
- Merging together multiple individual polygons to form a large polygon
- Deleting the 3D components and re modelling as a less detailed version

Each method of optimizing has setbacks as reducing too much of the 3D model can result in mesh warps. Warps basically render the 3D surface mesh with too less detail resulting in components such as the HVAC shown becoming distorted and un realistic. Therefore modifiers such as the *ProOptimizer* needed the tolerances to be controlled in a manner that maintained the realism of components properties whilst reducing detail.

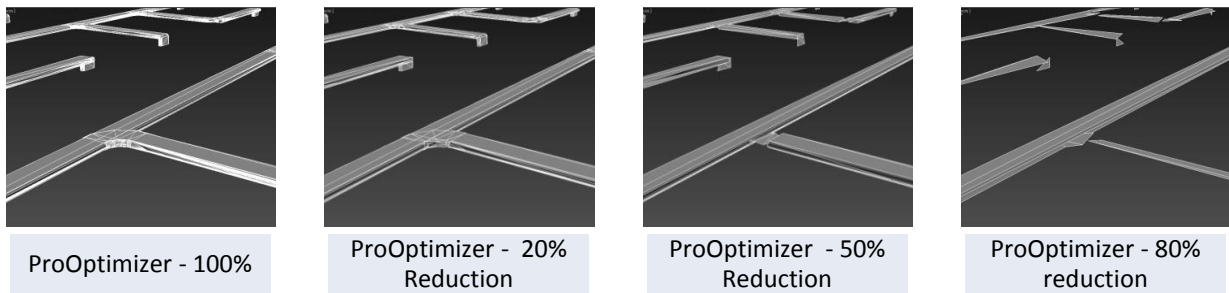


Figure 34: ProOptimizer results

### Grouping

At the end of each optimization period each construction component was merged to formulate logical construction groups as shown in figure 35.

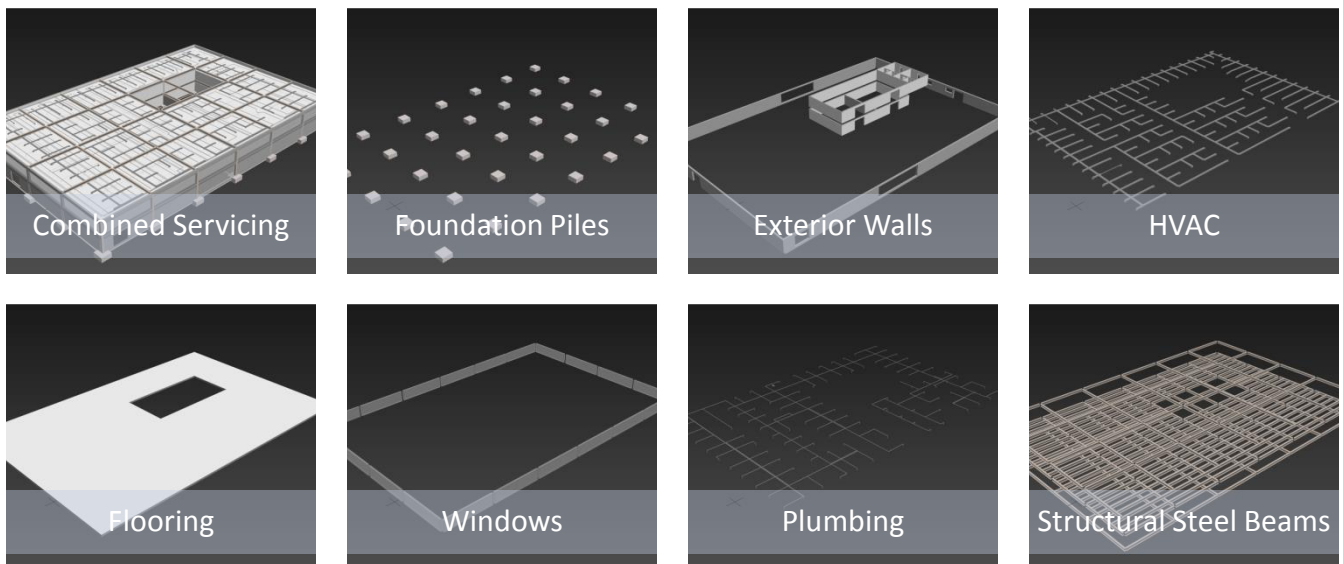


Figure 35: 3DS Max optimization and grouped geometry

### Web player final build

Similarly to the St. Pauls simulation the FPC was added and frame rate performance was assessed using the statistics and profiler. The resulting frame rate for this iteration was 85fps and all areas of the building model could be explored without any issues as shown below.

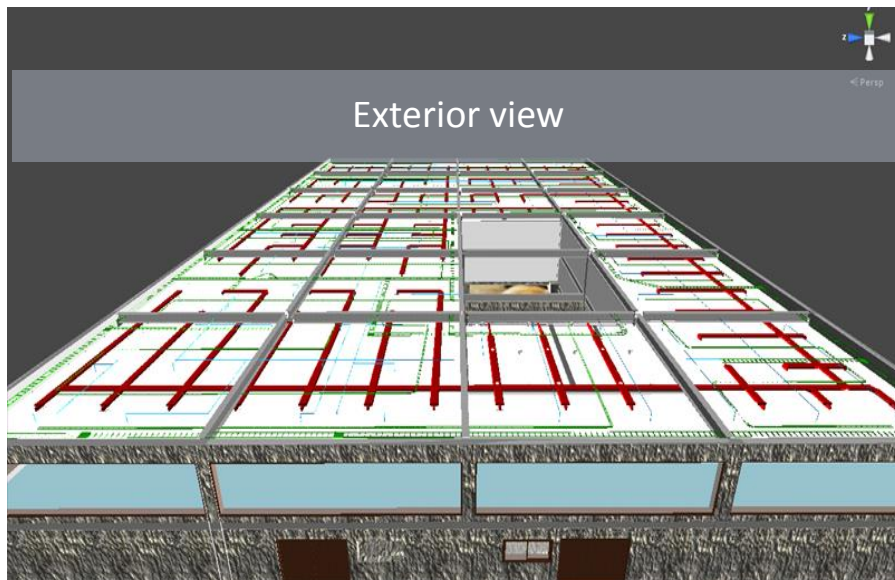
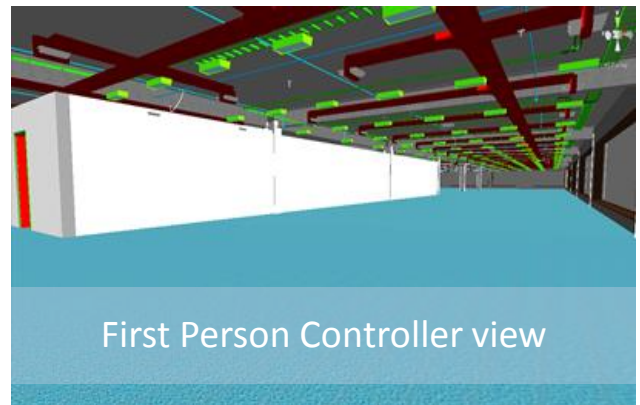
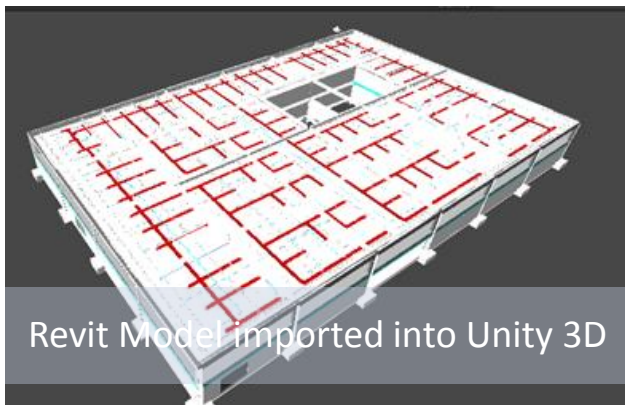


Figure 36: Optimized model in Unity 3D

## ITERATION 1.3 PRIME CASE MODEL: LYALL BAY SURF CLUB

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This iteration discusses the optimization and first person walkthrough performance testing for the prime case model used for this research. This model was significantly larger than the first two with a polygon count total of over 800,000 containing much more detailed 3D components. The Methods of optimization tested in the first 2 iterations allowed rapid optimization for this 3D model and are used polygon count down to a count of 60 - 80,000 polygons. Similarly to the Commercial building model once optimized each component would then be grouped into logical construction groups. Shown below is the LBSC model in its traditional format in Revit.

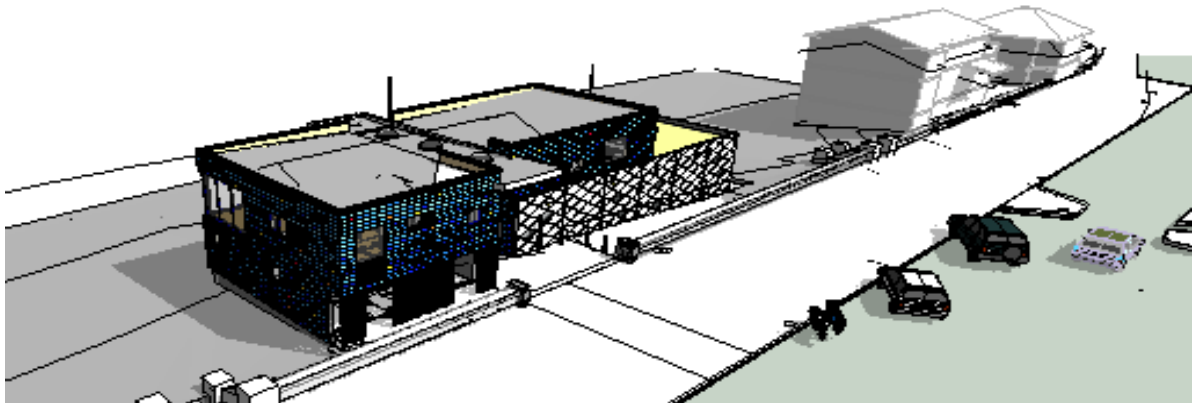


Figure 37: LBSC 3D Model in Traditional Revit scene editor

Similarly to the commercial building iteration the 3D model is exported from Revit to 3DS Max in .FBX file format.

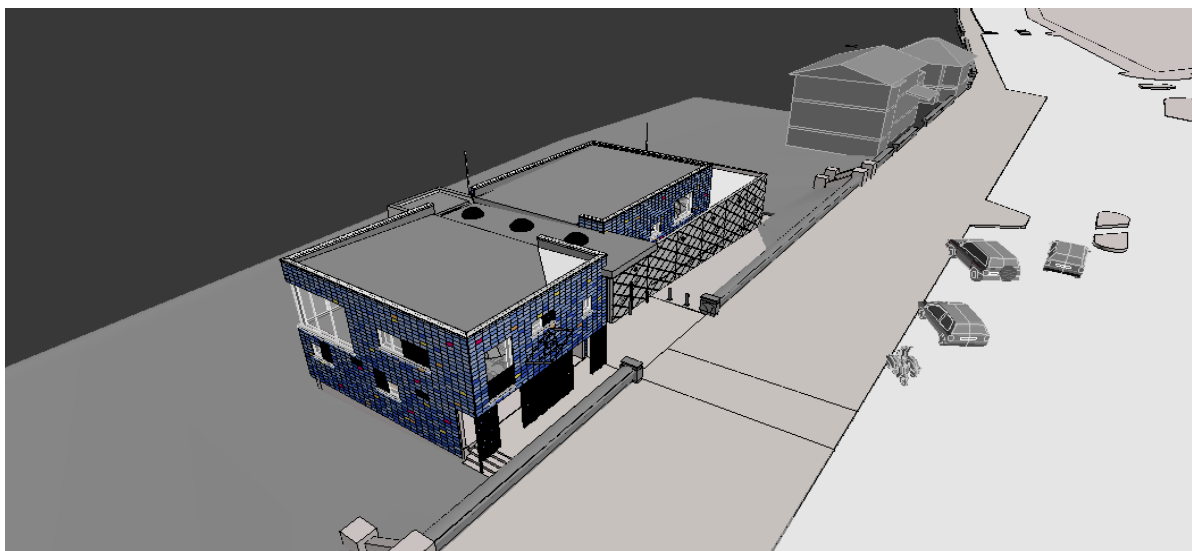


Figure 38: LBSC 3D Model now imported into 3DS Max scene editor



## Optimization

By the end of optimization a large amount of geometry had been grouped, deleted and reduced the polygon count down to 60,000. Similar to the previous iteration; the general workflow for optimization was to group construction components and constantly test optimization by exporting the 3D model into Unity 3D and assessing performance. The general rule was to keep the frame rate within Unity 3D stable by using the FPC to explore the interior of the building and assess for any issues. Every component had at least one or two of the following techniques shown below for reducing the overall polygon count such as merging components to become one mesh or applying a 3DS Max modifier.

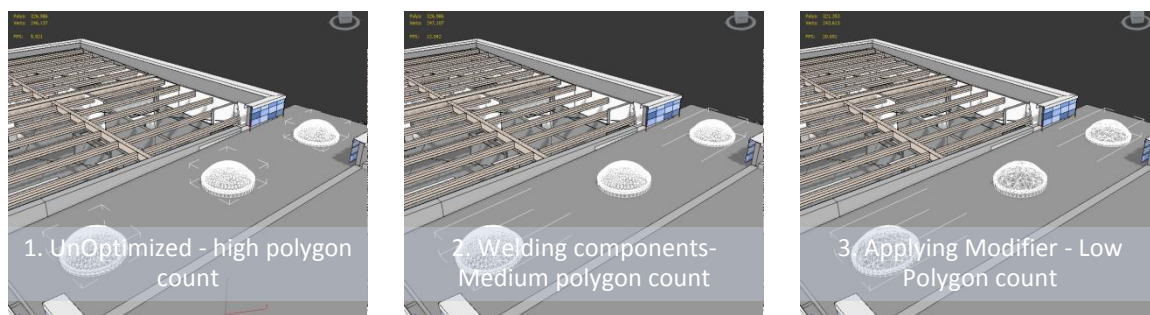


Figure 39: Optimization techniques

1. Components in raw format
2. Optimization technique 1 – Weld together similar components to form 1 component
3. Optimization technique 2 - Apply Optimizing modifiers to reduce polygon count further

## Grouping components

During optimization each component would then be combined and re named into logical construction groups as shown below. E.g. all components that consist of construction parts for the roof are combined and renamed as 'roofing'. This also allows easy identification of 3D components for when the 3D Model is imported into Unity 3D. The next page shows all construction groups that were created after optimization.

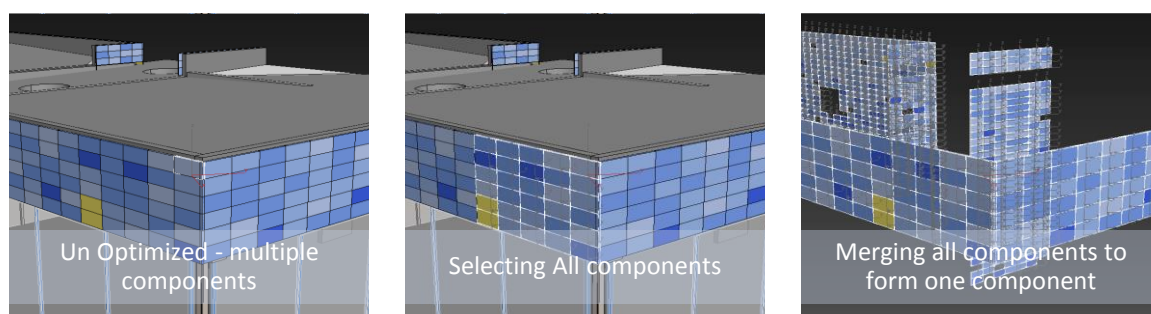


Figure 40: Merging components

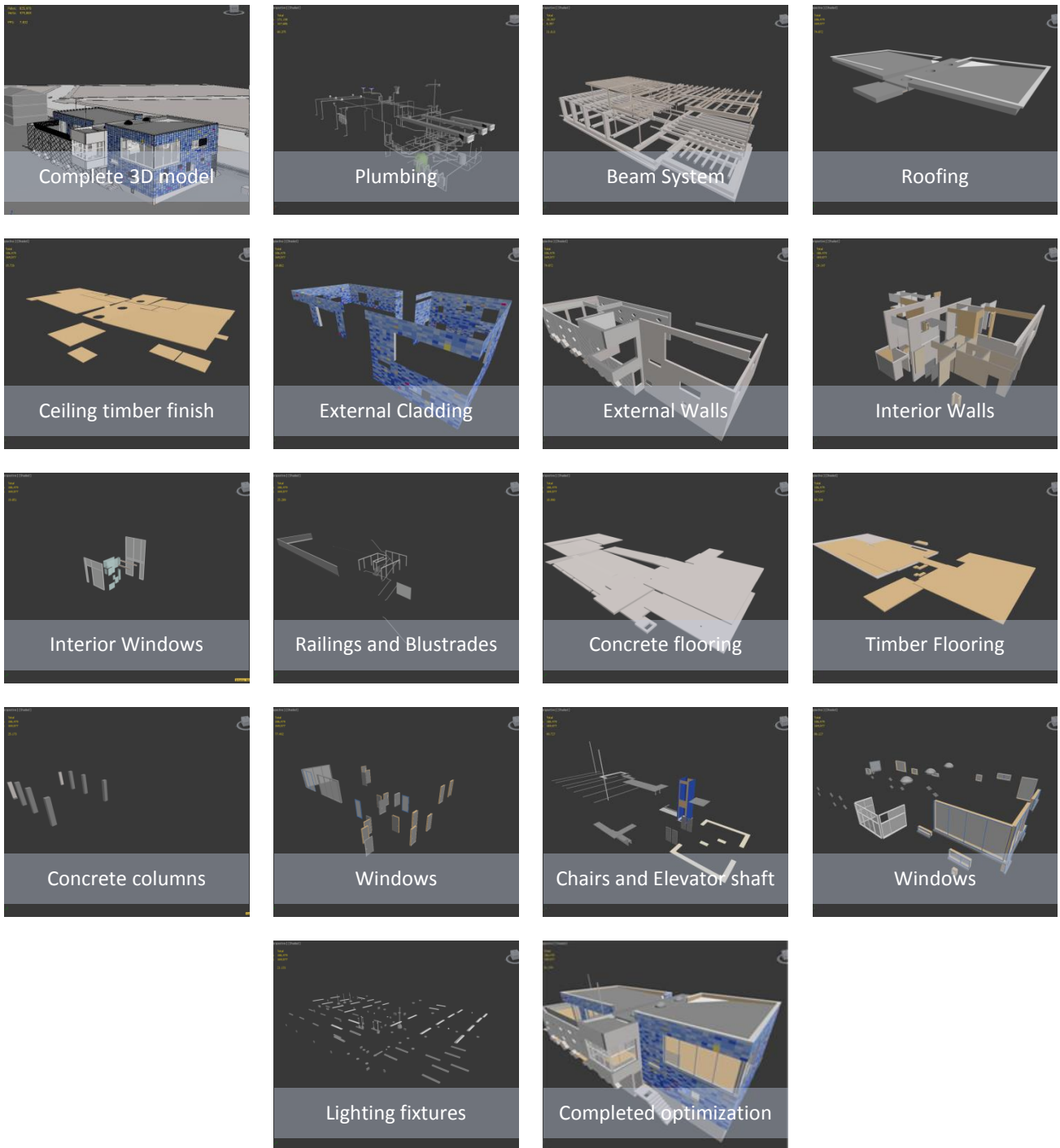


Figure 41: Optimization completed and components combined into construction groups

### Deleted components

Small components such as furniture and silhouettes that imported from Revit were removed as the focus of the simulation was solely on components that were related to the construction of the building.

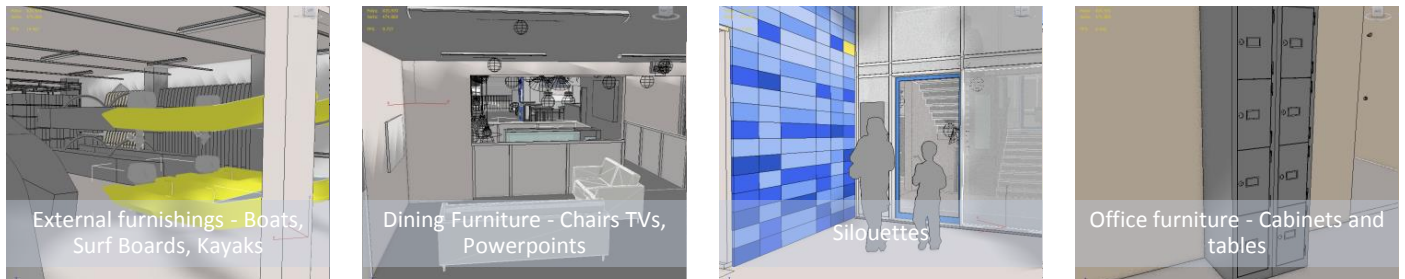


Figure 42: Deleted components

### Unity 3D Testing

Similarly to the first and second iterations the 3D model was exported into Unity 3D at various stages in optimization for assessment using a FPC. The final polygon count that resulted in a stable frame rate of 60fps was 60,000 – 80,000 polygons.

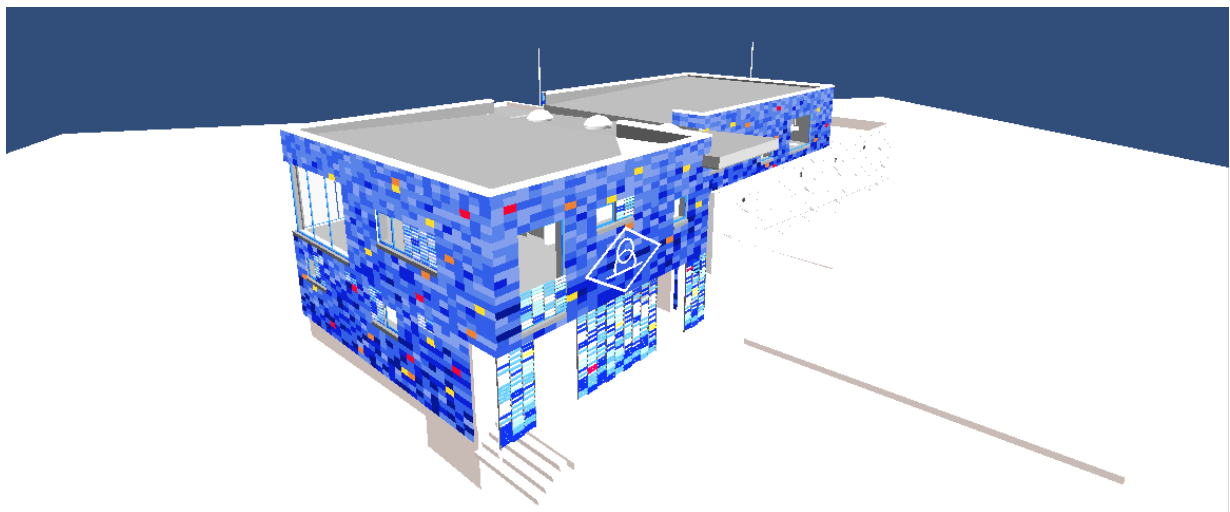


Figure 43: LBSC Model within Unity 3D

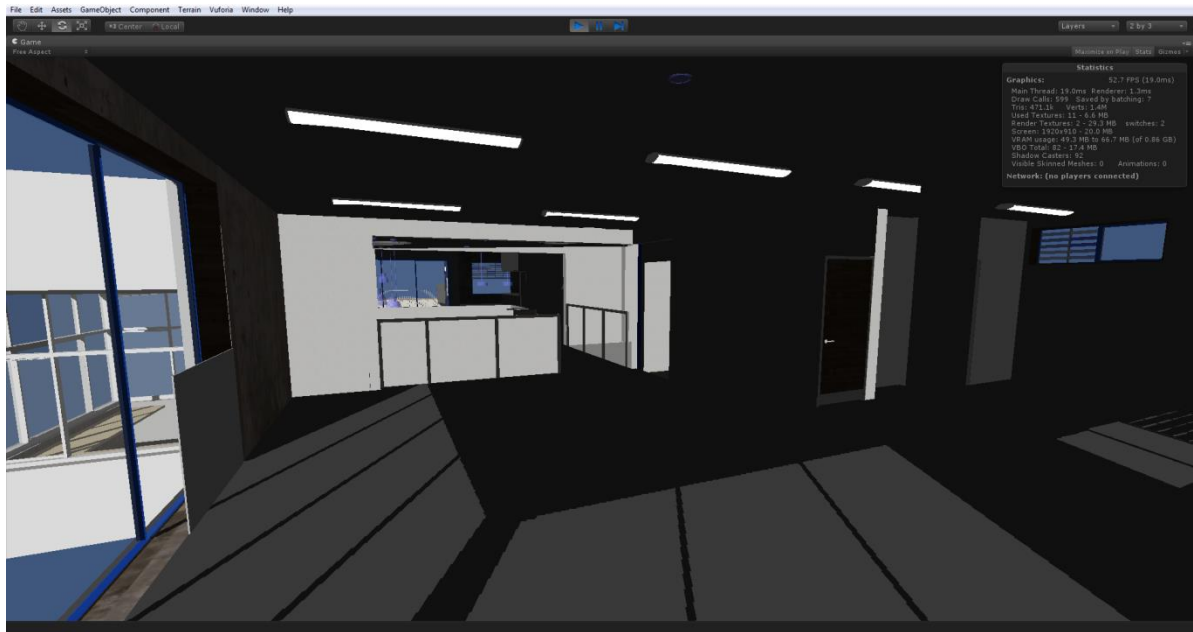


Figure 44: Adding FPC to explore the building and assess frame rate

### Problems/Issues elements

Two components that proved to be very problematic during the Unity 3D testing stages were the Hand dryer Unity within the bathrooms and a garage door. This was noticeable during the tests when the simulation crashed. This crash resulted from the FPC camera focusing on either of these two components yet was relatively stable around other areas of the 3D model.

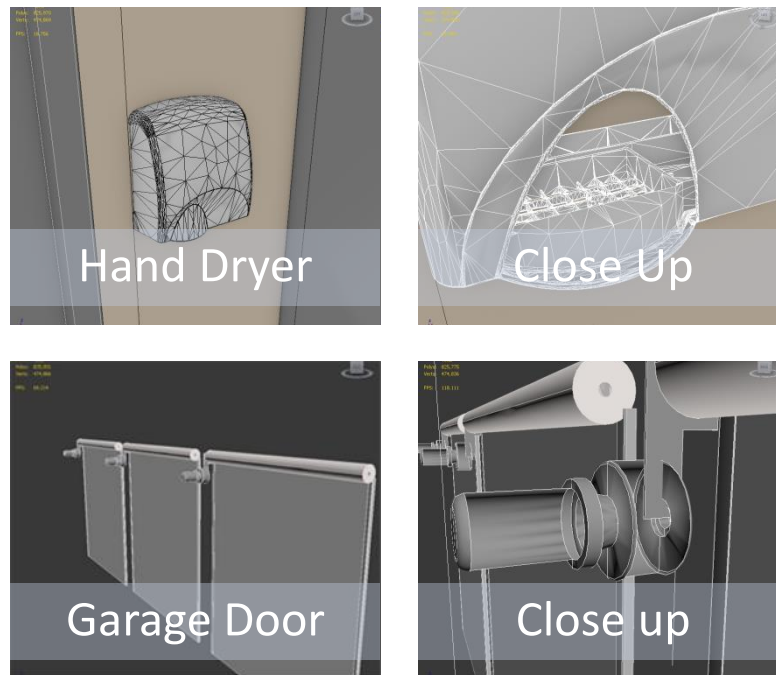


Figure 45: Invisible polygons

The second issue during run time within Unity 3D was the unusual flicker of some of the geometry. Inspecting the element within 3DS Max revealed that 2 components within the 3D model had been layered onto each other.

### Overlapping 3D components

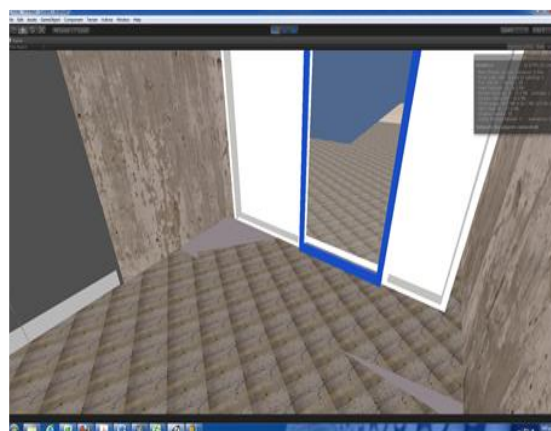


Figure 46: Overlapping geometry on floor – Floor mat modelled on the same level as concrete floor

## CRITICAL REFLECTION/DISCUSSION

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The 3D model was optimized through constantly editing it in 3DS Max and assessing the results of those actions by importing many different optimized versions into Unity 3D. The walkthrough was an assessment tool to see how the 3D model performed within Unity 3D and how much strain there was on the computers GPU. This part was undertaken using the frame rate and draw call statistics to categorize bottlenecks in the model that critically strained the GPU such as the hand drying unit and garage door examples.

Optimization during stages in which the prime case model had not yet been obtained was crucial to learning techniques beforehand. Literature provided precedents and tutorials on optimization but impacts on the 3D model only occur when those methods are implemented within 3DS Max.

3D modelling optimization is a very rich research area and there are many forums and research papers that discuss effective ways in which to optimize 3D content for use in Unity 3D. There are a variety of methods that could have improved optimization such as adding different levels of detail (LODs) for particular components and removing them out of scene using a method called occlusion culling. Through these techniques the application does not render the entire model during simulation run time but instead renders only parts of the model that are within the field of view to the user. However these techniques require multiple versions of 3D models to be authored, and was beyond the time scale available.

The process for exporting the 3D models from Autodesk Revit in iterations 1.2 and 1.3 into Unity 3D was complex and required close analysis of individual components. Revit as a design tool for architects is engineered to generate complex detailed building components since many 2D drawings are meant to be extracted from those details. The LBSC model was the perfect example of this in that it had hand dryers that contained details of the gears that operate it.

Components in Revit are referred to as families and these are what drive the polygon count high as they are mostly prefabricated online and downloaded with dense 3D content. This type of detail is not accommodated well within Unity 3D and this was seen when the Revit model was imported directly from Revit into Unity 3D. Running a simulation was impossible as the GPU became overpowered resulting in Unity 3D crashing during the FPC run time tests. From here on optimization was required to essentially tidy up the design and rename the hierarchy of the 3D model.

## 2. TEXTURE MAPPING

### INTRODUCTION

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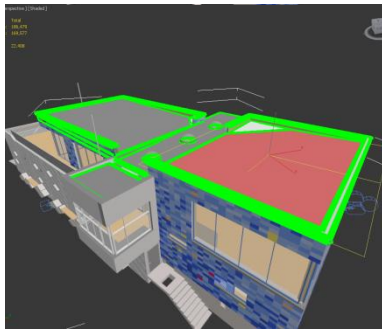
Each component that forms the 3D model is built with materials such as concrete, timber, porcelain and much more. When the model was imported into 3DS Max from Revit it did not contain any textural properties other than diffuse colours on each surface. Therefore this iteration focuses on adding materials and textures to improve realism to the now optimized version of the LBSC 3D model using 3 different methods. The objective was add effects that were of architectural quality so that when the application was showcased, it would demonstrate that augmented reality on a mobile device was also capable of high render quality finishes. This iteration is divided into 3 experiments which discuss a variety of texturing options within 3DS Max and Unity 3D.

- **2.1 LBSC UV Unwrapping**
- **2.2 LBSC Unity 3D direct import**
- **2.3 Light mapping**

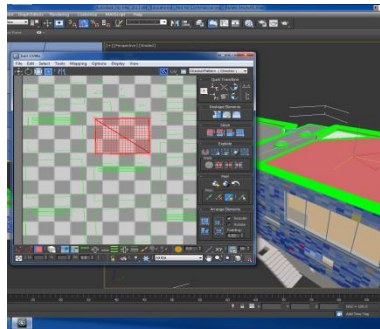
## ITERATION 2.1 LBSC UV UNWRAPPING

The UV Unwrap modifier within 3DS max shown below in examples 1 and 2 basically allow the user to peel off and flatten the surfaces of the 3D model as a UV Map. This UV map can then have different materials/textures painted onto various portions. This is particularly useful when the map needs to be exported and edited in a graphics editing program such as Adobe Photoshop.

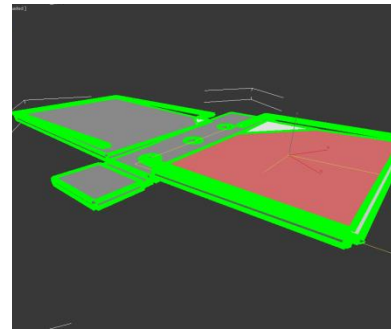
### Example 1



UV Map modifier application



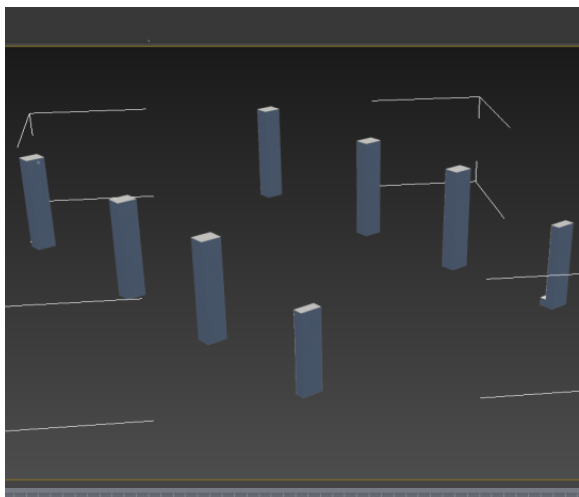
Assigning a portion of the model onto the map



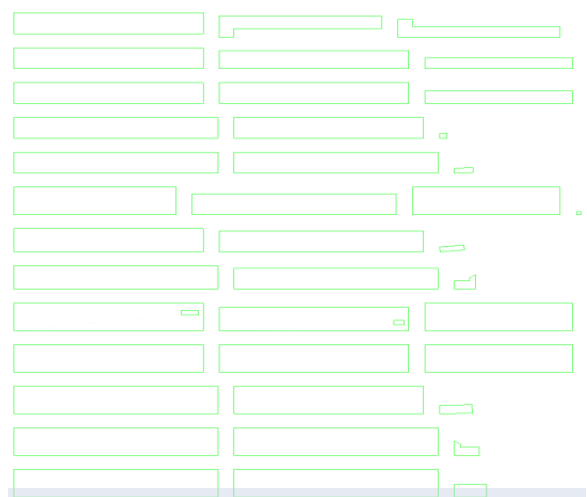
Isolating the component

Figure 47: Unwrapping UV maps for roofing construction group

### Example 2



Columns in 3DS Max



Unwrapping Column UV Map using UV Unwrap Modifier

Figure 48: Unwrapping Column UV maps



### Unity 3D testing

The UV map modifier was extremely useful for saving memory during simulation by limiting texture use usage and merging textures onto one large map which coats the 3D model. However when he 3D model was imported with textures into Unity 3D the UV maps did not spread properly onto the 3D model. Issues such as texture seams and map stretching could be seen in between textures resulting in unrealistic repetition of textures (figure 49).

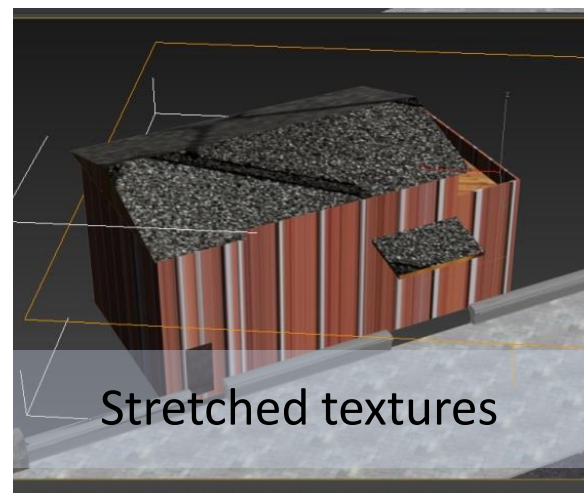
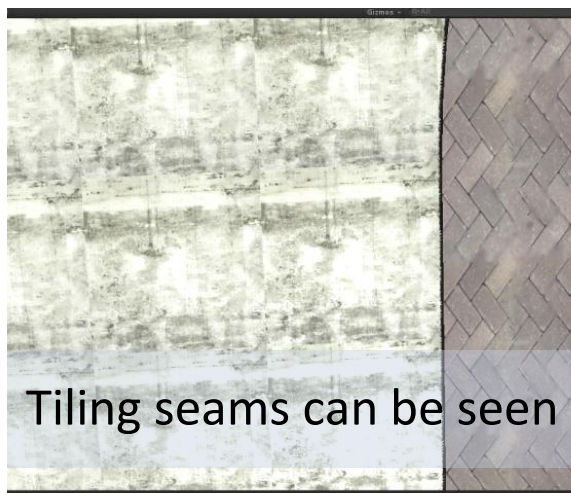


Figure 49: UV wrapping issues

## ITERATION 2.2 LBSC UNITY 3D DIRECT IMPORT

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The timescale for this project did not allow for UV mapping to be redone as an iterative process and therefore a different method was applied. As opposed to applying textures within 3DS Max in iteration 2.1 this experiment discusses the application of textures using tools within Unity 3D. This method is much easier than the 3DS Max method since there is virtually no unwrapping of surfaces involved. The key to the success of this iteration is the scale and size of the texture. As opposed to applying textures through UV unwrapping modifications in 3DS Max; the optimized model would instead import directly into Unity 3D. Unlike the 3DS Max workflow applying textures within Unity 3D has limited flexibility on editing smaller details using Photoshop. In addition this experiment also analyses the performance of the simulation when special maps are added.

### Special Maps

There are a variety of special maps that can be used in Unity 3D such as the Normal and Specular map. Normal maps generate the illusion of a bumpy surface during run time and are useful for textures on 3D objects such as rocks. A specular map generates the illusion of a shiny surface such as stainless steel or chrome reflections. The specular map is created with a variety of graphics software which in this case was Adobe Photoshop. The effects of both maps can only be seen when a light source is added to the scene. Shown in figure 50 below is the application of both maps to a bench top within the 3D model.

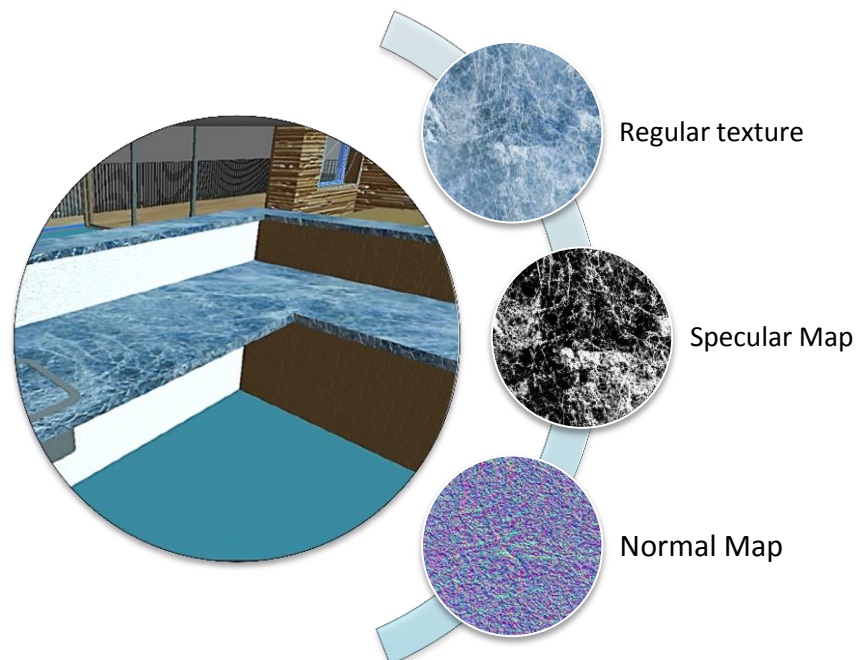


Figure 50: Applying special maps

Shown in figure 51 below is a demonstration of how effects are generated with the application of different maps. The interior areas of the 3D building model had the most special textures applied since they are the centre of attention in the FPC tests. Components such as the interior walls, carpet floors and wooden benches had special textures. Exterior components had no special textures applied to them in order to save on frame rate performance. Special maps are expensive to use and result in the computer having to work harder to simulate the desired effects.

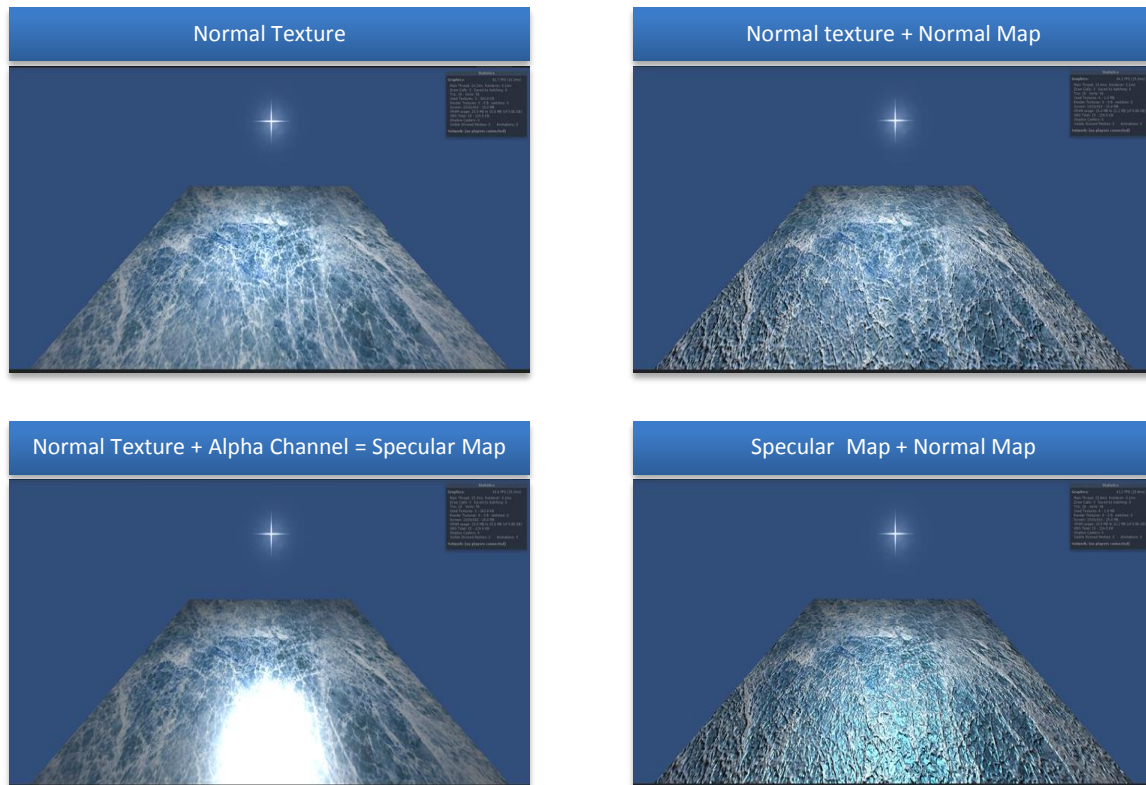


Figure 51: Special maps application

## ITERATION 2.3 LIGHTMAPPING

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The aim of this iteration is to test an in built feature of Unity called light mapping. Light mapping is an integrated part of the development engine and enables the user to add features such as ambient occlusion, baked in shadows and all special maps. Bump map and specular map details discussed in the previous iteration are essentially 'baked' onto the object as a large texture map. Light mapping is a great tool for saving on performance while retaining the realism that was added such as shadows and special maps. Successful light mapping and ascertaining the desired scene efficiently is a constant process of tuning the light map settings within Unity 3D. Creating light maps within Unity 3D is relatively similar to how a digital render within 3DS Max is made. The computer must calculate a range of operations to create the effect overtime.

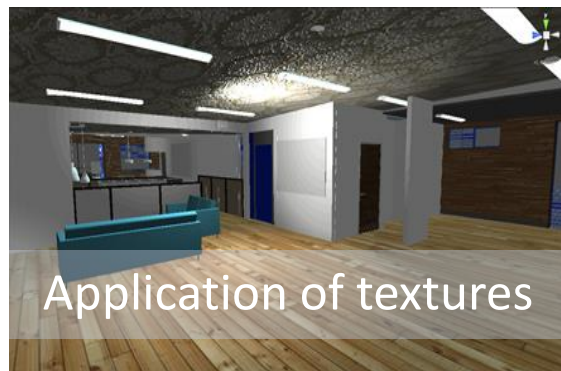


Figure 52: Textural Iteration

## CRITICAL REFLECTION/DISCUSSION

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The importance of UV Unwrapping was essentially for assessing whether textures could also be optimized similarly to 3D content to reduce file sizes in the simulation. Similarly to the optimization iterations the analysis of simulated performance was done by running the simulation within Unity 3D and assessing the textures for any issues and the amount of strain on the GPU. The application of materials and textures to the model had very minimal impact on the performance of the GPU. Therefore it was more a case of mapping textures efficiently to the 3D model. UV unwrapping in literature is a standard method in most virtual walkthrough simulations especially in game design for saving on texture file sizes. This allows 3D intensive simulations to focus on added content which will require computational effort such as animation.

Application of textures using tools within Unity 3D was the better option over UV Unwrapping since the textures tiled and mapped easier. The simplicity of the 3D Model at this point was also a factor in the GPU having low strain as it was only rendering one 3D model.

In game design multiple levels are designed with several levels of 3D detail. These details require a close attention to aspects of textures and therefore designers must be conscious of materials, textures and map sizes that are applied. Since this application only addresses the design of one model, textural application is relatively flexible. Most of the issues in iteration 2.1 were non-existent in iteration 2.2 since the materials mapped on easier and automatically scaled by Unity 3D. A UV map however when imported into Unity 3D required a lot of time to scale and map correctly onto a 3D component.

Light mapping within Unity 3D was more an opportunity than a requirement for the research as a whole. It gave an added level of realism that could be useful for when the application was presented to architects in particular. Since Architects are more interested in material appearances and in rendering building finishes. This iteration was essentially another way of articulating that render quality finishes can be applied to the surfaces of this 3D model and again accessible as a walkthrough simulation on a mobile device. This was made very clear during initial interviews that Architects are more accustomed to printing out large 2D renders and showing simulated walkthroughs on TV screens in office.

For all textural iterations a small level of graphics editing was required in order to tidy up the texture. Although very minimal editing in Adobe Photoshop was used for this process in order to map textures efficiently onto 3D components.

### 3. GRAPHICAL USER INTERFACE DESIGN (GUI)

#### INTRODUCTION

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With the model now optimized and performing within Unity, development of the user interface can begin. This iteration is informed from the analysis of precedents for key functions and aspects of construction management that appeal to interviewed practitioners. The design of the interface is also drawn from the authors experience in using Microsoft Project to graphically represent bar charts.

Four key functions were identified for development:

- **Integrated Gantt chart**
- **Deactivation function**
- **Timeline function**
- **Immersive function**

This section discusses the development of the first three functions and the scripting references that were used. The immersive level will be assessed in the final redevelopment iteration. The GUI is essentially a collection of buttons and sliders that enable a user to interact with the 3D model through scripted functions. The user interface was developed with both a variety of C# and Java scripting references that exist within the Application Programming Interface (API) within Unity 3D. These functions enable the user to interact with the LBSC 3D model and manipulate to show different types of information.

This section is split into 3 main experiments which discuss a different function that was created for the GUI. The final section displays all these functions combined on screen to form the GUI.

- **3.1 Deactivator**
- **3.2 Gantt Chart**
- **3.3 Timeline**
- **3.4 Combined Interface**

## ITERATION 3.1 DEACTIVATOR

From the early interviews practitioners expressed the need for standard deactivation tools that enable them to see different 3D layers. The “deactivator” function basically does this by introducing a switch that enables components in the 3D model to be turned on and off depending on the preference of the user. Shown in figure 53 is a very small part of the larger script that essentially creates the function on screen. By attaching this script to construction groups that were assembled during optimization in iteration 1.3 the user can activate and deactivate different construction layers via two buttons on screen.

### Primary Script Reference

Figure 53 below is the key reference from the body of a larger script that essentially situates two buttons on screen and adds on/off functionality. Translating this script into a readable format basically reads:

*“If this button (GUI.Button) called ‘on’ situated on this part of the User Interface (Rect (1130, 420, 40, 40)), all objects with the code name **target 4** should be activated (SetActive (true)) on screen”.*

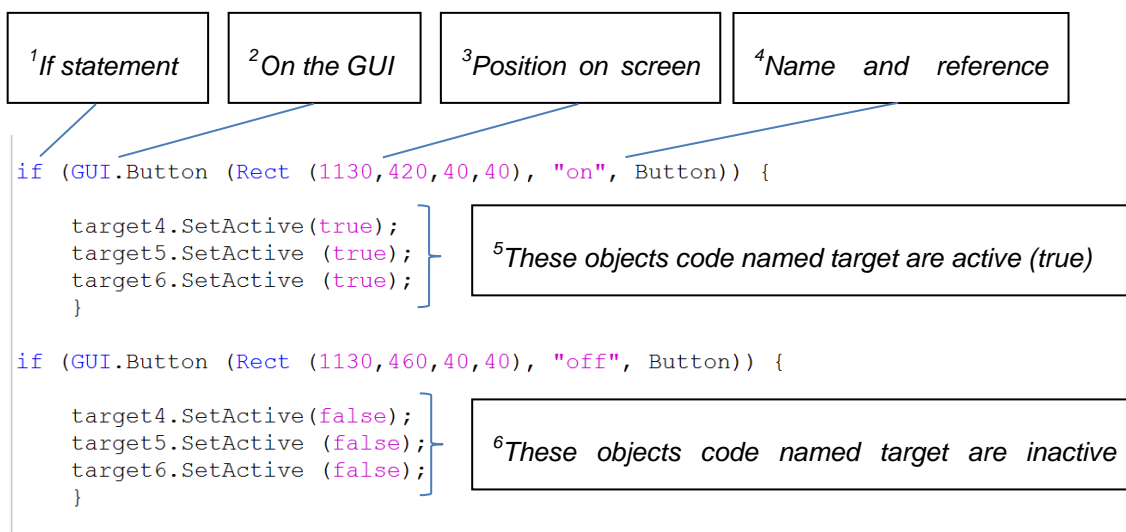
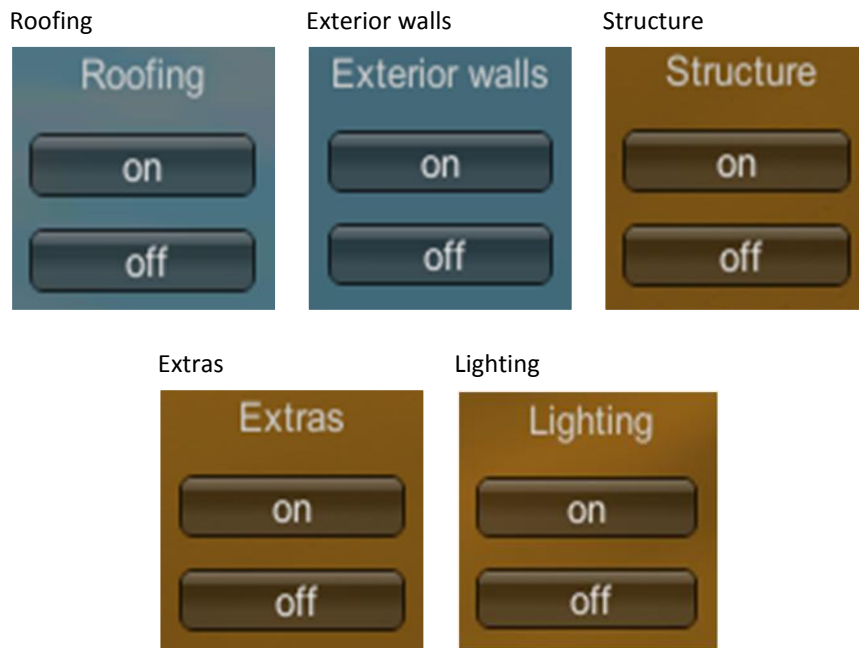


Figure 53: Deactivator key script references

### Key

1. **If Statement** – Stating that if this happens
2. **On the GUI** – Function occurring and called on the GUI
3. **(Rect (x,x,x,x))** – Identifying where on screen to create the button
4. **On** – Naming the button
5. **SetActive (true)** – Activate these objects/these variables/objects that are codenamed target 4,5,6
6. **SetActive(false)** – Deactivate these objects/these objects do not exist

The end result of this script is the creation of two buttons for each construction group labelled *on* and *off* on the GUI as shown below in figure 54. Pressing on activates the construction component, pressing off does the opposite.



**Figure 54: Deactivator function applied to all construction groups**

Shown in figure 55 are the results of this function toggling the exterior walls and roofing construction groups. Applying this function to other construction groups was relatively easy just by duplicating it after creating the base script. The completed list of construction groups are shown below on the left hand side of the screen.



**Figure 55: Deactivator toggling roofing and construction walls**



### Drop Down List

Initially the design of each deactivator was listed on the left of the GUI. Since this application was going to be ported to a mobile platform having a list of buttons took up too much of screen. Therefore to accommodate screen size and other GUI functions all buttons were stored and activated in a drop down list. Adding style scripts to the function enabled the design of each button to include edited icons which represented each construction group.

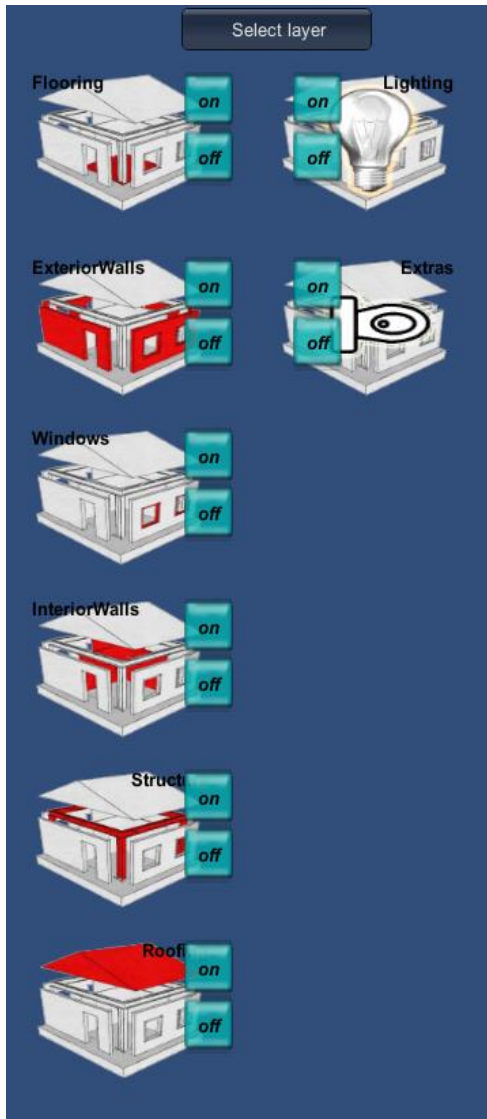


Figure 56: Drop down list with Icons

## ITERATION 3.2 GANTT CHART SCHEDULE

From the early interviews practitioners expressed the need for an integrated Gantt chart that can visually connect tasks to groups within the 3D model. The second feature and most complex of all GUI features is the Gantt chart function. The main aim of this iteration was to create a control that acted similarly to a MS project Gantt chart. The most important aspect of this function is that with any actions made to the Gantt chart there would be a reaction that visually appeared on the 3D model. This function is the link to 4D BIM in that any changes made on the information relating to time would directly be referenced back to the 3D model graphically. The Gantt chart is also scripted using JavaScript with initial attempts using C# which did not result in viable functionality. In order to design a Gantt chart within Unity 3D; inspiration was drawn from features that control tasks in MS project. There are 4 key features that control a task in MS project from the authors experience in the software: **Task name, Start Date, End Date and Duration**. There is also predecessors and successors, but as a scope to create a concept these will be used as a visual representation

### Primary Script Reference

Figure 57 below is a representation of how these script references have been used to visually situate a slider with 2 buttons next to it on screen. Translating this script into a readable format it basically reads:

*“Task is a Horizontal Slider situated on this part of the Graphical User Interface (Rect (20, 330, 170, 20)), and has units that start from 0 – 8. If this Button situated on screen (Rect (80, 445, 110, 50)) called ‘+’; Move the slider called task by one unit forward ++.*

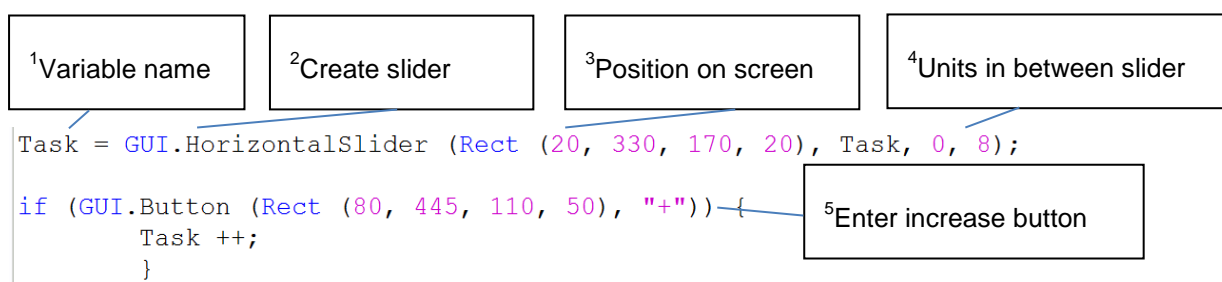


Figure 57: Gantt chart key script references

### Key

1. **Task name** – The name of the slider reference
2. **Call GUI.Slider** – Create a slider on the GUI
3. **(Rect (x,x,x,x))** – Identifying where on screen to create the slider
4. **Units** – How far does the slider count
5. **Enter increase button** – If this button is pushed increase the slider increment by 1 unit

**Task features/design**

From analysing the features of a task bar in MS project and how it is controlled in MS project, the author was able to fabricate a similar task bar within Unity 3D, i.e. copying how MS project works. The results of scripting this together are shown below and comparison of a task in the Gantt chart scripted and the Gantt chart from MS project. However instead of a bar appearing as it would in MS project, the interface uses a slider along a timeline of months and uses the slider tab to identify where along the timeline the task has progressed.

1. Name of task
2. Duration counter
3. Start and End Dates (months)
4. Task shown as a bar slider
5. Progress slider tab

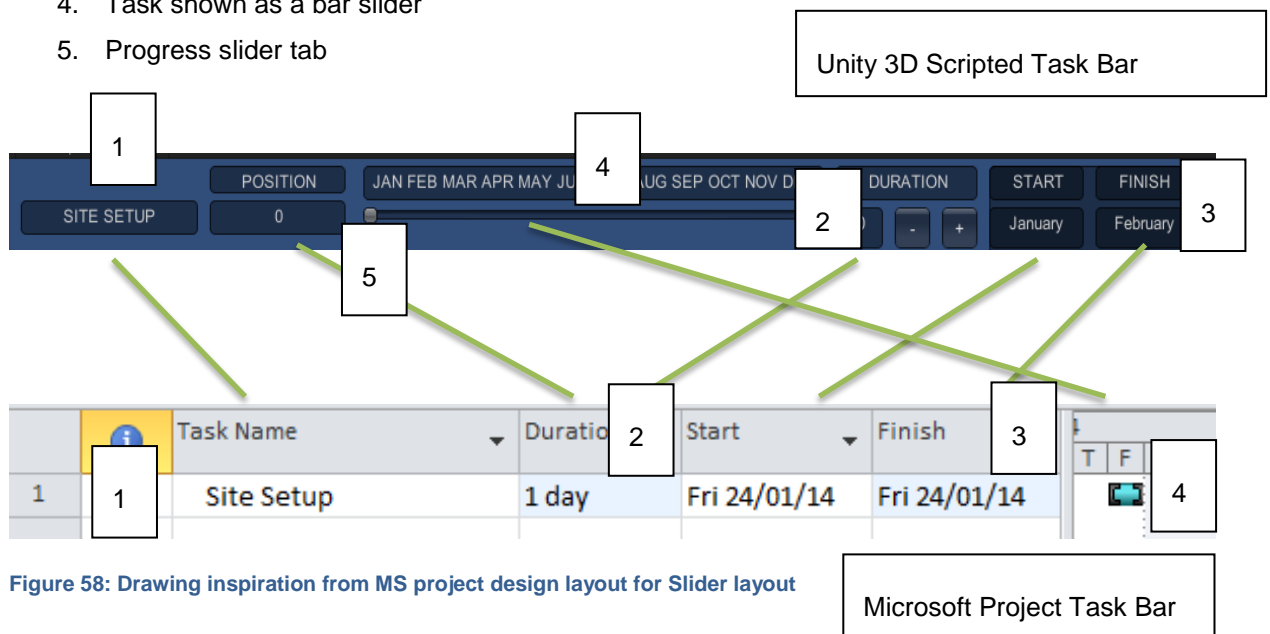


Figure 58: Drawing inspiration from MS project design layout for Slider layout

### Completed Interface

By the end of the scripting phase 7 key construction task bars were created and are named after the construction groups that were assembled in earlier optimization iterations. Task names were also drawn from names within the **actual** Gantt chart that was received with the 3D model. Shown below is the real schedule which lists the key tasks for construction of the LBSC.

	Task Name	Dur	Start	Finish
1	[-] Lyall Bay Surf & Life Saving Club	355 d	Fri 20/07/12	Fri 13/12/13
2	[+] Preconstruction	191 d	Fri 20/07/12	Mon 29/04/13
1	Contract start	0 d	Mon 6/05/13	Mon 6/05/13
2	[-] Construction	159 d	Tue 7/05/13	Fri 13/12/13
3	[+] Enabling works	25 d	Tue 7/05/13	Mon 10/06/13
8	[+] Structure	60 d	Tue 11/06/13	Mon 2/09/13
4	[+] Envelope	20 d	Tue 27/08/13	Mon 23/09/13
7	[+] Internal works	49 d	Tue 24/09/13	Fri 29/11/13
9	[+] Completion items	20 d	Mon 18/11/13	Fri 13/12/13
4	Practical completion	0 d	Fri 13/12/13	Fri 13/12/13

Figure 59: LBSC Gantt chart for construction

Completed scripting of tasks and names revealed the scheduler below

The screenshot shows a software interface for a Gantt chart scheduler. It features a list of tasks on the left, each with a 'Task' label, a 'POSITION' column with minus, plus, and zero buttons, and a progress bar. The tasks listed are SITE SETUP, FOUNDATIONS, STRUCTURE, ENCLOSURE, INTERNAL, SERVICING, and FINISHES. The progress bars are currently empty. To the right of the progress bars is a 'STARTDATE' column with 'January' selected, and a 'Start/End Date' column with 'February' selected. A 'Progress' callout box points to the progress bars. The interface is dark-themed with blue and grey colors.

Figure 60: Gantt chart features

**Modes of scheduling: Automatic vs. Manual Scheduling**

Within MS project there are 2 options for scheduling tasks that essentially allow the user to control the project using either automatic or manual scheduling. Automatic scheduling is when MS project uses an engine to automatically position new tasks in respect to other tasks and calculates start and end dates for the user in respect to tasks set out earlier. Manual scheduling is when the user has complete control over the entire schedule with no automated calculations taking control over progression of tasks. These two modes were integrated into the design of the Gantt chart for the application.

**Automatic Scheduling**

The design of the automatic scheduling mode on the interface was to duplicate a small part of this scheduling engine. Specifically how the duration of a task impacts on the next task. This was shown in the duration counter when a task was moved forward the task after it would decrease in time to complete unless it was also moved forward. Designing an engine script to automate tasks would have gotten extremely complex and even at a demonstration level the script incorporated a dense amount of algebra. Therefore this mode of scheduling was untied back to the 3D mode but rather just used for demonstration purposes.

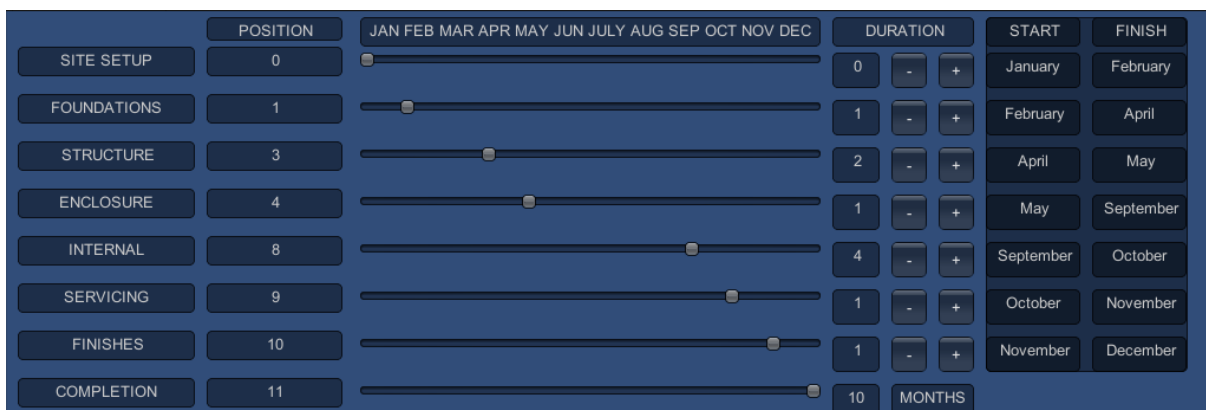


Figure 61: Automatic Scheduler

By default the application starts in automatic scheduling to showcase the actual progression of tasks. By clicking on the Manual control button the application automatically switches to the manual scheduling Gantt chart.

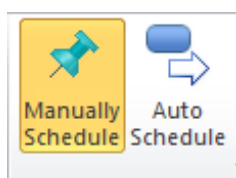


Figure 62: Switching between scheduling modes in MS Project

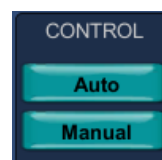


Figure 63: Switching between scheduling modes in the application

### Manual Scheduler

The aim in the design of the script for manual scheduling in the Gantt chart was to now connect each task back to its respective construction group (3D component). Any changes to the task properties such as the start/end dates register a colour change within the 3D model. These colour changes for each 3D component notify the user where the task is in respect to time and dates set.

When manual scheduling is activated all tasks are set to January and all buttons are set to green indicating all tasks are on time. The manual scheduler works by giving the user full control over each task and having colour coded connections with the building component. As shown below are the results from scripting and showcases the manual scheduler in use after creating 7 sliders that label the 7 key construction groups.

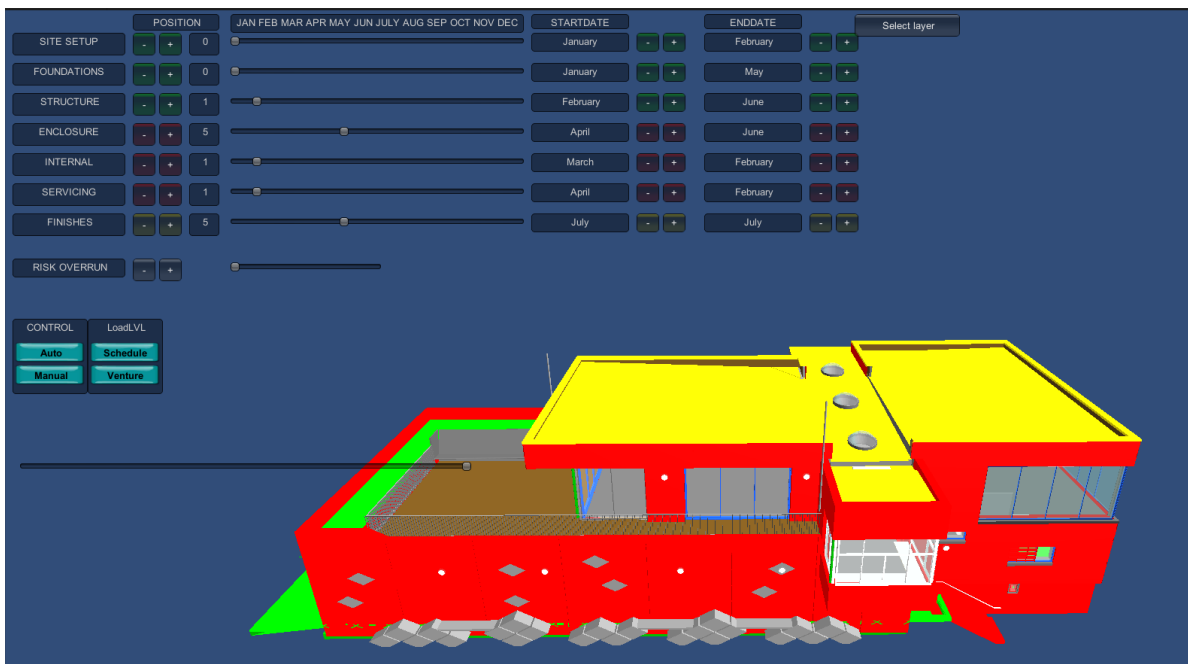


Figure 64: Manual Scheduler in use

Listed in order below is how to use the manual scheduler and the denotation of each colour state:

1. Activating Manual scheduling automatically sets all tasks and building components to Start Date January and End date February. All components are colour green indicating all task slider tabs (current progress) are behind the End date and are on time. The progression of each task is controlled with the slider tab. This tab can be moved along the slider by clicking and dragging the tab or clicking on the increase/decrease buttons underneath the 'position' counter.

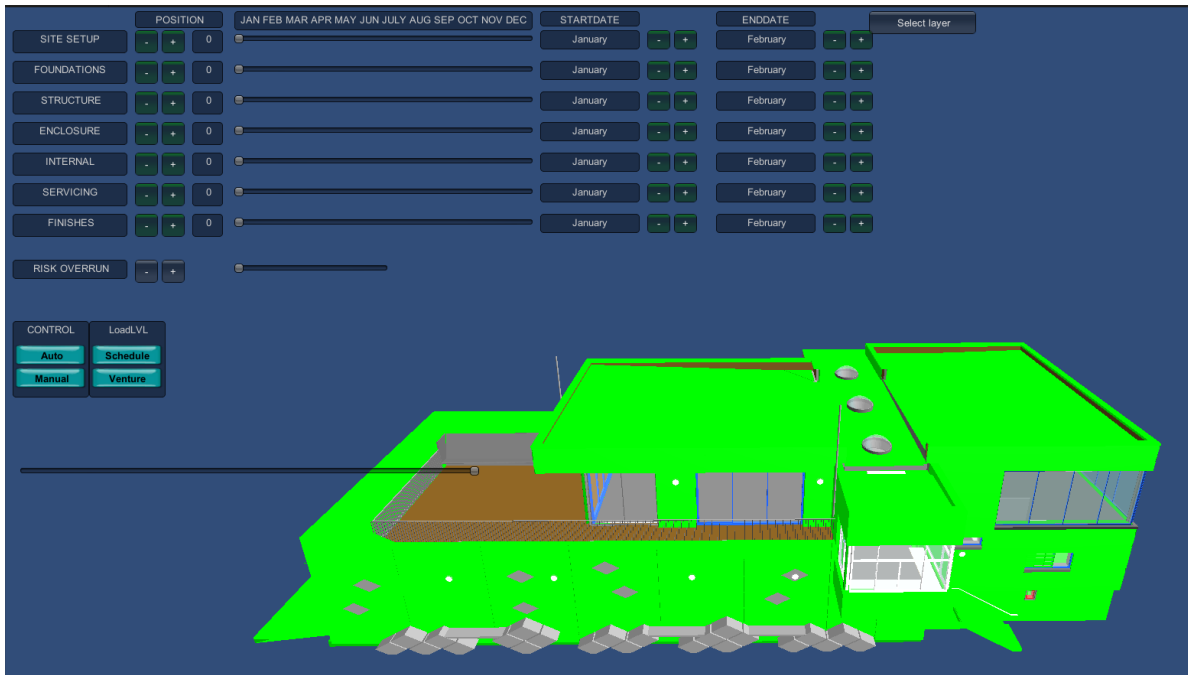


Figure 65: Activating Manual Scheduling

- 2. Similarly to MS project the user has to set start and end dates for each task using increase and decrease buttons next to each month counter. The slider controls where along the timeline the task has progressed. Therefore the slider tab moves forward along a monthly timeline according to the progress of each task between the start and end date.



Figure 66: Setting Start and End dates

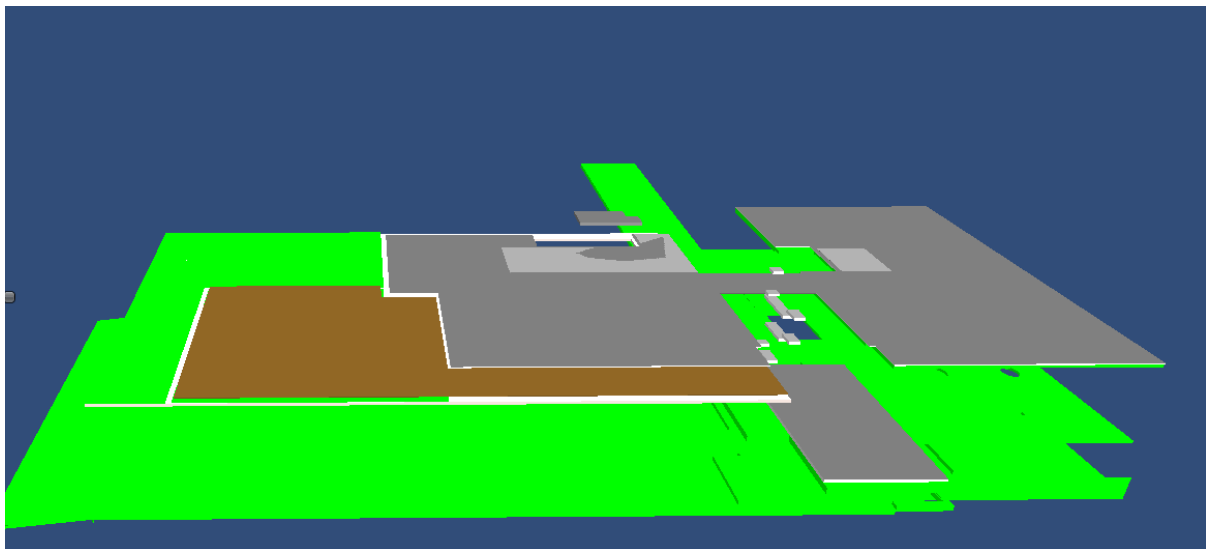


Figure 67: Using Deactivator to see foundations with manual scheduling active



- The slider tab represents where the task is in terms of progression and moves forward in the context of construction. The objective is to keep the slider tab behind the end date i.e. Progress must always be behind the finish date.

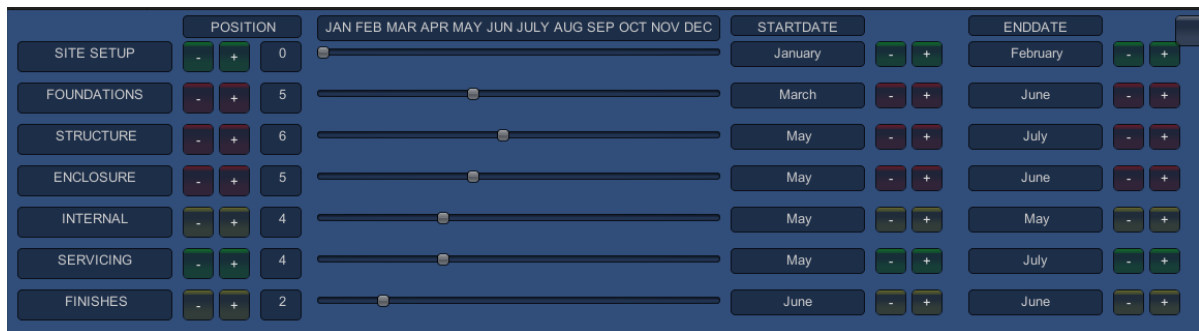


Figure 68: Using the progress sliders to identify where the task is along the timeline

- Having the progress tab exceed the end date results in the task changing to colour red indicating that task has gone beyond its finish point. This indicates to the user that the end date that was set before has been exceeded and the task should be finished.

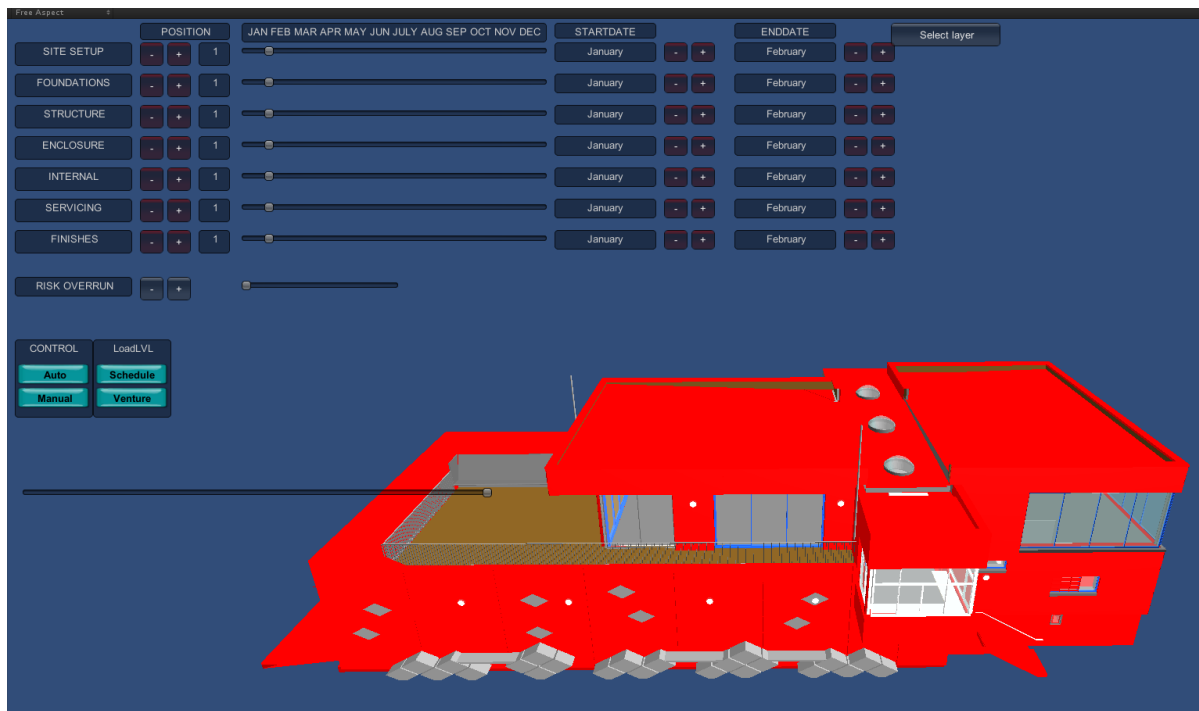
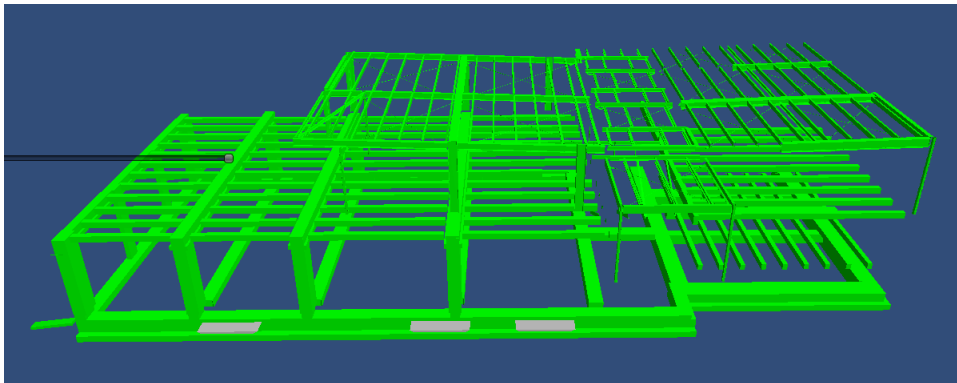


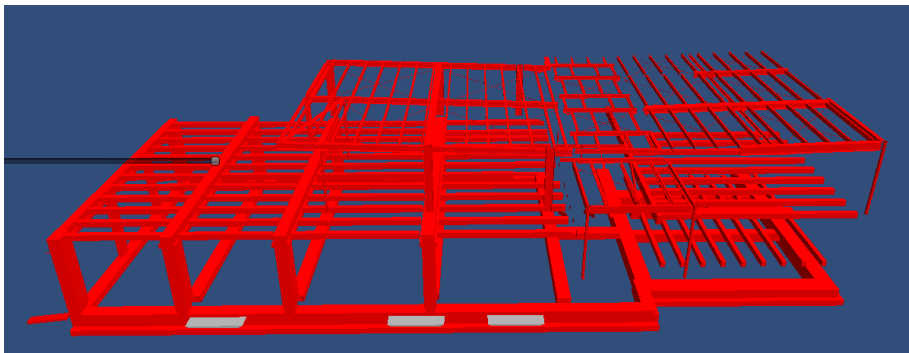
Figure 69: When the current progress exceeds the end date

Each task bar is capable of being in 3 states; the example below shows how changing start and end dates impact the colour coding of the 3D model. Note: the deactivator was used to switch off all components and focus on the structural construction group.

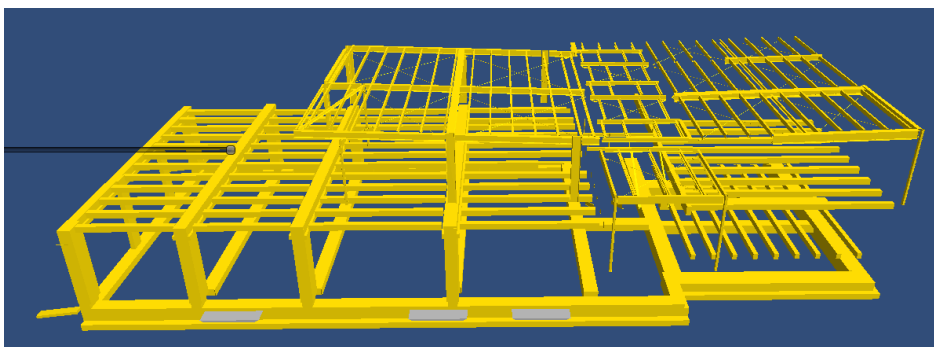
- **Green** – Task is on time and is behind end month



- **Red** – task has gone beyond end month



- **Yellow** – Task starts and ends on the same month i.e. Milestone task



### ITERATION 3.3 4D CONSTRUCTION TIMELINE

The design for this function was informed by interviews in which practitioners expressed the need for tool that acted as a slider that builds the 3D model along a timeline. The timeline function essentially does exactly this by building the 3D model from ground up using a slider function. The timeline was relatively simple to set up within Unity 3D and the core function that makes each component appear is a similar script reference used in the deactivator script. The timeline function was also inspired from the early interviews when a practitioner drew a sketch of a timeline that would benefit construction management. Figure 70 below articulates the need for a type of timeline that enabled on-site comparison of what had currently been built and what could be built. This would enable the user to capture on site observations using a mobile tablet and further send notes to various stakeholders to analyse where the project has progressed.

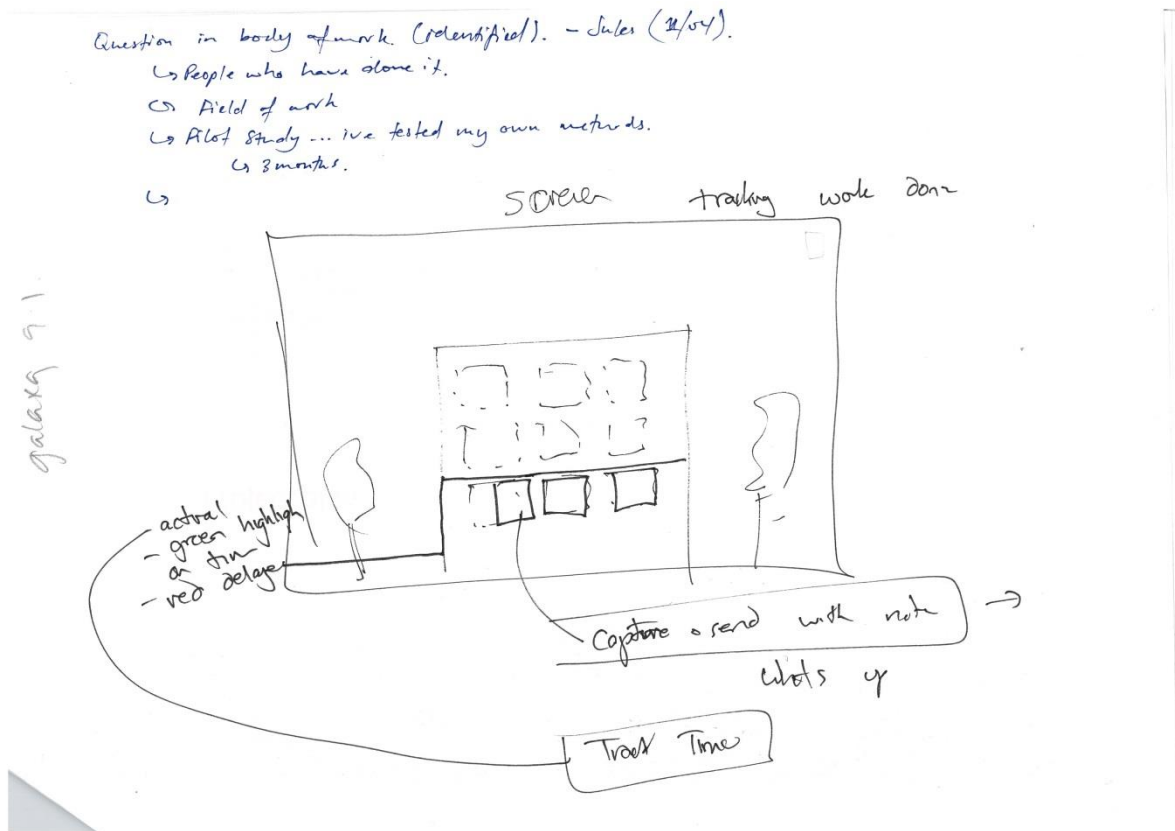


Figure 70: Practitioners sketch of Timeline

## Primary Script Reference

The script for creating this slider was relatively simple to create by utilizing a scripting reference relatively similar to the deactivator *Set.Active* function called *SetActiveRecursively*. This script reference essentially allows a construction component to appear at a specific point along the slider. This means all construction components start off inactive until the slider reaches a point along the timeline.

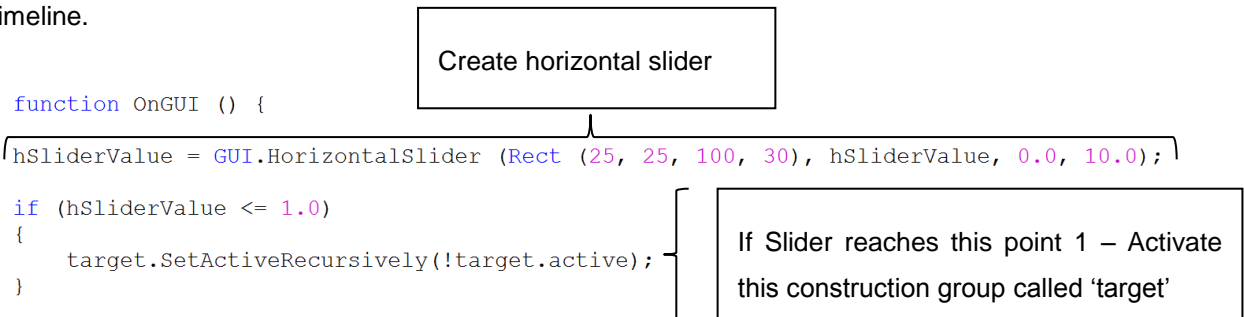


Figure 71; Timeline key script reference

The end result of this script is the creation of a horizontal timeline on the GUI during run time. By moving the slider tab from left to right the model builds in 3D during simulation. The progression of construction was referenced from the Gantt chart that accompanied the 3D Revit model.

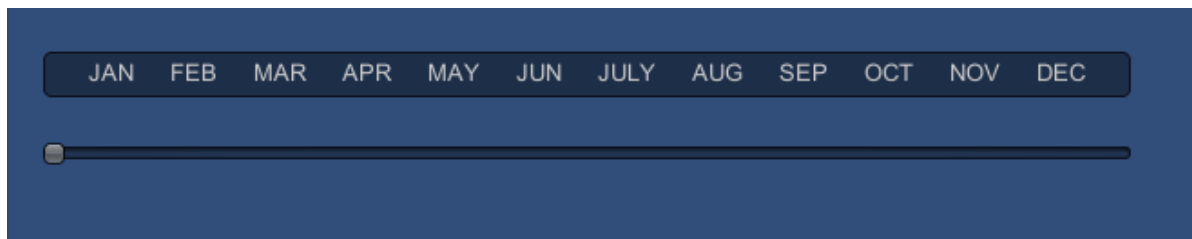
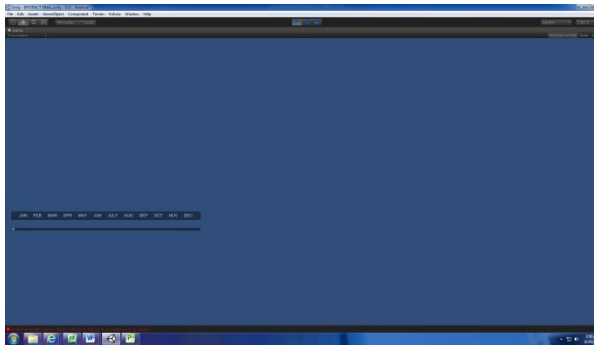


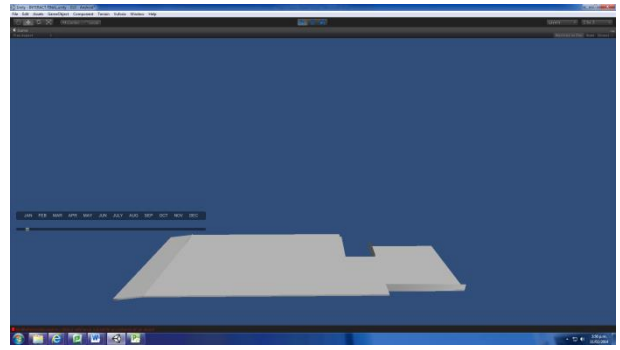
Figure 72: Timeline Slider

The next page shows how each construction component appears in sequence using the timeline.

### Timeline progression



**a) Timeline activated**



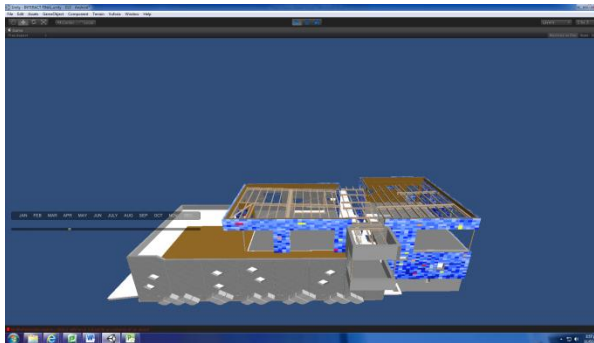
**b) Timeline progress in January**



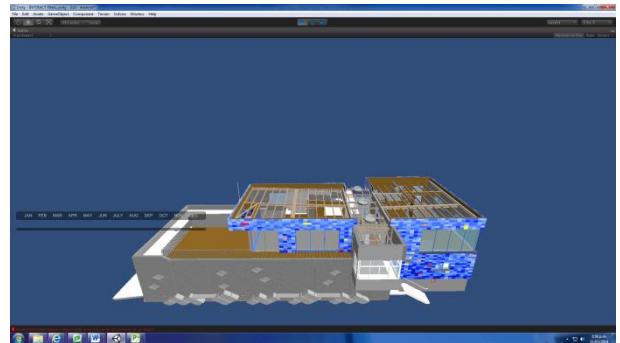
**c) Timeline progress in February**



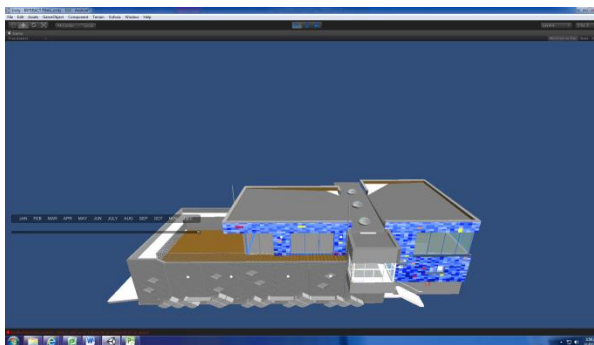
**d) Timeline progress in March**



**e) Timeline progress in April**



**f) Timeline progress in November**



**G) Timeline in December**

## COMBINED GRAPHICAL USER INTERFACE

The three main functions designed for this iteration were driven and informed from practitioner feedback as well as aspects driven from precedent review. Figure 73 summarises all core functions combined as an application for a desktop computer.

- 1** Deactivator  
Drop down list of construction groups with toggle buttons
- 2** Gantt chart  
Tasks controlled via slider
- 3** Scheduling Mode  
Auto/Manual scheduling
- 4** Timeline  
Constructs building ground up

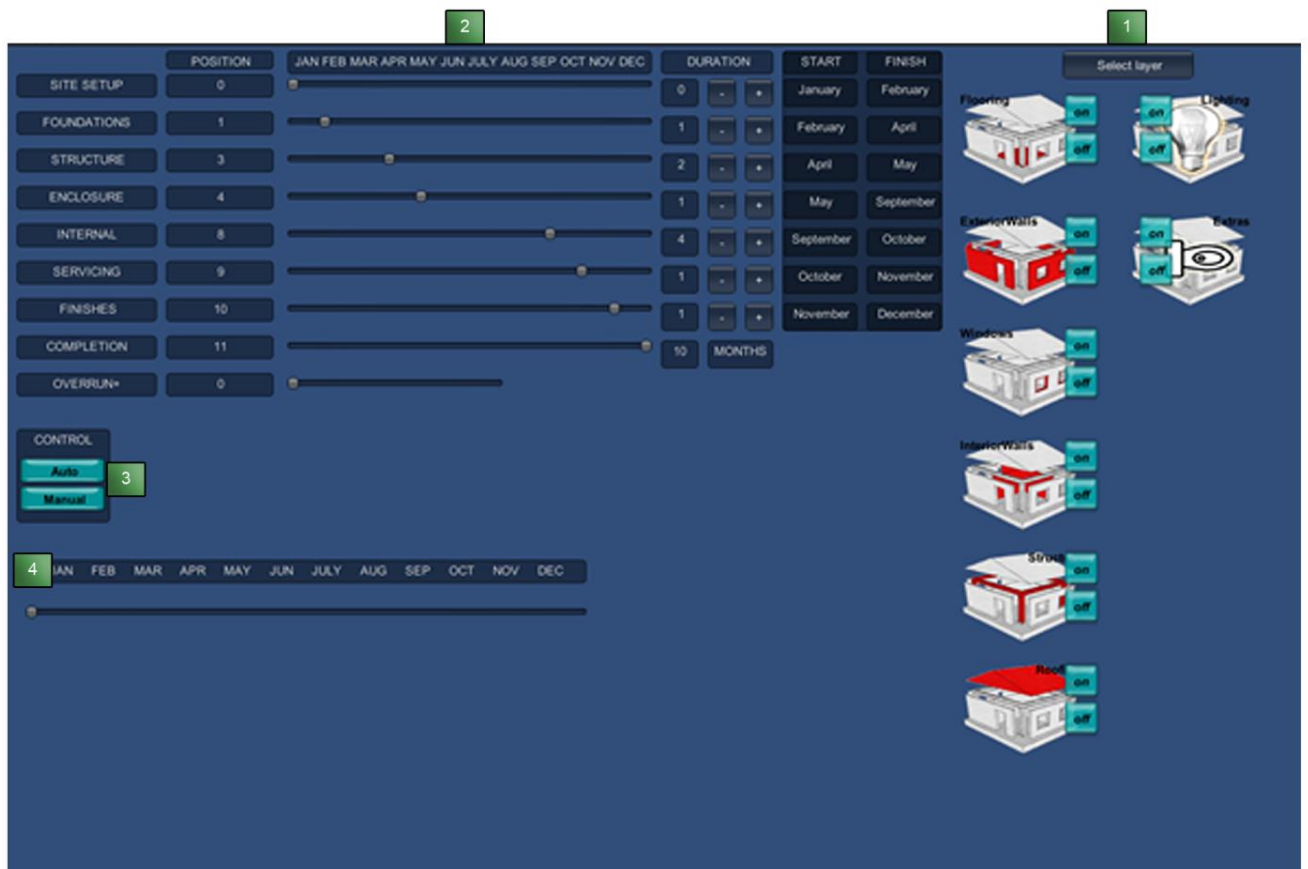


Figure 73: Complete GUI with combined functions

## CRITICAL REFLECTION

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### **Deactivator**

A Deactivation function that could switch on/off different construction layers is relatively standard in most computerized applications. Some smart mobile applications during the precedent review had much more interactive methods of doing this such as deactivating components by directly clicking them on screen. There are a variety of ways in which this function could have been approached but was left as a drop down list for simplicity and presentation.

### **Gantt chart**

The design of the Gantt chart was at a very minimal level following the design and functionality of key aspects in Microsoft project. This function was more informed by the authors experience as opposed to the feedback received. The 3 key controls that a project manager is always changing in a Gantt chart program are the start and end dates. This enables them to analyse the durations of a particular task and generate different paths. The other key factors that are controlled are the predecessors and the successors. These factors have a very key role in calculating the tasks that are on the critical path.

By identifying start and end dates, the user is able to track where a task is situated on a timeline. This is represented in the task bar as a slider that represents the duration of the task. In MS project long tasks are represented with extended bars and usually are on the critical path. The aspect of having a bar chart represent this visually was recreated as a slider for this application.

Even at a prototype level this script is extremely complex as it requires each task to function on its own and display the right information. It was decided that green and red would be good indicators of 'good' and 'bad'. Manual scheduling was given more emphasis in terms of development as opposed to automatic scheduling since the controls were simpler to create. Automatic scheduling would also require including predecessor controls which were out of the scope of design.

### **Timeline**

The timeline was created by stringing together scripts that had been compiled from the deactivator script. The timeline would have been much more realistic given it could change construction groups along the slider path. For example if external walls came before structural walls; perhaps the timeline could change that via drop down list as opposed to being a fixed timeline. Tasks always change in the construction environment and therefore having a fixed timeline of construction groups does not reflect how the project will actually progress in 3D.

## 4. AUGMENTED REALITY PLUGIN AND MOBILE PLATFORM TESTING

### INTRODUCTION

---

With GUI scope of design now completed porting the application to an augmented reality platform could now begin. This section focuses on implementing and testing augmented reality using the LBSC 3D model and associated GUI using an extension for Unity 3D called Vuforia. The Vuforia installation plugin for Unity 3D is a toolkit for creating and developing augmented reality applications within Unity 3D. The most important features of this plugin that enable AR are the *AR camera* and *'image target marker'*. The AR camera is a special feature which essentially activates the camera on a mobile device that tracks the image marker. The image marker is the pattern/surface that the 3D model superimposes onto. The target marker has to have noticeable features such as colour or jagged patterns for the camera to track easily (Qualcomm, Augmented Reality (Vuforia) , 2012).

This iteration is split into 2 sub sections which discuss the early tests before porting onto a mobile tablet computer.

- **4.1 Augmented reality - Desktop computer**
- **4.2 Augmented reality – Tablet computer**



## ITERATION 4.1 AUGMENTED REALITY - DESKTOP COMPUTER

This section discusses the initial stages of augmented reality (AR) where the 3D model is simulated in AR using a desktop computer web camera. This step essentially checks if the plugin is functioning and the 3D model is appearing on the 2D marker. Setting up the scene in Unity 3D is relatively straightforward after the Vuforia plugin has been installed. A series of tools allows the user to select an image target and situate it underneath the 3D model as shown in figure 74 below. The GUI in this first test was removed for initial tests and re-applied during tests on the tablet computer.

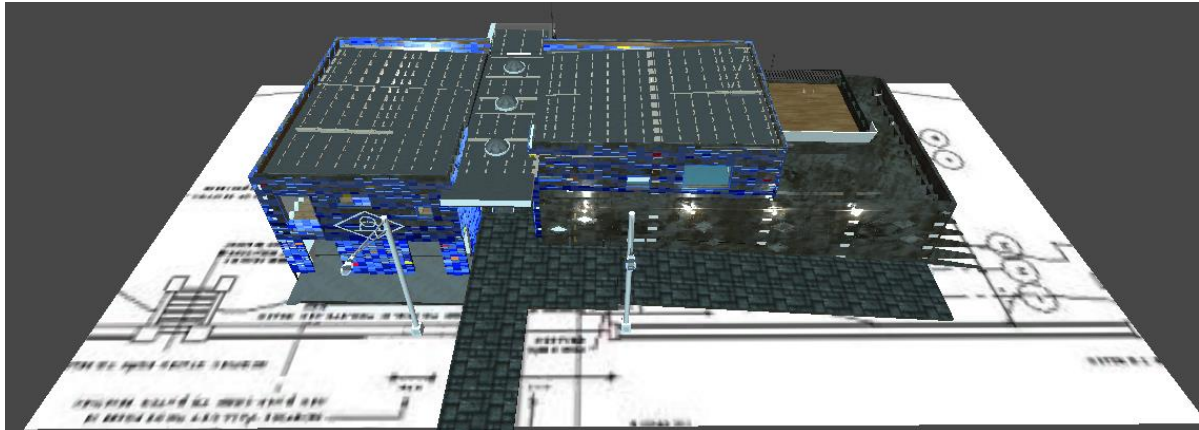
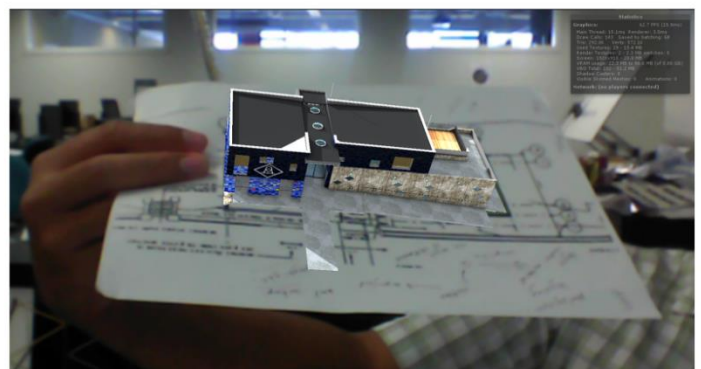


Figure 74: Scene Setup within Unity3D – Placing 2D marker underneath 3D model (2D Plan)

Testing AR on the desktop computer was necessary to assess if an integrated web camera would track and build an augmented 3D model on the target marker. During run time the computer's web camera automatically activates and situates the 3D model onto the 2D marker as shown in figure 75 below. Given that the 3D model is superimposing onto a 2D marker, this confirms that the plugin is operational and tests can now move to porting the application on a mobile device.



Integrated web camera  
Active  
2D Marker situated in  
front of camera



Augmented Reality  
LBSC 3D model superimposed in  
augmented reality

Figure 75: Augmented Reality testing on desktop computer

## ITERATION 4.2 AUGMENTED REALITY - TABLET COMPUTER

This iteration discusses porting the application as a final build from Unity 3D onto an Asus transformer tablet computer. This is done by compiling all scene levels developed and selecting the Android platform as opposed to the desktop computer platform for a final application - build within Unity 3D. Shown below were the steps taken to create the application .APK file from Unity 3D for installation on the android device.

### 1. Final Build settings

This is the final build dialog box which enables the user to add details and select a Following establishing these settings the 'Build and Run' button is selected and Unity 3D begins creating the application as a .APK (android) file. This file is then stored on the tablet computer.

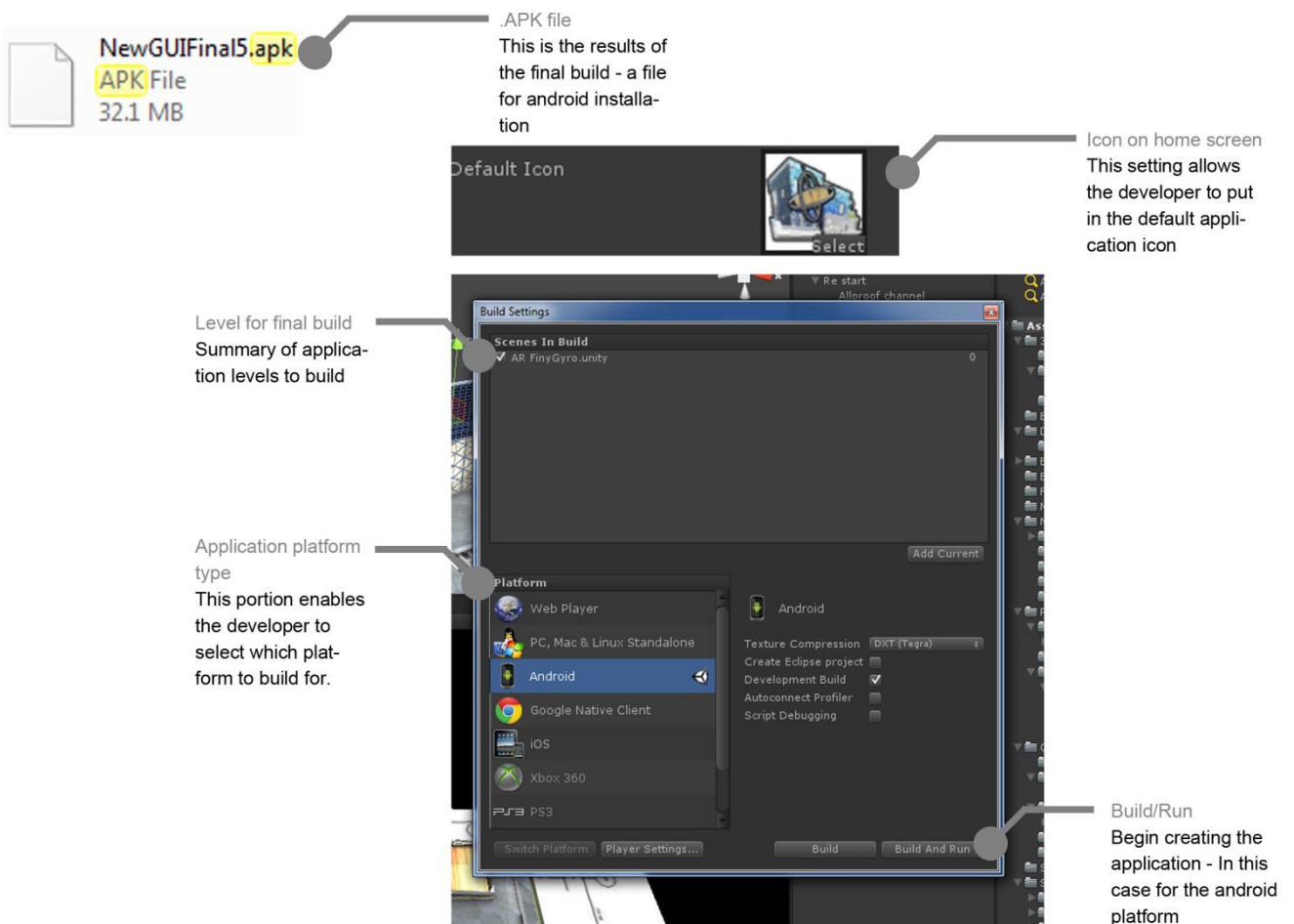


Figure 76: Application final build and platform selection

## 2. Installation on tablet computer

Accessing and activating the .APK file stored within the tablet computer begins the installation sequence for the application.

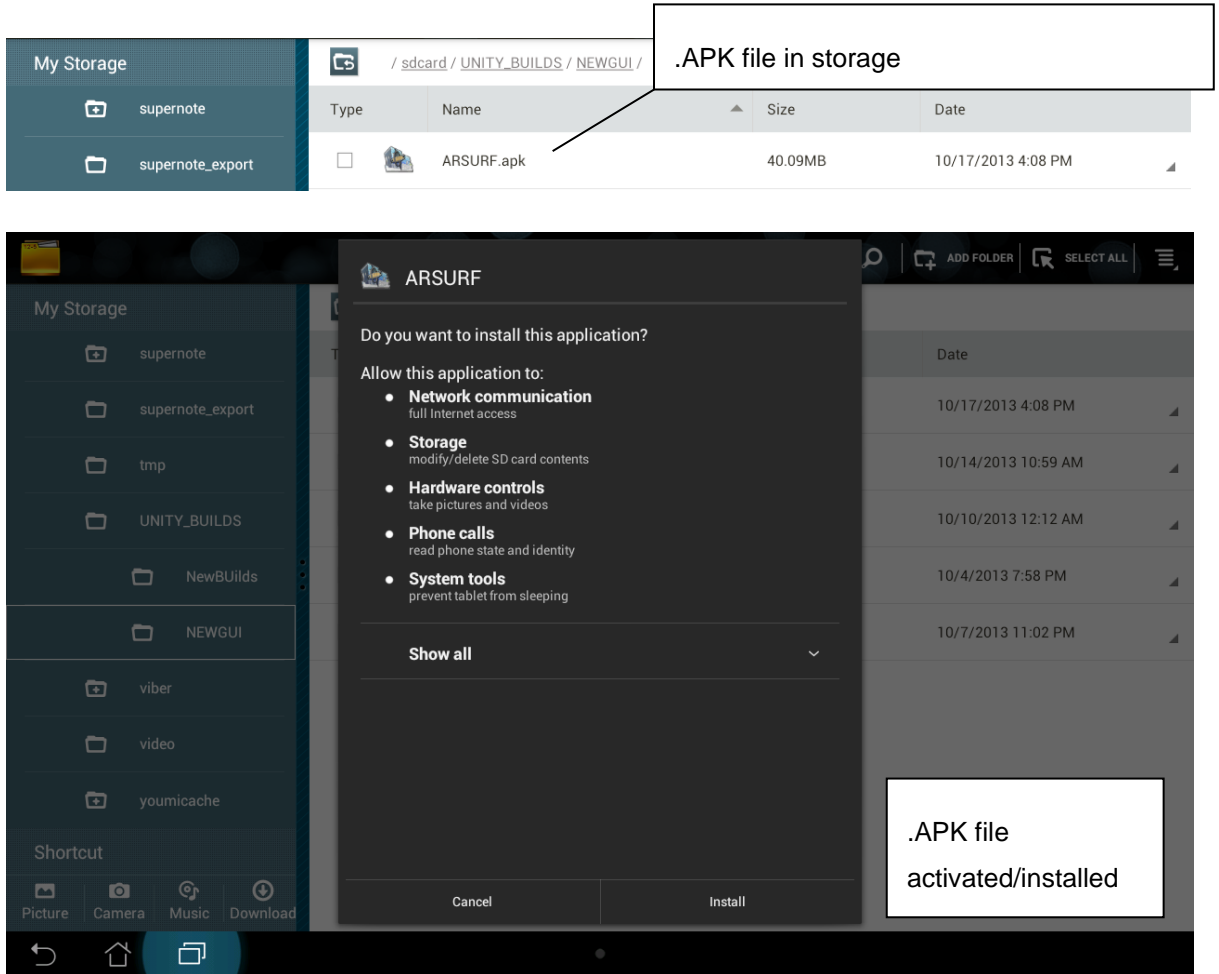


Figure 77: Android Application Installation sequence

### 3. Application Icon on home screen

Following installation the applications icon shortcut will appear on the tablet computers home screen

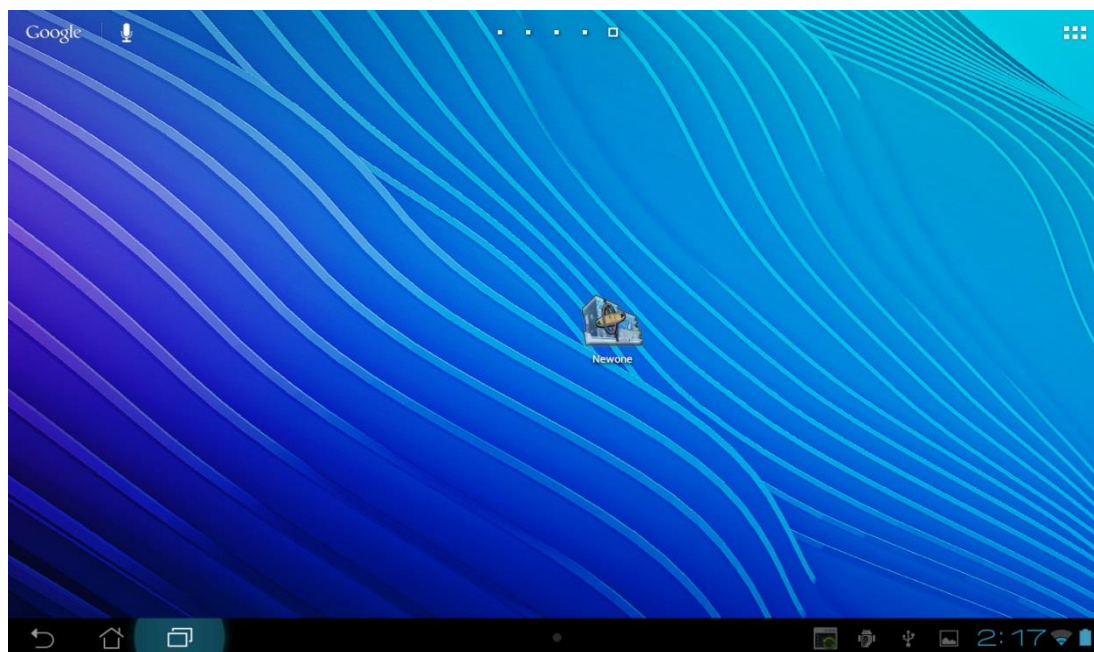


Figure 78: Application Shortcut created

### 4. Activating the application

Activating the application will switch the tablet computers camera on and track the 2D image target



Figure 79: Application Activated on Android Tablet

### 5. Augmented Reality with GUI

The Figure 80/81 shows the GUI on the tablet screen and the activation of the 3D model using the timeline. The next page shows the each GUI function that was scripted activated in succession using an AR 3D Model.

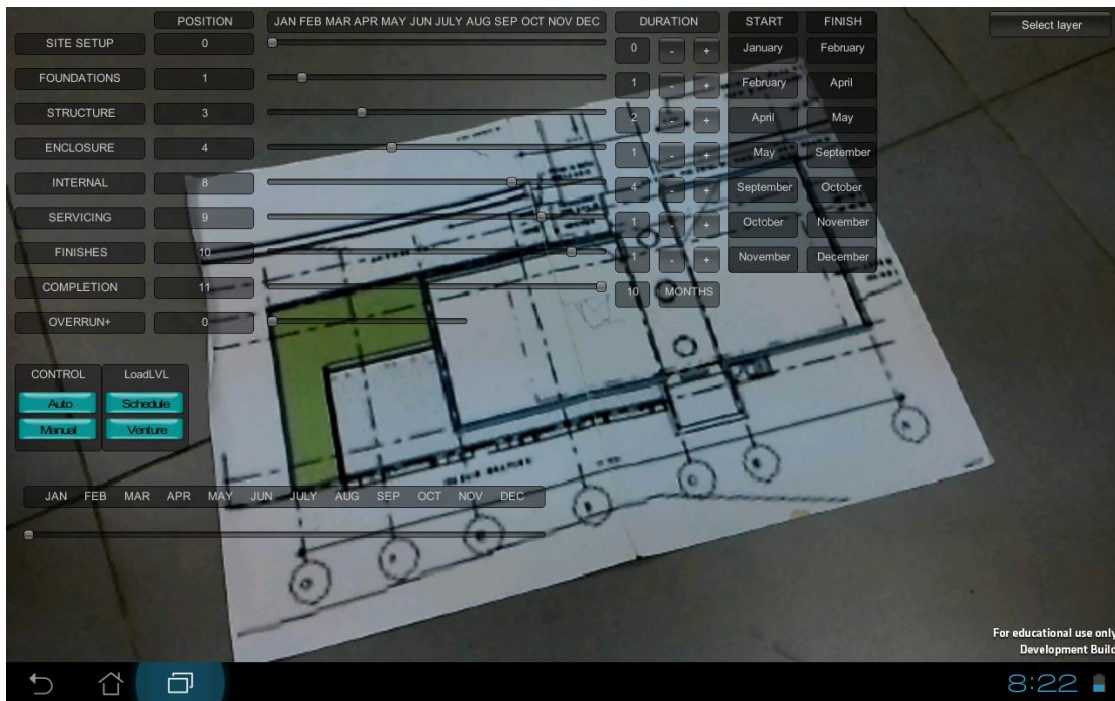


Figure 80: Application Activated on Tablet computer

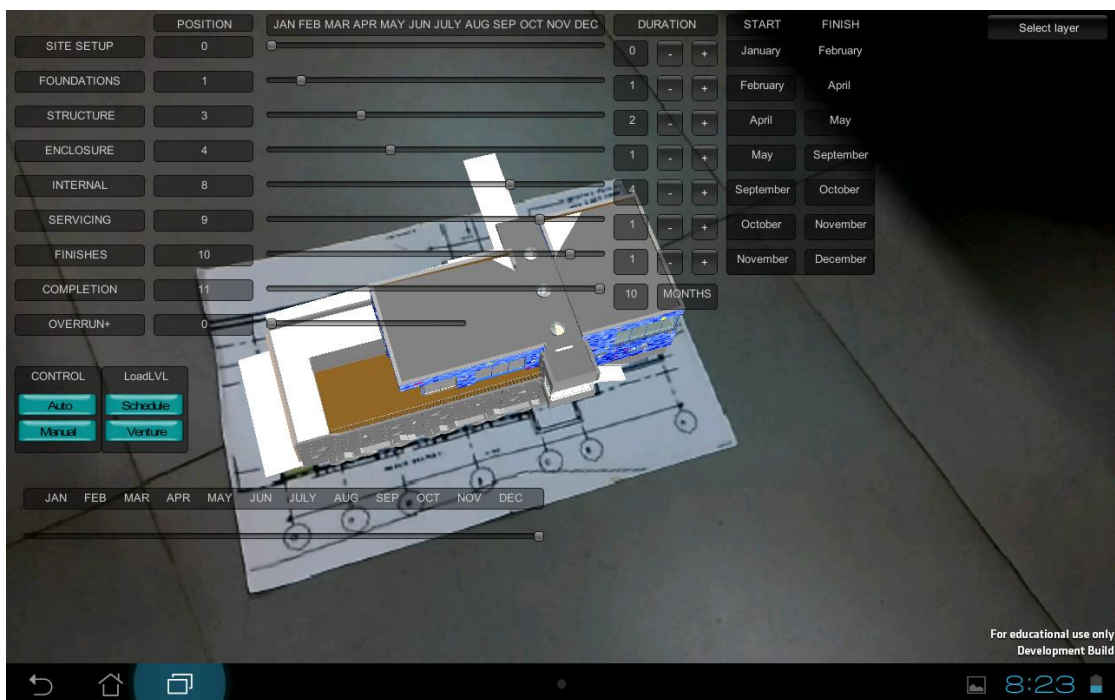


Figure 81: Timeline Set to December - Construction completed

APPLICATION IN OPERATION



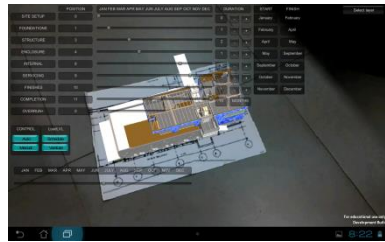
Application is activated from the tablet home screen

a) Application Active



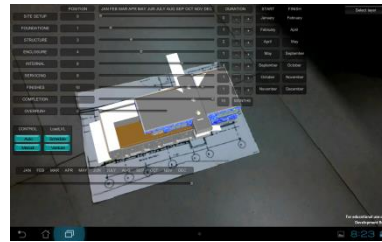
Timeline is moved onto February March period

b) Timeline initiated



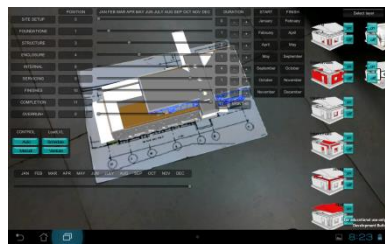
Timeline shifted on screen to November

c) Timeline at November



All Components active – Timeline at December

d) Timeline at December all components active



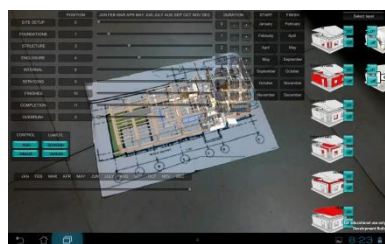
Drop Down list activated to access construction groups

e) Deactivator Activated



Switching off The roofing construction group

f) Roofing Deactivated



Switching off Enclosure, Roofing, Interior walls

g) Enclosure/Interior walls inactive



Manual Scheduling Activated – Schedule on time

h) Manual Scheduling activated



Enclosure task modified – Now behind schedule

i) Enclosure task to end date



Accessing Deactivator to switch off the roofing to see structure

j) Roofing Deactivate

## CRITICAL REFLECTION

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Minimal coding was required for this iteration as Vuforia had all the in - built settings to develop the content created in Unity 3D into a working AR application. It should be stressed that the value of the optimization efforts were evident in this iteration. When the earlier larger versions of the 3D model were simulated on the tablet computer using AR; there were noticeable delays in the ability for the camera to track the 3D model. It was also noticeable that the computing components behind the tablet heated up not long after the application was activated indicating a lot of computing power was going into simulation.

Using the desktop computer to simulate augmented reality was not the same as when it was ported to the mobile platform. The tablet is made up of different GPU and CPU components and performs at a much lesser rate compared to the desktop computer. Therefore a multitude of crashes on the tablet computer were experienced before the application began running smoothly. Even with an optimized 3D model of the LBSC, it was noticeable that the application was drawing a lot of power out of the tablet computer from screen freezes to long loading times.

Every time large components such as the enclosure or interior walls were deactivated and reactivated. Considerable lag/wait time occurred as there were so many components in the construction group being re simulated back on screen simultaneously and this put intensive strain on the computing performance. This also showed in the timeline when the construction sequence would simulate the project start components but when it reached the interior walls the slider tab would first freeze for 5 - 10 seconds before the group appeared and the slider tab resumed its path along the timeline slider. Further optimization of these components solved the problems.

## 5. FINAL INTERFACE REDEVELOPMENT AND GYROSCOPE

### INTRODUCTION

---

Since this application would be demonstrated in front of practitioners, it is also expected that they will want to experiment and observe the use of the application. Therefore this section focuses on redevelopment of the interface to include common interface features in order to enhance a more user friendly experience. It also discusses the extension of the Gantt chart in order to include other features which aid in displaying start/end date information.

This iteration also discusses the integration of the Gyroscope sensor for augmented virtuality. Many smart devices have in built sensors such as the gyroscope and accelerometer that allow them to essentially monitor the orientation of the device. This enables developers to create applications where a range of motions such as tilt, shake, rotation, or swing are required to interact with an application. The gyroscope and accelerometer are common sensors that are used in mobile gaming applications such as driving games whereby the user must steer the car by rotating the device in such a way that they are holding a steering wheel (Android, 2013).

This was an opportunity to embed a sensor that would give the illusion that the user was on site. During the initial interviews; practitioners valued the use of augmented reality on site. However the timescale and limitations of the tablet computer did not allow for the integration of a GPS located 3D model. Therefore a concept would take its place to showcase a similar scenario by creating an immersive environment within the application which used a tablet sensor for interaction. This was done by adding a function in the application where the user was transported into the interior of the building model in VR. They would then have to change the tablets orientation by tilting and rotating it in order to examine inside the building.

This section has 2 sub experiments:

- **Iteration 5.1 Interface Refinement and Layout**
- **Iteration 5.2 Immersive Walkthrough views**



## ITERATION 5.1 INTERFACE REFINEMENT AND LAYOUT

---

This experiment discusses improving the design and layout of the GUI to be more user friendly on a mobile device. The overall aim was to make it appear similar to other software program interfaces where there is a ribbon at the top of the screen and functions are called out one at a time. Since the tablet computer would have limited screen space compared to a computer screen it was important to position functions sparingly around the screen. Functions such as the Gantt chart that took up too much screen space needed to be stored and accessed by a drop down menu.

The deactivator functions were re positioned alongside the Gantt to link the scheduling tools to the deactivator and give the interface a more coherent look. Extra GUI features such as a summary ribbon at the top were added to give the appearance of a typical computer interface and to summarise all the changes in the main Gantt chart functions. All these efforts were to enable the GUI to fit on a tablet screen and to also improve the interaction with the GUI.

The redevelopment of the interface focussed on setting out functions in a tidier layout by decreasing button sizes and storing the Gantt chart in a drop down list in order to increasing the view of the 3D model. The most noticeable changes are the addition of custom made Buttons/Sliders that have colour and custom designs made in Photoshop and imported into Unity 3D. These are integrated with the use of script reference *GUI.Style* added to the main script.

Switch to AR enable the user to switch to the augmented reality simulations with the tablet computer. Switch to VR also enables a virtual simulation of the application. Figure 82 shows the redeveloped GUI and labelled areas. The full script for the redevelopment phase can be found in appendix 2.

### Redeveloped Interface

The 2 images below show the redeveloped interface and all associated buttons/functions. Each numbered feature in the GUI below will be discussed in the next pages.

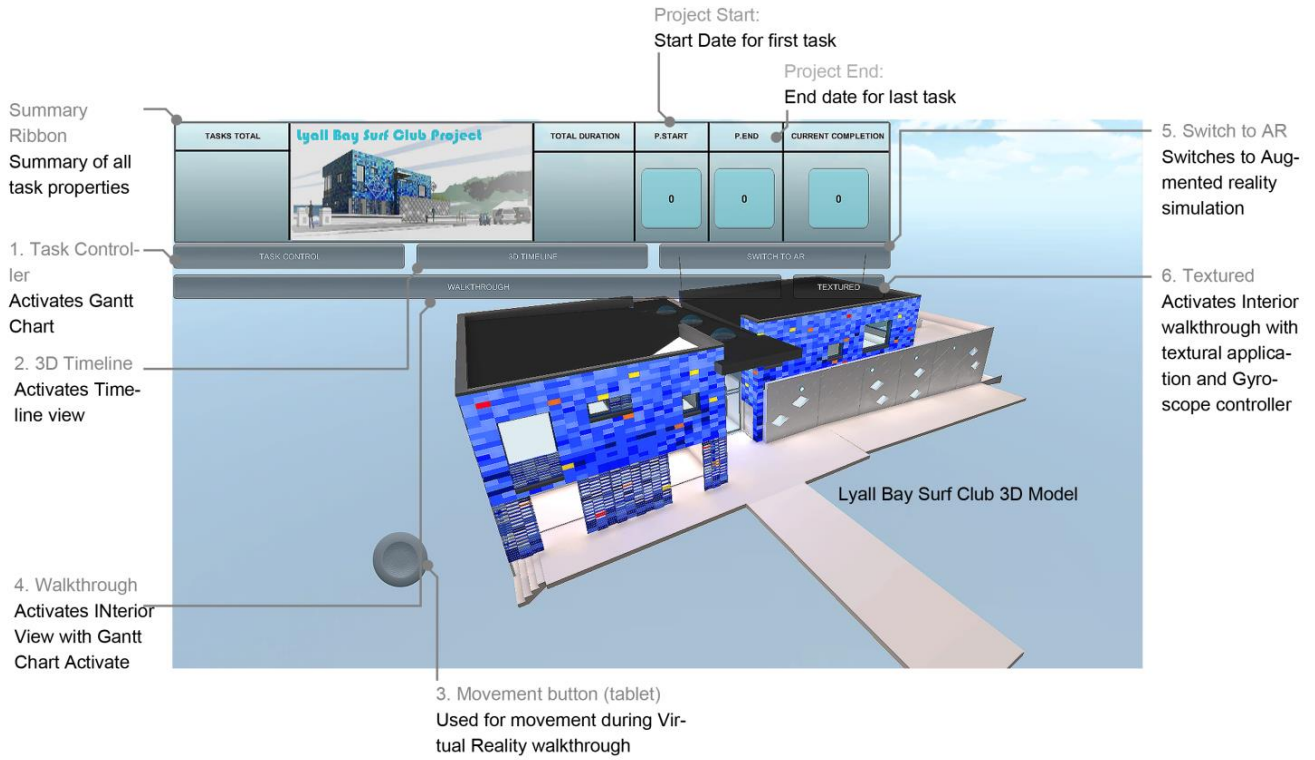


Figure 82: Redeveloped Interface in Virtual Reality

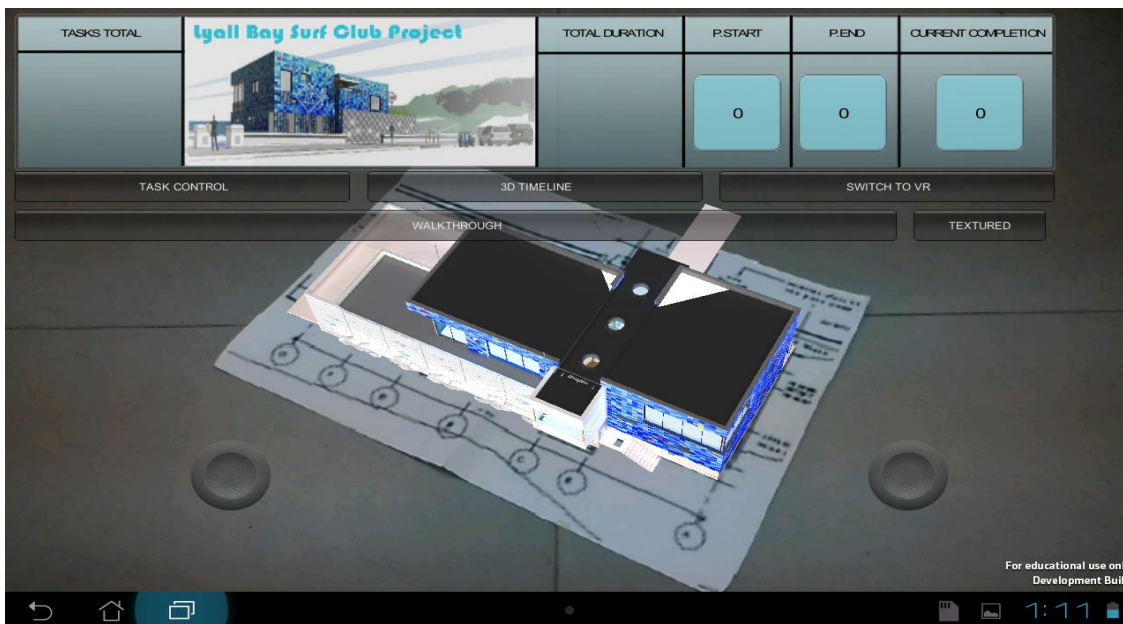


Figure 83: Redeveloped Interface in Augmented Reality

### 1. Task Control

The task control button activates the Gantt chart. The Gantt chart was redeveloped as a series of drop down ribbons. Each ribbon contained four sliders that controlled in the context of a real project; the start and end dates plus indicators of progress made on the task with respect to the current date in the construction project. The design and scripting of this Gantt chart is capable of displaying more states compared to the Gantt chart in the previous iteration.

Figure 84 below shows the results of activating the Gantt chart function in the redeveloped GUI. The scheduling method here does not have the option of automatic scheduling and solely uses manual scheduling to control all tasks. Each slider operates generally the same as the previous iteration.

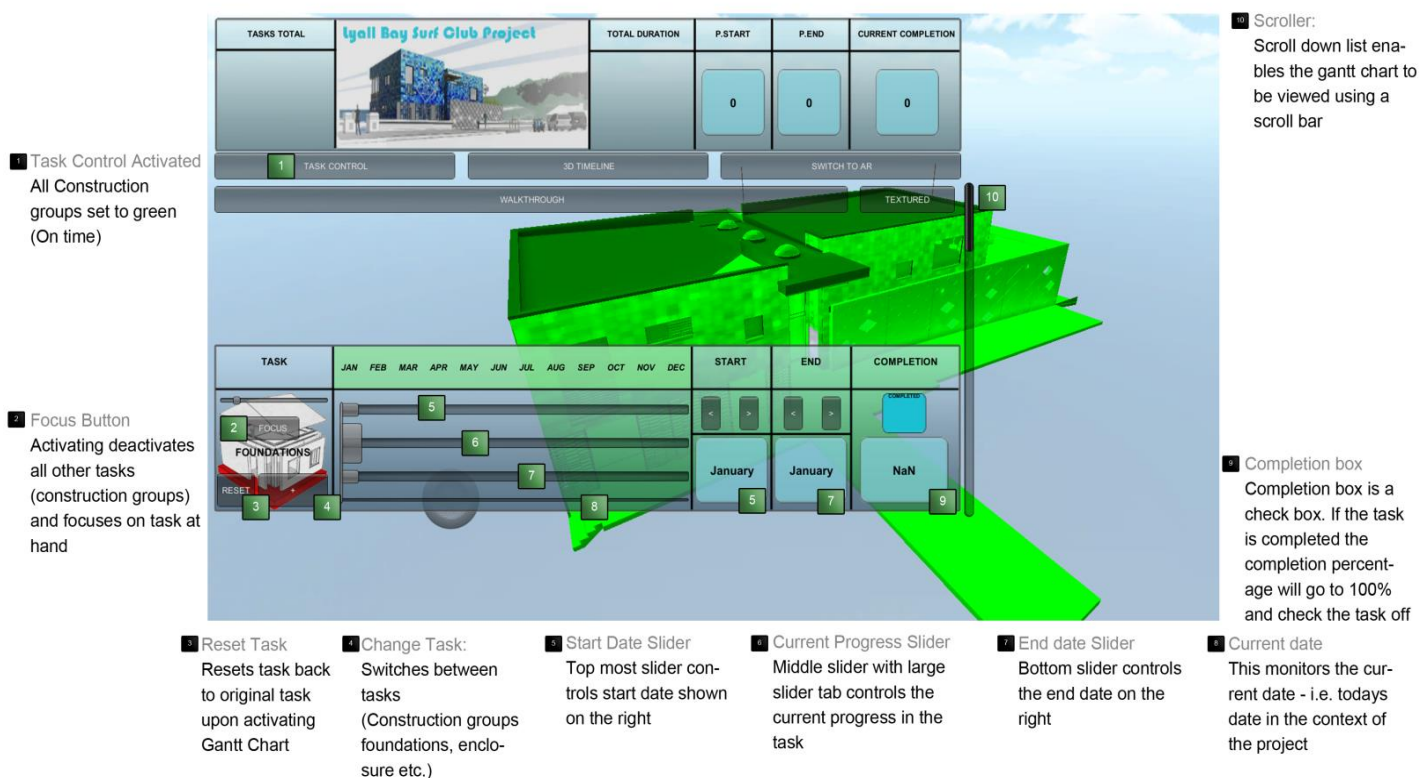


Figure 84: Task Control activated

### Task control - Gantt chart

The Gantt chart was re developed to include more indicators of where a task sits along a timeline. In the context where the project manager is on site and needs a Gantt chart to see where construction has progressed for each task in 3D. He/she can activate the application and use these controls to assess where a specific task has progressed on a timeline.

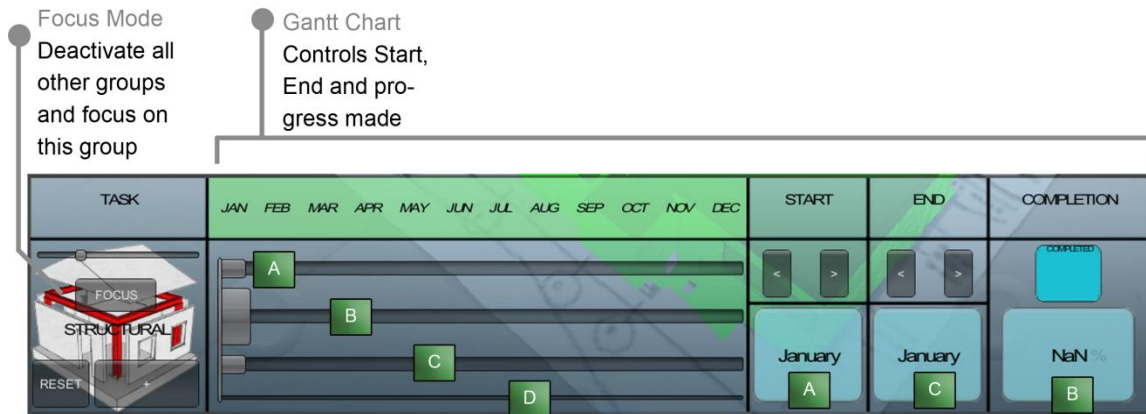


Figure 85: Task controls

- Start Date Slider (SD)** – This slider controls the start date of a task
- Current progress Slider (CP)** – The progress slider controls where the task has reached in terms of progress
- End Date Slider (ED)** – This slider controls the end date of the task
- Current date Slider (CD)** – This slider is essentially the current date in the context of the construction project. This is a fixed date and essentially is meant to move forward as the project progresses.

### Focus mode

Instead of having a drop down list of components in the deactivator; Focus mode inverts the deactivator script and does the opposite. Instead of clicking on/off buttons; focus mode deactivates all groups except the construction group that is associated with the task. This allows a user to zone in on a particular task and view the exact 3D components of the 3D model that are associated with the task at hand.

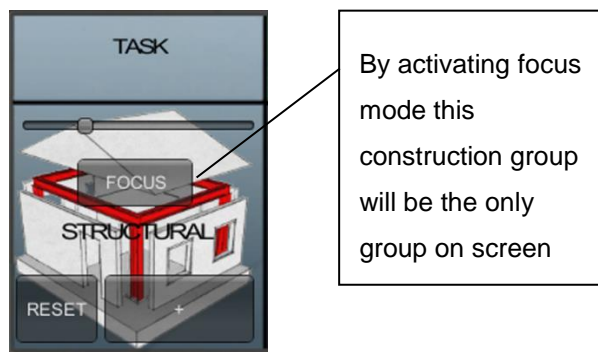


Figure 86: Focus Mode + Task

### Task progression states

When the task controller is activated the objective is to modify aspects of the task by moving sliders A, B and C. The typical scenario on site would be that the user sets the start date (A) and End date (C). The current progress slider (B) moves in between the start and end dates and monitors completion via a percentage counter (Completion). The current date slider (D) updates every day and registers the current day in the context of a project.

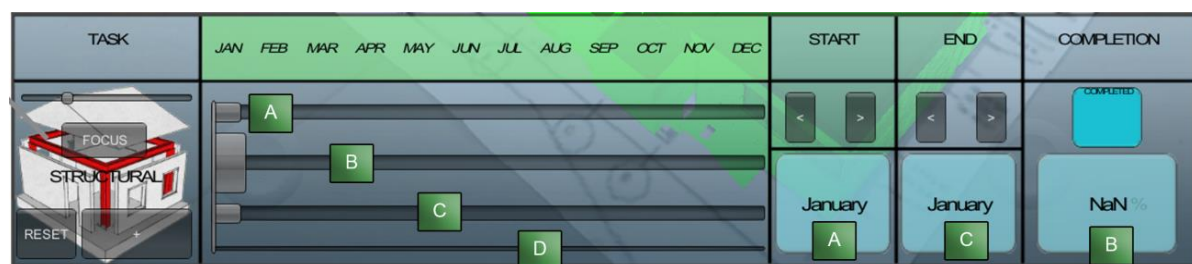


Figure 87: Task controls

3D components associated with the task are capable of changing into 3 colours which indicate what state of completion it is in:

- Green – ahead of schedule, completed
- Blue – ahead of schedule, not completed (in progress)
- Red – behind schedule, not completed (in progress)

Shown in succession in the next pages are the states that the task controller can display on the 3D model. This is important for showcasing changes that occur on the Gantt chart registered on the 3D model. In this example; a typical use of the application will showcase changing controls for the Foundations task.

1) **Task control activated** – Gantt chart with all tasks set to January (no progress).

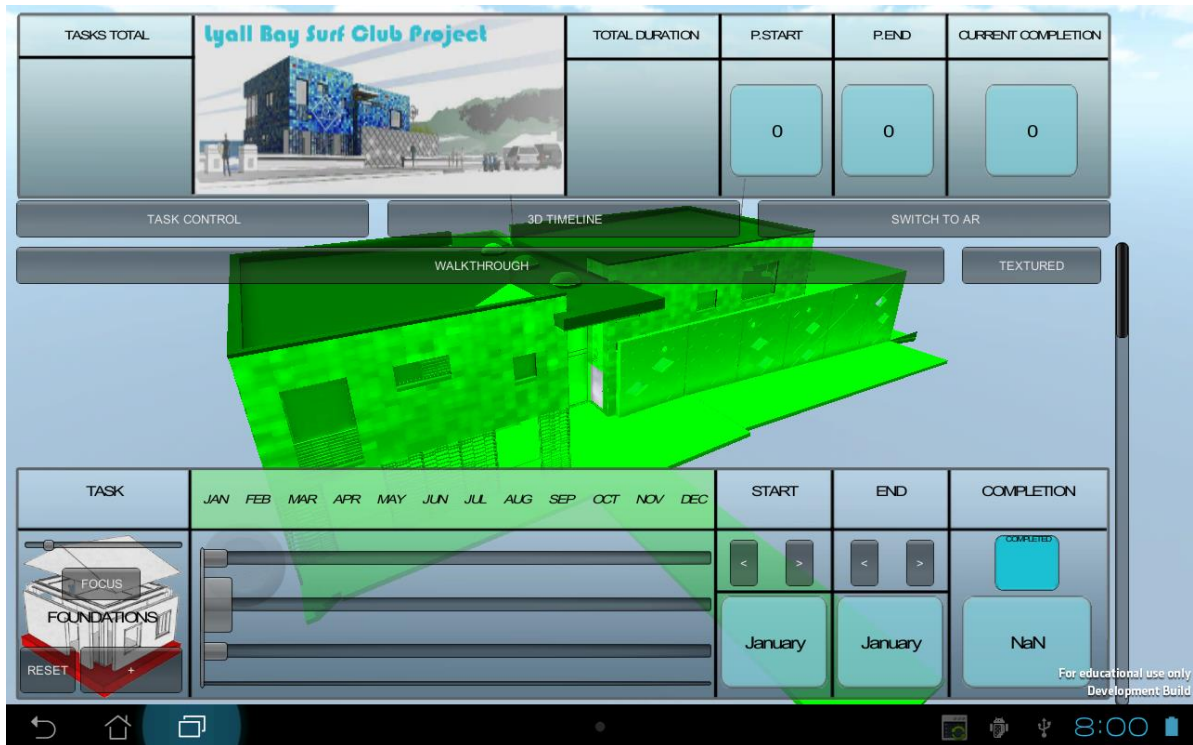


Figure 88: Task Controller activated

- 2) **Focus mode activated for this task** – All 3D components deactivated to enhance view of foundation related components.

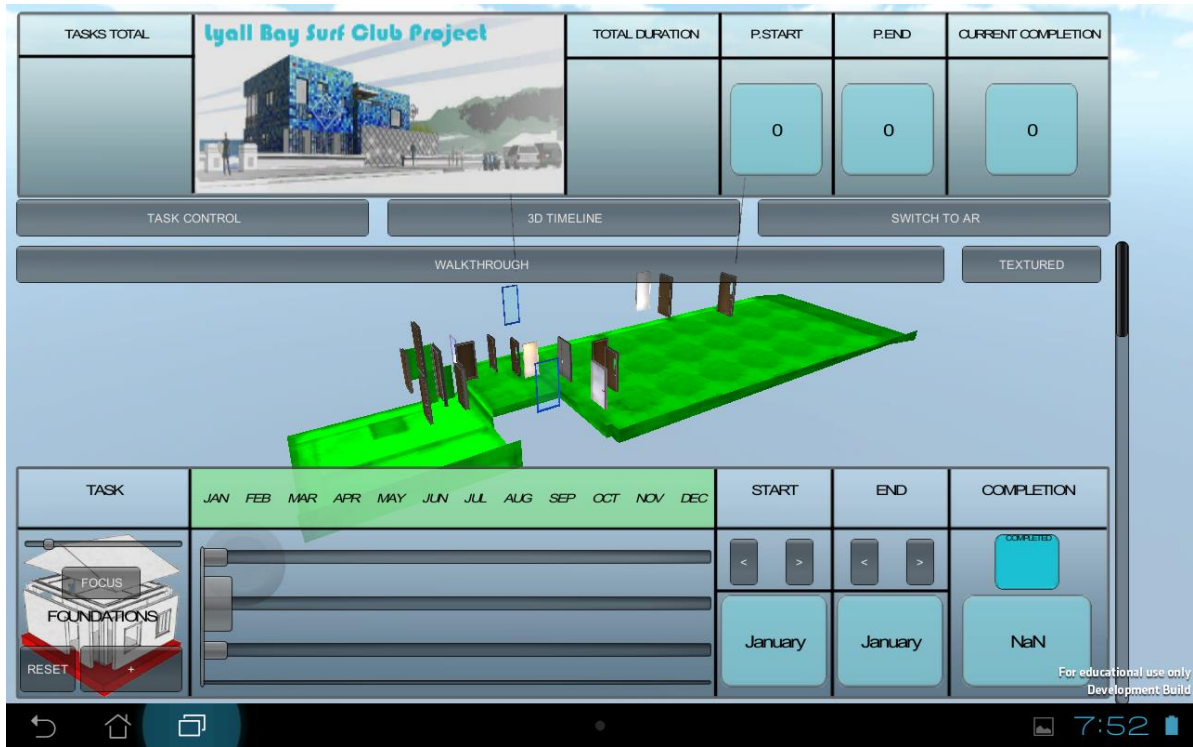


Figure 89: Focus Mode activated for foundations



- 3) **Start date and End date set** – Model changes to blue identifying that task is not complete but ahead of schedule. i.e. ahead of current date in January.

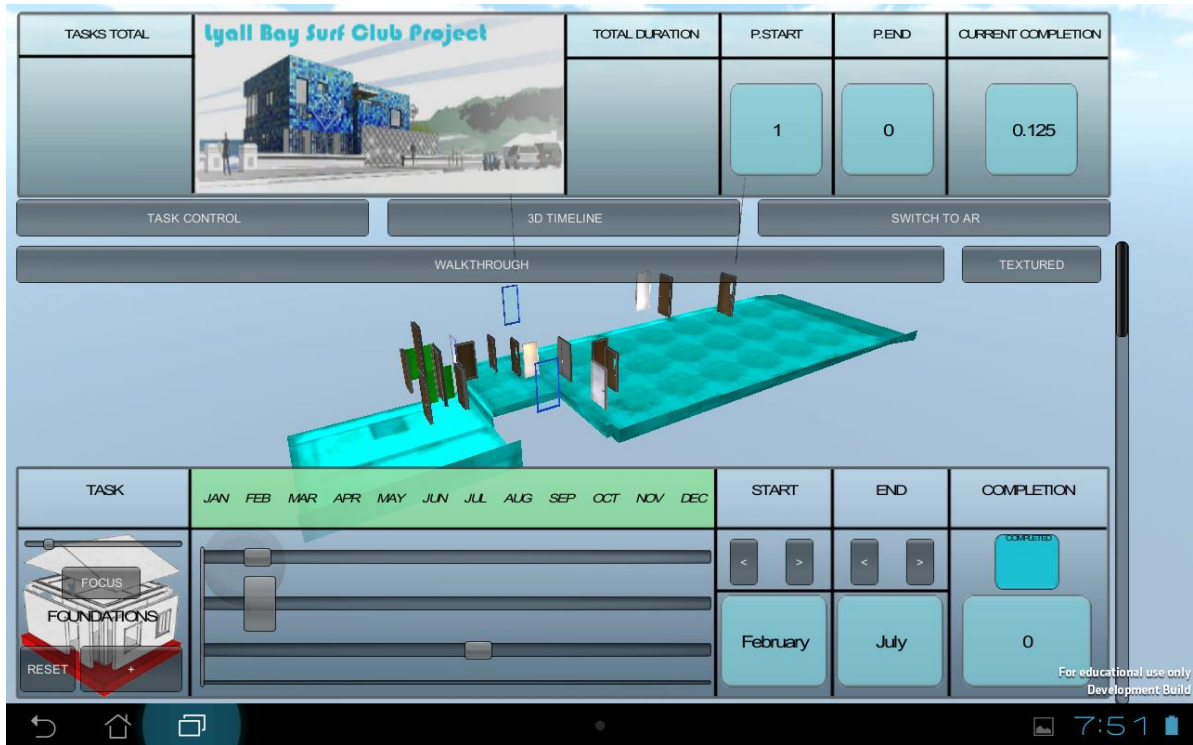


Figure 90: Start and End dates set

- 4) **Progress made on task** - is at 49% but is not complete and therefore the 3D component is blue. Current date at Mar.

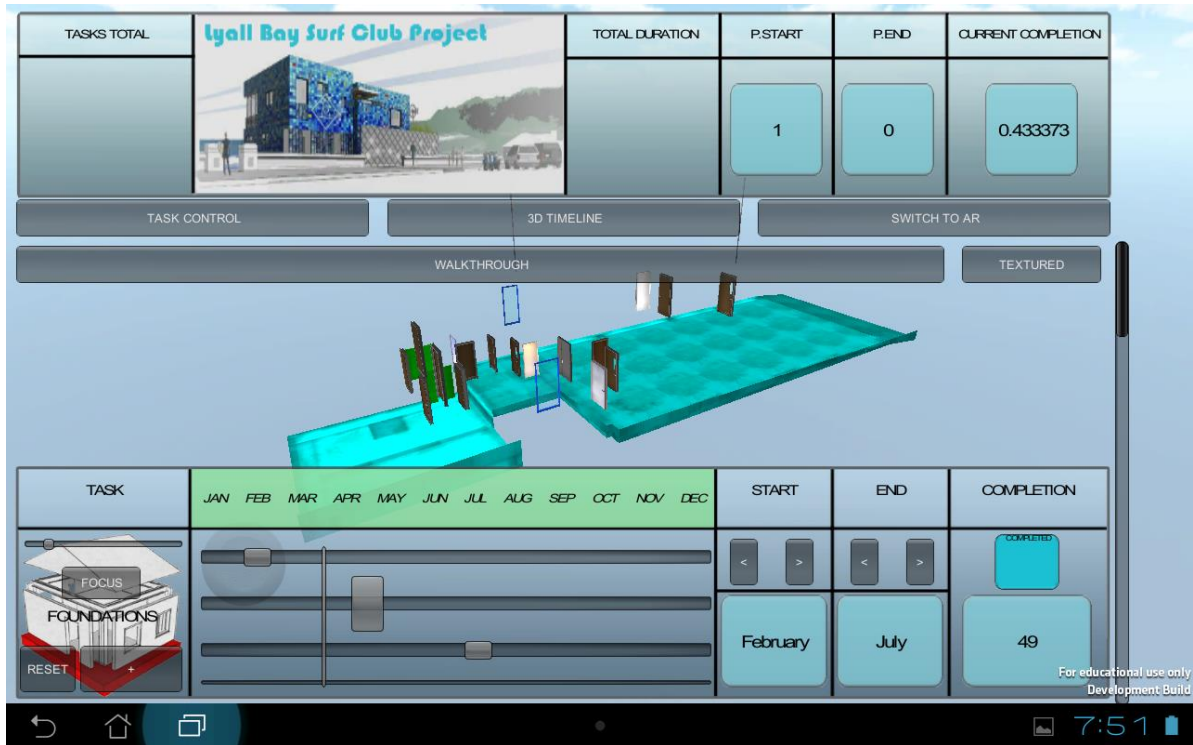


Figure 91: Progress at 49% Current progress - Progress ahead of current date therefore still blue

- 5) Progress has been made but the amount of progress has **fallen behind the current date** in the context of the project. Therefore the component changes colour to red indicating that the task needs attention.

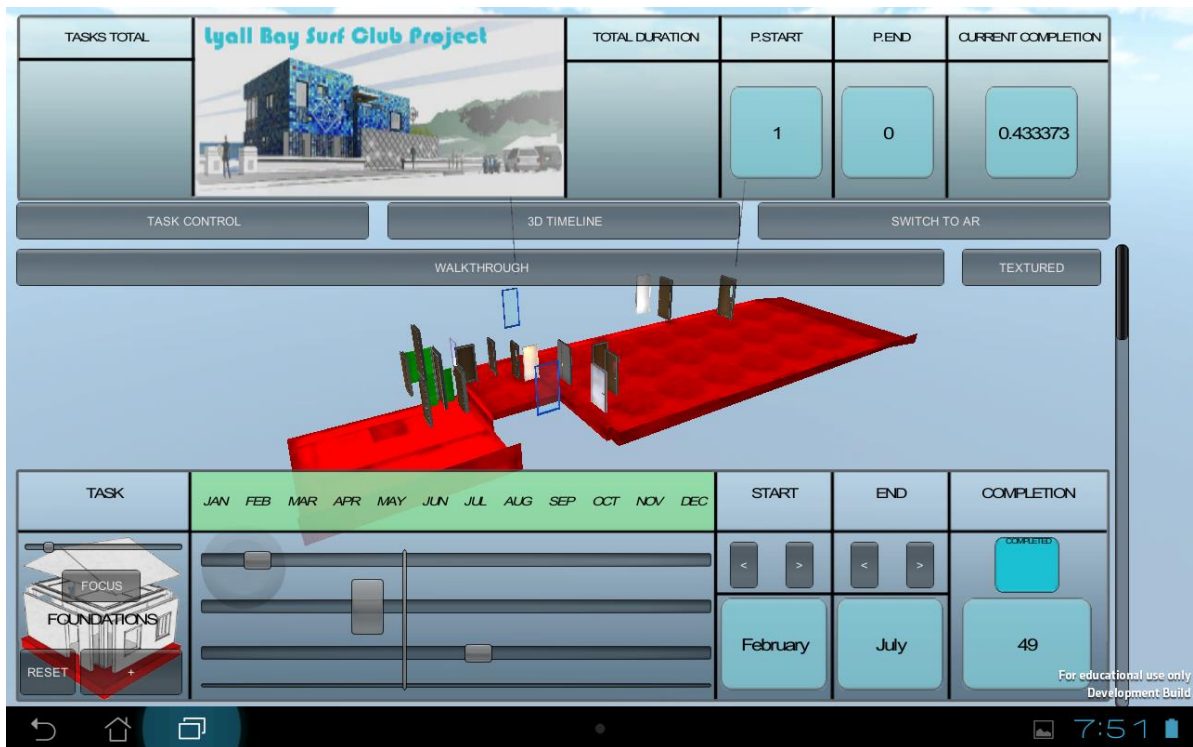


Figure 92: Current Progress has fallen behind current date

- 6) The progress slider is at 100% completion since it is equal with the end date slider. This is further shown in the checkbox above the completion percentage counter which is filled when the task reaches 100%. Even if the current date slider surpasses the current progress slider the component will stay green as long as the check box is ticked.

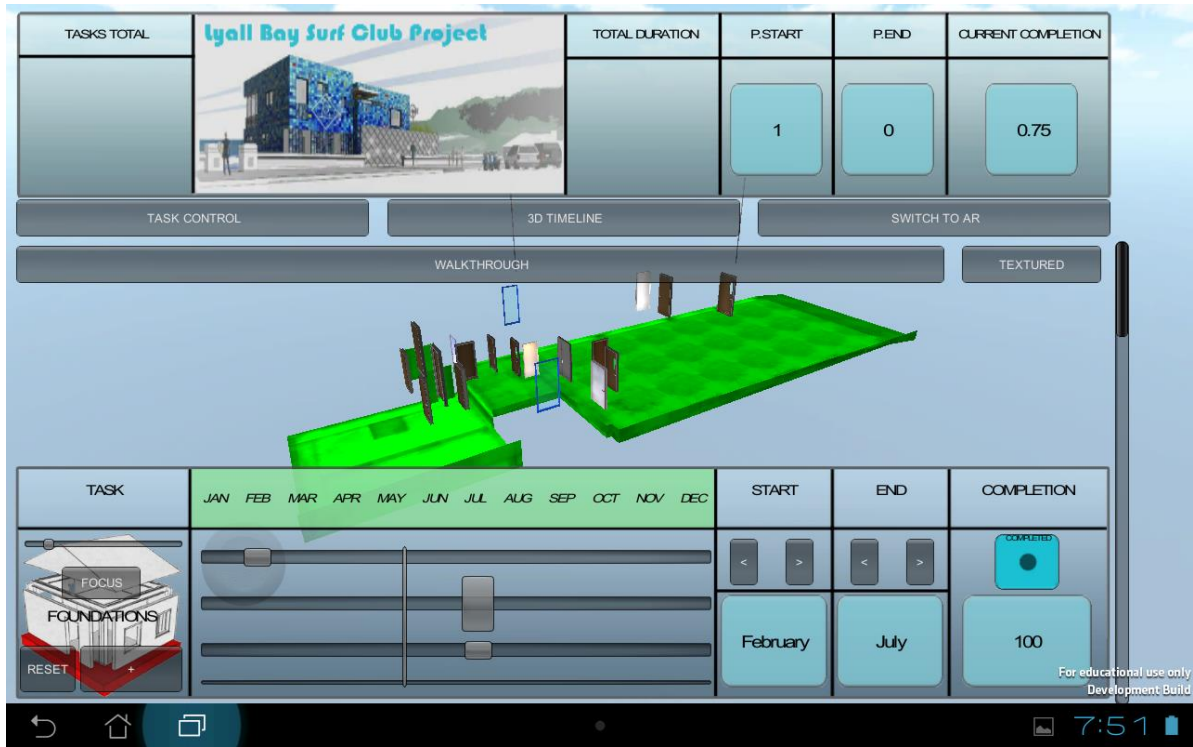


Figure 93: Task completed (100%)

## 2. Timeline

Improving the GUI for the timeline was simply moving it to a different level in the simulation and activated with the button '3D timeline'. In the previous GUI the Gantt chart functions wouldn't operate until the 3D model was made visible by first pushing the timeline to completion. Now the timeline operates individually and is located separate from the Gantt chart.



Timeline Start - Site Setup

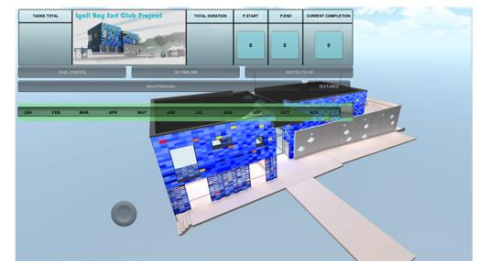
Timeline at January



Timeline in April



Timeline in July



Timeline in December - Completed

**Figure 94: Redeveloped Timeline**

## 3. Movement joystick

The movement joystick on the GUI screen is for when the user is transported into the interior of the building. This walkthrough will be discussed in the next iterative section.

#### 4. Switch to VR

This function upon activation essentially transports the user into the interior of the building and enables the user to instead analyse the use of the GUI from within the building. This function will be discussed more in-depth in the next section.

#### 5. Switch to AR

This function upon activation allows the user to switch to an AR view. Activating this function also changes the same button back to 'switch to VR' as shown in the image below. This allows the user to alternate between using the GUI in AR or VR mode.



Figure 95: Switch to AR visualization mode

#### 6. Textured/Walkthrough

These functions transport the user into the interior of the 3D model and enable them for explore the 3D model from first person view. This will be discussed in the next experiment.

## ITERATION 5.2 IMMERSIVE WALKTHROUGH VIEWS

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This experiment discusses the integration of a function that puts the user into a first person view within the actual building model in virtual reality. It also discusses the functions that were integrated to control the movement of the user inside the building. As opposed to scripting on screen joysticks to control the movement within the building a gyroscope script is instead attached to control where the user looks. The gyroscope script functions by accessing sensors that essentially monitor the orientation of the tablet computer. This forces the user to manoeuvre using human gestures to orbit within the building. The tablet computer is essentially a window that is looking into the building and if the user moves the tablet the window moves according to the orientation of the tablet.

### Primary script reference

The script reference used for the gyroscope uses complex call outs and essentially requires references that address the orientation of the tablet screen and sensitivity setting corrected for this specific tablet computer.

```
mParent.transform.eulerAngles = Vector3(90,90,0);
```

Identify the orientation of the Tablet  
and correct VR camera

```
if (Screen.orientation == ScreenOrientation.LandscapeLeft) {  
    quatMult = Quaternion(0,0,1,0); /**  
} else if (Screen.orientation == ScreenOrientation.LandscapeRight) {  
    quatMult = Quaternion(0,0,1,0); /**
```

**Figure 96: Gyroscope orientation key script references**

### Modes

Two modes in this iteration enable the user to visualize the building from within called walkthrough and textured. The buttons appear below the task controller and timeline buttons on the GUI.



Figure 97: Immersive Walkthrough buttons

Both modes are controlled using the gyroscope script for exploring around the building and with an on screen joystick which controls the users forward, side and backwards movements inside the building. Figure 98 shows how the gyroscope is used to orbit inside the building.

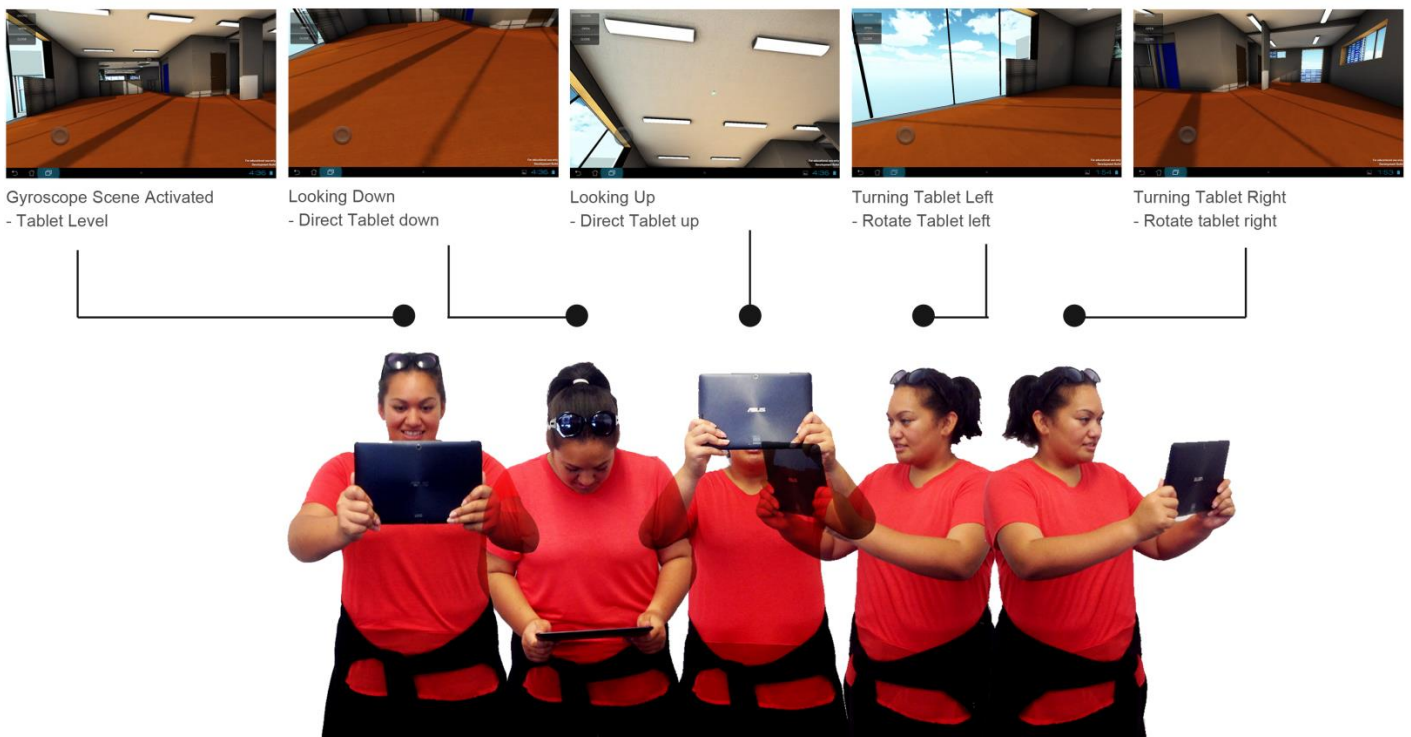


Figure 98: Using the tablet to view inside the building model



### Walkthrough

The walkthrough button transports the user into the building whilst maintaining **ALL** functions for the GUI as shown below. This way the user can modify the start/end/current progress sliders and visualize from inside the building. This showcases augmented virtuality in the context of being on site and using the Gantt chart tools from an interior perspective.



Figure 99: View from outside the 3D model/Walkthrough mode activated

### Textured

Activating this mode also transports the user into a different version of the same building model. This version essentially has the light mapped textures from iteration 2.3 applied and allows the user to view the interior of the building without the interface and with added lighting/shadow effects.



Figure 100: Textured Walkthrough mode activated

## CRITICAL REFLECTION

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The redevelopment stage was essentially to make the GUI presentable and appear more as a common computer software interface as opposed to a collection of buttons and sliders. It was also to add colour to sliders and add customized button shapes. Prior to this stage mostly all scripts that had been created in the early iterations were scattered as individual files. The redevelopment stage allowed organization of these scripts neatly into one file for easy identification and for linking functions. This is particularly important for functions such as the Gantt chart that have algebraic equations that are difficult to link if all scripts are separated from each other.

Described in early interviews were precedents that used GPS and Wi-Fi to Geo locate a 3D model in augmented reality. Although a large precedent for design it could never be implemented as a result of the tablet computers capabilities with wireless internet which played a key role with GPS. The timescale of this project also did not allow for development to go this far. Therefore a concept of a similar situation was instead created. This concept used augmented virtuality to showcase a 3D model that embedded a GUI to control the sequence of construction.

Similarly to the FPC in the optimization tests the interior of the building had an FPC added. There are a variety of options for controlling an FPC on a tablet computer touch screen.

- Using accelerometer sensor to enable the user to control movement by tilting the tablet in different directions.
- 2 thumb joysticks on the GUI that enabled the user to control it like they would a video game controller.
- 1 thumb joystick to control movement and use the Gyroscope sensor to control the direction the user was looking using the tablets orientation.

The 3<sup>rd</sup> option using the Gyroscope was the most viable option as it was the easiest to use and required human gestures to control. The tilt control and joysticks were more difficult to use and did not contribute to the concept of on-site 4D AR BIM. By having this interior view of the building and being able to access the interface; it could be voiced during demonstrations that 'this is what augmented reality would be like on – site'. Essentially a user with a tablet on site would be moving and holding the tablet up in order for the 3D model to show. Although it was not the same; using the gyroscope sensor essentially gave the impression of how AR could work on site with controls that displayed construction sequence.

The Gantt chart drop down list although simplified from the re design was still too large and overpowering on screen. Buttons were difficult to press and sensitivity of the scroll menu was not set properly. Similarly to the timeline when focus mode was deactivated and all the other construction components had to be reactivated, the application occasionally crashed as a result of too much computing power trying to re simulate all objects simultaneously.

## 6. DEVELOPED DESIGNS

This is a summary of the outputs of all iterative stages and the prototype application that was created for demonstrations for the final stage. The final stage presents the application to practitioners in order to assess the effectiveness of tools to improve their understanding of construction management and to gather feedback for redevelopment. The interface completed the full scope of design that was set out at the start of the iterative design stage where 4 key aspects of construction management were identified as shown below.

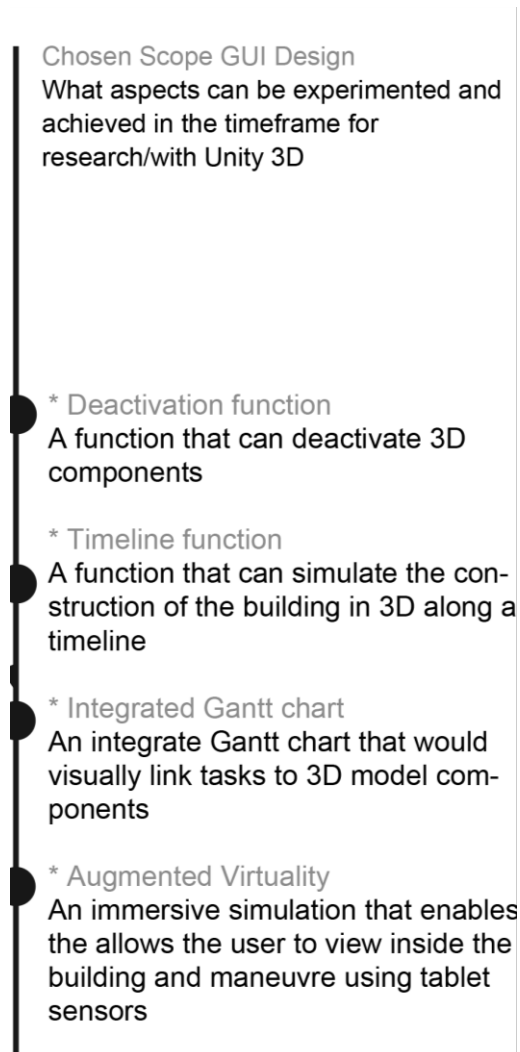


Figure 101: Scope of design - Reiterated

## COMPLETED APPLICATION DESIGN USE

Figure 102 below is a summary of a typical scenario where the application is used and how each function appears in sequence.

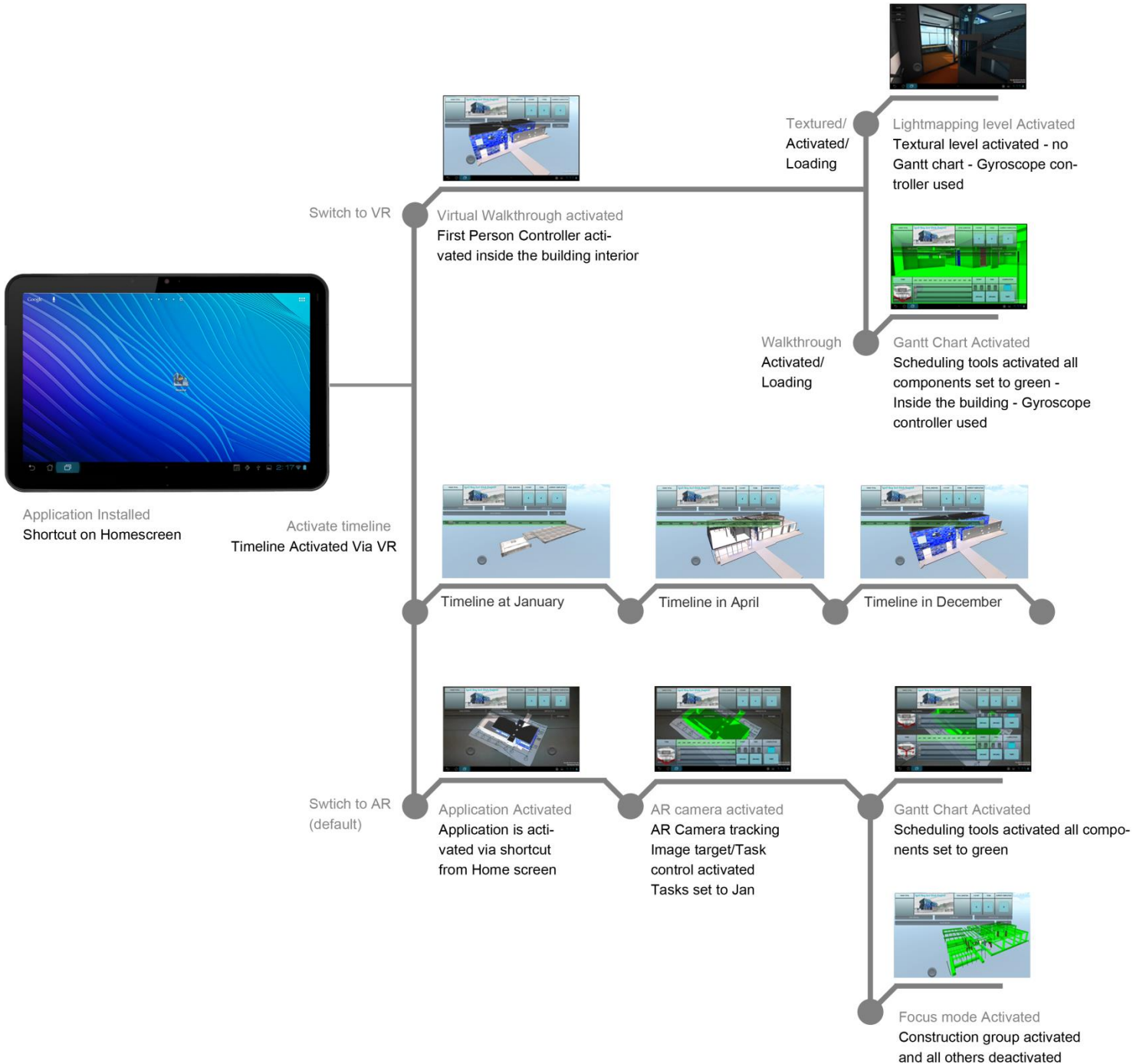


Figure 102: Application usage and summary

## RESEARCH DESIGN SUMMARY

In summary, the functions that were developed through iterative design are illustrated in Figure 99.

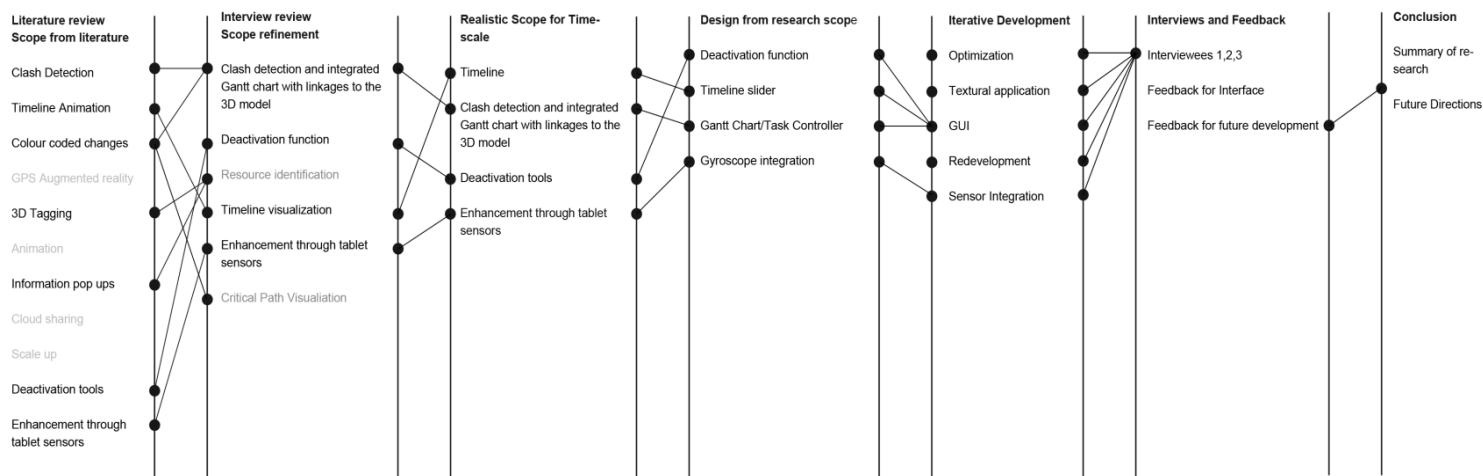


Figure 103: Summary of workflow/process

- **Ascertaining scope for design**  
Beginning with scoping a variety of aspects from construction that inform the design.
- **Precedent review**  
Identifying functions, features and aspects of real applications that practice 4D BIM.
- **Interview review**  
Supporting these aspects and refining the scope through practitioner interviews to achieve the final scope.
- **Iterative design**  
With the scope of designs set, the iterative stage can now being to create functions.
- **Optimization**  
Preparing the model for simulated use on desktop and tablet computer platforms
- **Textures**  
Additional features for realism and for re use in the immersive level
- **GUI**  
Development of key functions for prototype demonstration
  - Deactivator
  - Timeline
  - Gantt chart
- **Immersive level**  
Integrating Gyroscope sensor for concept level
- **Developed design**  
Complete design ready for demonstrations

## 6. PRACTITIONER INTERVIEWS

With the application now completed and operational on an android tablet, the final stage of this research was to demonstrate it to practicing AEC professionals in Wellington. This enables an identification of future directions for AR in construction management and an assessment for improvements to the GUI. Selection of firms to participate was done by emailing an invitation to a variety of practicing Architects and Engineers within Wellington. The invitation listed the agenda for the presentation, the aim of their feedback and the requirement for ethics. Many of the firms that responded were firms that initially participated in the interviews at the very start to scope possible aspects that are useful for construction management and to request building models. All signed participant consent forms for each interviewee are located in appendix 1.

The agenda for each interview was to present a brief 8 - 10 minute PowerPoint presentation on how iterative design process followed by demonstrations of the actual application on a tablet computer. Each interviewee was given the Asus computer tablet to hold and observe the capabilities of each function. During these experimentations observation were also made of on which functions appealed most of each practitioner.

The interview questions were divided into 2 main sections for discussion which were focused on improving the applications GUI followed by discussing functions that could benefit the practitioner or their respective firm using augmented reality. These discussions were more for encouraging the interviewee to bring forward and express concerns for improving the interface design and to brainstorm concepts of functions that would benefit them in practice. From here guidelines on future design can be developed.

### **1. How can the interface and functions be improved?**

- What parts of the interface need re work/redesign?
- Does the colour coding improve your control of specific components?

### **2. How can this type of technology be used in your practice?**

- If you could design a similar application what type of functions would you want it to have?
- How could augmented reality be utilized within your firm?

## 6.1 CCM ARCHITECTS

**Interviewee: Guy Cleverly**

**Date: 19/09/2013**

**Role: Director and Architect**

Questions/Answers:

- How can the interface be improved?

### **Removing interface overlay**

*“The interface needs a lot more thought put into the user experience and the graphic design layout. There needs to be some kind of home button in the corner of the screen that can remove or deactivate the whole interface entirely because it obstructs the users view from what is happening with the 3D model. Contrasting between the 3D model and graphical user interface is very important for usability and in the application there is too much happening on such a small screen. The Gantt chart sliders and buttons cover almost a quarter of the screen so it is important to remove these functions when they are not in use”.*

- How can mobile augmented reality be utilized in your firm?

### **Sun path analysis**

*“Well with the onsite scenario (walkthrough demonstration) it could be a very useful design analysis resource for looking at shadow paths from the sun. In the sense that if the 3D building is superimposed on site we could virtually go inside the building and see where light radiates within the building”.*

*“It would also be a useful if we could take a tablet on site, simulate a building with augmented reality and then manipulate the orientation of the building through rotation. This enables us to evaluate different positions that the building could sit on which in turn we could discuss with a client. Even taking a photo and superimposing the 3D building model onto the photo gives us a variety of design options”.*

### **Client Presentations**

*“As a management or visualization procedural tool, it is still at a stage where it is a valued tool for giving understanding at a client level. As an industry tool it would only be valuable if it could be a CAD program plugin in which we could automatically convert a 3D building model into an augmented reality resource. This would give our clients a greater understanding of 3D content”.*

## 6.2 STUDIO PACIFIC ARCHITECTURE

**Interviewee: James Wallace**

**Date: 01/11/2013**

**Role: Architect**

Questions/Answers:

- How can the interface be improved?

### **Removing Interface Overlay**

*“The interface needs a lot of thought put into it in terms of the contrast of all these buttons and sliders and the 3D model which is the main attraction. Take for example these buttons (Iteration 4 demonstration) the labels which are not buttons almost look like buttons themselves. If I were using this I would probably think those were buttons as well. It is important to create contrast through design and differentiate what has a function and what is there for directing the user. The GUI can be improved if you attract the attention of the user to the important buttons by adding colour and less attention to labels by fading them using transparency”.*

### **Integrate Actual Gantt Chart**

*“There should be a function that can bring up the actual Gantt chart itself (MS Project document). So that if the application fails to show the information that I need, I could always refer back to the original document whilst still being on site. The application might be aimed at providing a light weight method of assessing complex Gantt chart information but the Gantt chart is still a valued asset which still has a higher accuracy if the application fails to display the information I want”.*

### **Help Function**

*“Having a ‘Help’ Button would be beneficial for this type of technology because it isn’t standard practice to use yet. This could be a text box that lists simple help tips on how to use the application and navigate the interface by using signature gestures to make elements appear and disappear”.*

### **Blurring out surrounding objects**

*“It would also be helpful if objects surrounding the target marker are blurred out of the scene so that the user’s attention is solely on the 3D model”.*



- How can mobile augmented reality be utilized in your firm?

### ***On site comparison tool***

*“This technology would benefit us if the model were blown up to a 1:1 scale as you demonstrated in the gyroscope and virtual walkthrough example. It enables us to check a lot of different components of the project in real time and in the real world on the spot. It almost can be compared to a pair X-ray vision goggles where we could see how the design was modelled via computer and how the builders are constructing it. If a beam was missing in a framing structure for example we could essentially detect this faster with an application that can augment the digital model over the real model in the real world”.*

### ***Section plane***

*“A function that I think would be helpful from an Architectural perspective would be to have a type of cutting plane that could essentially section the model in augmented reality. What you have shown is that you can deactivate the 3D model using a series of buttons. It would be useful if a user could pan their finger across the screen and the model gets sectioned along the user’s gesture”.*

### ***Clash Detection***

*“Clash detection has a very big use with this type of technology. If you can colour code areas of the 3D model in this app (Gantt chart features) than colour coding potential clashes should be possible. If there are areas of concern such as a duct that possibly might be clashing with another then the application needs to have a highlight for this such as a red blinking light/graphic on the 3D model”.*

**Interviewee: Whare Timu**

**Date: 04/11/2013**

**Role: Architect**

- How can the interface be improved?

***Removing Interface Overlay***

*“You could develop the interface further by removing all this material that is happening on the tablet screen. There are so many functions operating at one time that should instead be opened up to the user one at a time. Increase the contrast of buttons with the 3D model in order to improve user experience”.*

- How can mobile augmented reality be utilized in your firm?

***Geo located models***

*“A mobile device application with augmented reality could be very useful if we could have multiple integrations with GEO DATA suppliers such as Google earth or Koordinates. This would give us not only a visualization tool but a service for sharing data on site to online cloud services that map real data and project it in 3D format”.*

**Interviewee: Michael Lowe**

**Date: 24/10/2013**

**Role: Architect**

- How can the interface be improved?

### **Removing Interface Overlay**

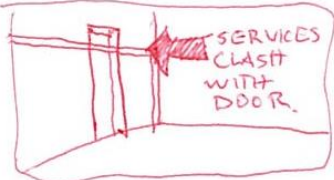
*"You can remove a lot of the interface that is blocking most of the 3D model".*

- How can mobile augmented reality be utilized in your firm?

### **Clash Detection**

*"Having the ability to 3D tag items on site and review these tags back in the office computer could be very valuable. Areas that are of concern to the design team can be reviewed back on the main CAD program or even presented to the client. With the improvement of wireless transmission technology even being able to make these tags on site and have the tablet/smart phone feed that information back to the office computer where perhaps another architect is reviewing what I am tagging on site would provide us with another lens to understand potential clashes or issues on site. Using both mobile phones and tablets integrated with your usual standard computer".*

- Being able to '3D Tag' clash items on site. ie. tag notes onto the 3D model so other consultants can view clashes back at the office when they have the model open.



**Figure 104: Michael Lowes sketch concept of useful AR in practice**

## 6.3 ACCENT ARCHITECTS

**Interviewee: Malcolm Fleming**

**Date: 05/11/2013**

**Role: Architect/Director**

Questions/Answers:

- How can the interface be improved?

***Reprint 2D Marker***

*“You can improve overall user experience by replacing the blurry drawing (2D Marker) with a more refined 2D plan drawing. It might be improving the performance of the simulation to enable the 3D model to pop up easily but the 2D plan is also an important document that is used for discussions”.*

- How can mobile augmented reality be utilized in your firm?

***Client Presentations***

*“This is a great communication tool for showing our clients a final design or a variety of 3D information right on the desk. We often have seminar meetings where BIM is presented to our clients using visualization software we have in our firm on a regular basis. So we show a bigger interest in the augmented reality portions of the application over the virtual demonstrations (Gyroscope demo)”.*

**Interviewee: Gina Jones**

**Date: 05/11/2013**

**Role: Lead Architect**

Questions/Answers:

- How can the interface be improved?

***Removing Interface Overlay***

*“There is too much happening on screen for the user to focus on what element at a time. Improve this by carefully considering how to re-design your interface so that the user can focus on specific functions. Even accessing another function could be difficult”.*

- How can mobile augmented reality be utilized in your firm?

***Client Presentations***

*“Sometimes when we have discussions with clients about particular designs we communicate specific information on building components through 2D plans, sections etc. These plans are located in a large catalogue that could potentially have hundreds of different pieces of information. As opposed to just having a catalogue full of 2D drawings; augmented reality has the capacity to make this into both a 2D and 3D catalogue. Since a 3D model extrudes from the 2D marker almost every drawing within this catalogue could have a 3D component by insetting 2D QR code on each drawing. This way we could use smart phones or tablets to build 3D augmented models of our drawings and extrude a wide variety of perspectives for our clients during meetings or even on site”.*

## 6.4 BECA

**Interviewee: Kade Motley**

**Date: 05/11/2013**

**Role: Assistant Project Manager**

Questions/Answers:

- How can the interface be improved?

### **Removing interface overlay**

*“The buttons and sliders need to be hidden somehow. The transparency of the buttons simply isn’t enough to see what is happening on the model. The contrast between the model and functions is not well defined so improve on this by adding mobile features that are unique to a mobile phone. E.g. pinch to zoom, swipe to turn the page etc.”*

*“The colour coding is good, most people would understand that green means good and red means bad. So if certain components are lighting up in red it’s a decent indication that I need to address something about this area”.*



Figure 105: Using common interface gestures for mobile devices – BIM 360 demonstration (Marchese, 2013)

- How can mobile augmented reality be utilized in your firm?

### **Critical Path/Lag in time**

*“Lag is a really important issue/task that is directed by a project manager. Lag in time is the impact that one task has on all the others if it falls behind or moves ahead of schedule. At the moment we can identify this in Microsoft project using different functions and critical path. We don't have a visual aid however that we can take on site with us so we can see what particular construction components are causes for lag”.*

*“For example: Say we need the structure to go up today, but it can't since the guys on concrete have only just poured in for the foundations only a few days ago and is still curing. We have to assess the impact on the rest of the project and direct resources accordingly to ensure everyone is doing the right job at the right time”.*

### **On site comparison tool**

*“Augmented reality on a mobile device lets us (BECA) superimpose 3D construction components on site and merge project management information as an overlay. This gives a very powerful visualization tool for assessing different when, what and where scenarios”.*

*“Servicing components such as inflow and outflow plumbing, what pipe has hot water? What pipe has cold water? HVAC and sprinkler layouts are key tasks in construction that potentially could have a massive impact on the flow of the construction schedule because they have a high risk of clashing. The Ability to visualize these components on a 2D plan as demonstrated here using augmented reality is helpful to an extent because the 3D model is still too small. Visualizing these components at 1:1 scale using the tablet computer would be a more valued asset that can be used in practice. Take for example a renovation: The contractor wants to drill a hole through a wall on the spot; consultation needs to take place to establish if there are any possible servicing pipes behind the wall that may be affected. Augmented reality here would enable the contractor and manager to visualize any servicing that may be behind the wall without having to rip it down. This method would be the key asset to providing our clients with a better understanding of the construction process since it is all visual and easy to understand”.*

## 7. DISCUSSION OF INTERVIEWS

The purpose of the structured interviews was to obtain feedback on the application and to clarify where this might be most usefully included in practice. There was a consensus that the overall interface and the careful positioning of all elements within the GUI, needed further work. In retrospect, during the iterative design stages undertaken to develop the application, not much attention was given to the layout of the interface and therefore everything was positioned on screen without any regard for contrast and transparency with the 3D model. Also, as I was very accustomed to using the applications features it was extremely useful to obtain input from practitioners seeing and using the application for the first time.

The demonstration with the gyroscope sensor gave every practitioner the impression of how it could work on-site with a 1:1 scale model both for architectural and project management purposes. Many practitioners were not even aware that a tablet computer had these built special features. This was the key function that appealed most to practitioners in terms of possible uses on site. Although the gyroscope example was simulated using VR the concept of using a tablet on site was successful. All practitioners shared the common view that the value of augmented reality is more applicable at a 1:1 scale on a construction site. Table 1 below summarises each interviewee's considerations on improving the interface and on functions they would value using mobile augmented reality.

Summary of interviews								
	Improvements to Graphical User interface				Valuable functions for AR			
Interviewee	Improve interface and 3D model contrast	Redevelop buttons and sliders	Replace 2D Marker with better Drawing	Include help functions	Client presentation tool	On site comparison tool	Design Analysis Tool	Critical Path
1	*	*			*	*	*	
2	*	*	*	*		*	*	
3	*				*	*	*	
4	*	*			*		*	
5	*		*		*		*	
6	*						*	
7	*	*			*	*		*

Table 1: Summary of Interviews

### Feedback for GUI functions

Most of the Architectural practitioners showed a general understanding of Gantt charts but were not accustomed to using them very often so they could only provide minimal feedback. It was only when the assistant project manager was approached was there a much more critical discussion on the Gantt chart functions and the colour coded connections. The colour codes were very helpful for identifying the link that the Gantt chart had to the 3D model. However this was not enough, as stated from the early interviews the key task for any project manager is to deal with lag and identify shifts in the schedule using the critical path method (CPM). This was not addressed in the scope of design



and should be a future precedent for further research. Given this could be visually integrated on a mobile platform using augmented reality only then would it have significant use.

The deactivator functions showed moderate attention amongst all practitioners. Since it is such a common CAD tool it was no surprise to them that this application would have something similar. The deactivator was a key tool to show them the 3D model was a lot more than just a building shell, but had underlying steel beam details hidden in between the roofs and walls. Essentially it was an addition that gave the impression that a lot of detail was happening on a small device. The main feedback for this was to improve the buttons and make them more user - friendly. At the moment they are difficult to press and most times the tablet was given back to the author to activate the functions and show how they work properly. This was because the sensitivity was not positioned properly on screen and was particularly evident when a practitioner tried to use sliders in the Gantt chart feature. If they tried to move a slider; either the slider tab did not move or another slider below moved accidentally as a result of each slider activation point being positioned too close to each other. The timeline was the biggest 'wow' factor for all practitioners since it was easiest to use and easiest function that gave understanding of the process of construction. All practitioners shared the same view that this was the feature of the GUI that most CAD programs lack is a tool which visually builds the construction in 3D and have the flexibility to go back and forth on the timeline. Most architectural practitioners expressed the view that the timeline was a valuable feature for showing clients how construction would progress. The timeline needed re development in terms of adding more detailed information such as text boxes showing the name of the component. It also needs flexibility in terms of exchanging particular tasks within the timeline. During interviews it became obvious which features appealed to each practitioner, through observation of them using the tablet and through discussion. Table 2 summarises the GUI functions that practitioners thought could be of use to them on a mobile platform.

GUI Features				
Interviewee	Gantt chart	Timeline	Deactivator	Gyroscope
1				
2				
3				
4				
5				
6				
7				
<b>Key</b>				

Figure 106: Application features - Practitioner feedback

## 8. SUMMARY OF RESEARCH FINDINGS

### Overview

This research was inspired by the lack of tools that aid project managers with 3D visualization of construction sequence on site. It addresses this by creating a mobile application that gives AEC professionals perspective on the process of construction using augmented reality. The development of this application was informed by guidance that was initially gathered from precedent and further refined by approaching construction professionals. The feedback that was gathered enabled development of functions that would be useful in project management.

Literature has identified that 4D BIM applications are well established and are widely used today. It has also identified that there is precedent in 4D BIM applications for mobile devices and that suggest it is slowly shifting to mobile platforms. 3D BIM, 4D BIM are all well-established areas of research. Precedents that support augmented reality for construction management are presently limited. Currently there are only a few prototypes available that are capable of 4D AR simulation.

Achieving the scope of design for this research was established by viewing and analysing aspects and features that trend amongst mainstream 4D applications, 4D research applications and popular mobile applications identified in the precedent review. The scope resulted in a large range of possibilities that could inform the design of the prototype. Instead of selecting a few of these aspects for research; further consultation with practitioners on which aspects they support from this list allowed the scope to be further refined to focus on four key aspects of construction management. These four key construction management aspects formed the basis for iterative development and predominantly in the design of the GUI.

Development of the application underwent five iterative design stages and ended with the creation of a prototype AR application for an android tablet computer. This showcased a 3D model from a real project. The GUI essentially allowed a user to experience a scenario in which the project was being constructed and common management tools were available to control the movement of construction and access information on various portions of the 3D model. The key aim was to demonstrate as many concepts as possible (within the time constraints) in which augmented reality could be used in construction management.

Following the development of this application, industry was again approached to give feedback on the use of the application. This was to engage practitioners on the use of augmented reality and also to review the functions that had been created. Observation of practitioners using the application and structured interviews enabled identification of features that appealed most to practitioners. Feedback was summarised and common trends were tabulated to evaluate future directions for construction management. From this analysis the research questions that underpin the thesis can be addressed.

## Research Questions

- 1) *From a stakeholder perspective, what aspects of project management could AR BIM on a mobile device best address?*
- 2) *What are the key performance criteria and guidelines for development of AR BIM on a mobile device?*

## Research findings

In relation to question (1) the research has identified the following aspects of project management that would most benefit from AR BIM applications on mobiles devices.

### ***Improving critical path with AR – Visualizing Lag***

*Project managers would find it extremely useful if AR could visually represent lag and critical path as highlights on the 3D model. The integrated Gantt chart allowed this concept to be visualized when paired with the interior walkthrough. Practitioners that were familiar with MS project wanted tasks on the critical path to be identified via colour highlights on the 3D model. For example when the critical path is calculated within MS project, tasks along this path will be highlighted red. In augmented reality; show the 3D groups that are associated with this task and highlight them in red. This would enable them to direct resources accordingly to the situation and make sure that attention is given to these tasks to reduce the likelihood of tasks falling behind schedule.*

### ***On site design analysis tool***

*All architectural practitioners valued augmented reality as a design analysis tool. Although not an aspect of construction management, it was important as a pre design tool in the context of a projects life cycle. Assessing sun path, orientation of buildings and having the ability to send pictures of analysis would greatly be enhanced with augmented reality. It was also important to connect this information from the site back to teams in office in order to improve coordination and ascertain information collaboratively. This feedback aligns with some of the functions from the precedent analysis i.e. BIM 360/AutoCAD 360, where pictures/notes from site investigation are delivered back to office via wireless internet.*

### ***Coordination and communication***

*Coordination can be enhanced greatly with the use of mobile AR. Smart devices are essentially small computers capable of making calls. Project managers being people who are constantly in contact with key stakeholders can link not only management information but contact information. Practitioners noticing that the application was operating on a tablet immediately realized that it would probably be compatible on a mobile smart phone as well. Given the on-site scenario where contact information about a person responsible for a*

*particular task. It would be beneficial to 3D tag or link the phone book within a smart phone to the 3D model for easier access to details on a task.*

### **Client Side communications**

*All practitioners expressed this was the perfect client side presentation tools because most times they would present sheets of drawings to clients. Clients who needed extra understanding had walkthrough on big screens displayed to them. The alternative to this was 3D renders which practitioners required payment for. With AR practitioners could essentially go with the client on site, superimpose a 3D model and again view 4D information of construction sequence showing them exactly where and when things were going to happen. Practitioners from Accent described the idea of having 3D AR models for all their 2D drawings. This would enhance the clients understanding of 2D information.*

In relation to question (2) the research has identified the key issue for the development of AR BIM on a mobile device is the graphic user interface. The feedback from stakeholders in relation to improvements to the GUI, falls into the below categories.

### **Overall layout of the interface**

The overall layout of the interface is the main issue that needs to be addressed. Although all functions were compressed into ribbons and drop down lists; the usability and transparency still failed during demonstrations. Practitioners struggled to press buttons on the touch screen, scroll down the Gantt chart - often resulting in the timeline crashing during demonstrations. It became clear that the overall design of the interface was more appropriate as a demonstration tool, than an application that could be used in practice.

Re-design should focus on an interface that enables the user to deactivate the entire GUI and focus on the 3D model. This would appear to be essential given the small screen space and the amount of model information required to be usefully viewed. Care must be taken in designing an interface that contrasts well against the 3D model visualization. Focus needs to be put on further compacting functions within the GUI and displaying specific information individually. For example - construction tasks would be best displayed to appear on screen one at a time. Overall the application as demonstrated was too cluttered, and further research is needed to develop ways to segment functionality in a way that would map to use in practice.

**Model visibility**

Most practitioners stressed the poor visibility of the 3D model as a result of the interface overshadowing most 3D elements. Aspects such as the contrast between the 3D model and the Gantt chart should be addressed with re-design. Small improvements such as scripting a help buttons to access useful instructions and blurring exterior objects were main areas of concern for practitioners.

**GPS Integration**

There was much discussion the need for this technology to be demonstrated and tested on site application using the GPS tracking technology. This was a focus in the scope of design during initial stages of research but limitations to the tablet restricted an iterative design stage. All previous aspects of management that could be enhanced using AR were all stressed as on site usage. This was expressed by both architects and project manager that participated. This is well established area of research but further research could address using GPS located 4D building model with a timeline slider as was shown in this application. Practitioners noted that testing geo locating 3D models on these websites would greatly aid them.

**Integration of known approaches from touchscreen GUI**

Embedding features that are unique with smart devices such as 'swipe' or 'pinch' would improve the ease of using functions. For example: instead of having the Gantt chart in a drop down list; it could on screen in sections and change by swiping the screen. Therefore by activating the Gantt chart the screen will show the task as a ribbon and swiping the screen from right to left will move the page onto the next task. The deactivator function should be removed as a visible button on the GUI and replaced with an on screen interactive feature where the user can simply touch the group to deactivate it. For example to deactivate the roofing, the user would have to touch the roof component on screen. This saves screen space and integrates a more interactive tool for visualization. The timeline needs to communicate together with the Gantt chart through scripting. In the sense that the Gantt chart lists the construction sequence that the timeline builds the 3D model in. This way a user can change and swap various construction groups and have a timeline that can build different scenarios.

**Final reflections**

I trust that this thesis will aid further research in the field of 4D BIM on mobile devices. Given the constraints on a one year Master's thesis and the limitations of my application development knowledge and programming skills, the research has only been able to demonstrate a select range of uses (refer to figure) and obtain feedback from a representative number of stake holders. Despite this, it is clear that AR BIM has the potential to address aspects of project management and that there is demand and excitement from the industry for its application. The research also demonstrates that sophisticated interfaces with a full range of AR functionality are achievable with limited resources. This bodes well for further research, and I have no doubt that AR BIM on mobile devices will eventually be an indispensable aspect of project management.

## 9. BIBLIOGRAPHY

- 3DOn. (2014). *Make your Google SketchUp models mobile on the iPhone and iPad*. Retrieved January 14, 2014, from Youtube: <http://www.3don.co.uk/>
- Alcaraz, J. C. (2010, April 30). *Real Time Architecture Visualization unity3d* . Retrieved January 08, 2014, from Youtube.com: <https://www.youtube.com/watch?v=Y4t-C0pH1rs>
- Android. (2013). *Android*. Retrieved February 10, 2014, from Motion Sensors: [http://developer.android.com/guide/topics/sensors/sensors\\_motion.html](http://developer.android.com/guide/topics/sensors/sensors_motion.html)
- Architecture, S. L. (2012). *Building Information Modeling (BIM) Solutions*. Retrieved January 10, 2014, from Smith LaRock Architecture : <http://www.slarc.com/bim/>
- ARToolkit. (2013). Retrieved February 6, 2014, from ARToolkit: <http://www.hitl.washington.edu/artoolkit/>
- ARToolkit. (2013). *How does ARToolKit work?* Retrieved February 12, 2014, from ARToolkit: <http://www.hitl.washington.edu/artoolkit/documentation/userarwork.htm>
- ARToolworks. (2014). *ARToolKit for Android*. Retrieved February 10, 2014, from ARToolworks: <https://www.artoolworks.com/products/mobile/artoolkit-for-android/>
- Autodesk. (2013). *AutoCAD 360 Spotlights*. Retrieved January 03, 2014, from Autodesk AutoCAD 360: <https://www.youtube.com/watch?v=bwo-ARgfUZg>
- Autodesk. (2013). *BIM 360*. Retrieved January 03, 2014, from Autodesk: <http://www.autodesk.com/products/bim-360/features/bim-360-glue/all/gallery-view>
- Autodesk. (2013). *Navisworks*. Retrieved January 05, 2013, from Autodesk: <http://www.autodesk.com/products/autodesk-navisworks-family/overview>
- AutodeskNavisworksHelp. (2014). *Supported Scheduling Software*. Retrieved February 04, 2014, from Autodesk Navisworks: <http://help.autodesk.com/view/NAV/2014/ENU/?guid=GUID-1879F810-B3D3-419A-A138-0D2F02A8BFBA>
- Bargstadt, H. J. (2012). *Contable benefits of visualizing one of a kind processes*. *12th International Conference on Construction Applications of Virtual Reality* (p. 29). Taipei : National Taiwan University Press.
- Belcher, D., & Brian , J. (2008 ). *ARchitectureView An Augmented Reality Interface for Viewing 3D Building Information Models*. *Education and research in Computer Aided Architectural Design in Europe (eCAADe)*, (pp. 561 - 568). Belgium .

- Benham, J. (2014, January 26). *A new way to visualize your construction projects*. Retrieved January 28, 2014, from Smart Reality Beta: <http://smartreality.co/>
- BIManywherePro*. (2013). Retrieved January 13, 2014, from BIManywhere: <http://bimanywhere.com/features.php>
- Craig, A. B. (2013). *Understanding Augmented Reality Concepts and Applications*. Morgan Kaufmann.
- Cronin, C. (2011, December 22 ). *3DOn ARchitecture: Augmented Reality for iOS devices*. Retrieved February 03, 2014, from SketchUpdate: <http://sketchupdate.blogspot.co.nz/2011/12/3don-architecture-augmented-reality-for.html>
- Danko, M. (2012, October 30). *A Day in the Life: Senior Construction Manager*. Retrieved January 20, 2014, from Bloomberg Business Week: <http://www.businessweek.com/articles/2012-10-30/a-day-in-the-life-senior-construction-manager>
- DesignBoom. (2012, September 14). *architecture in augmented reality with urbasee*. Retrieved JANUARY 30, 2014, from Design Boom: <http://www.designboom.com/architecture/architecture-in-augmented-reality-with-urbasee/>
- Fear, E. ( 2009, June June 23). *Develop*. Retrieved January 13, 2014, from The Top 10 Game Engines: <http://www.develop-online.net/tools-and-tech/the-top-10-game-engines-no-4-unity-3d/0116475>
- Gantt.com. (2012). *What is a Gantt chart?* Retrieved February 12, 2014, from Gantt.com: <http://www.gantt.com/>
- Haller, M., Billingham, M., & Thomas, H. B. (2007). *Emerging Technologies of Arugmented Reality: Interfaces and Design*. United States of America: Idea Group Publishing.
- HellsPizza. (2013). *How to Play*. Retrieved January 6, 2014, from Zombies From Hell: <http://hellpizza.com/zombiesfromhell/>
- Henderson, J. (2013, November 28). *Smartphone sales set to smash one billion mark* . Retrieved January 5, 2014, from The Channel - Techday: <http://techday.com/the-channel/news/smartphone-sales-set-to-smash-one-billion-mark/174192/>
- Holzer, D. (n.d.). BIM's Seven Deadly Sins. *International journal of architectural computing*, 468.
- Ibrahim, M. (2006). *To BIM or not to BIM, This is NOT the Question: How to Implement BIM Solutions in Large Design Firm Environments*. Retrieved January 25, 2014, from Academia.edu:



[http://www.academia.edu/373207/To\\_BIM\\_or\\_not\\_to\\_BIM\\_this\\_is\\_NOT\\_the\\_question\\_How\\_to\\_Implement\\_BIM\\_Solutions\\_in\\_Large\\_Design\\_Firm\\_Environments](http://www.academia.edu/373207/To_BIM_or_not_to_BIM_this_is_NOT_the_question_How_to_Implement_BIM_Solutions_in_Large_Design_Firm_Environments)

Jang, S. H., & Hudson - Smith, A. (2012). *Exploring Mobile Augmented Reality Navigation System for Pedestrians*. London: University College.

Jie, J., Yang, K., & Haihui, S. (2011). Research on the 3D Game Scene Optimization of Mobile Phone Based on the Unity 3D Engine. *2011 International Conference on Computational and Information Sciences* (pp. 875 - 877). Chengdu: IEEE Computer Society.

Khanzode, A., Fischer, M., & Reed, D. (2005). Case study of the Implementation of the lean project delivery system (LPDS) using Virtual building Technologies on a large Healthcare project. *International Group for Lean Construction* (p. 144). Sydney: QUT ePrints.

Logiseek. (2012). *BIM Clash detection*. Retrieved January 08, 2013, from Logiseek CAD services company: [http://www.logiseek.com/BIM\\_clash\\_detection.php](http://www.logiseek.com/BIM_clash_detection.php)

Marchese, P. (2013). *Webinar: The Glue that Binds us: BIM 360 Glue*. Retrieved February 14, 2014, from Youtube.com: <http://www.youtube.com/watch?v=k8qGekENwpA>

Messner, J., Riley, D., Horman, M., Otto, G., Wang, L., Jaruhar, S., et al. (2011). The Development of the Virtual Construction Simulator 3 – An Interactive Simulation Environment for Construction Management Education. *Proceedings of the 2011 ASCE International Workshop on Computing in Civil Engineering* (pp. 454 - 461). Miami: American Society of Civil Engineers.

Milgram, P., & Kishino, F. (1994). A Taxonomy of mixed reality virtual displays. *IEICE Transactions on Information Systems*, 2-5.

Mohd, F. S. (n.d.). *Virtual Office Walkthrough Using a 3D Game Engine*. Experimental report.

MontotoMods. (2012, January 8). *Basic Building UV Mapping with 3DS MAX 2008*. Retrieved August 13, 2013, from Youtube.com: <http://www.youtube.com/watch?v=1GYs8hZwuJo>

Morkos, R., Macedo, J., Fischer, M., & Somu, C. (2012). Quantifying effects of specific tool functionalities on 4D modelling productivity. *CIB W78 2012: 29th International Conference*, (pp. 17-19). Beirut.

MrAsBuilt. (2014). *Clash detection/Interference*. Retrieved December 02, 2013, from MrAsBuilt Inc.: [http://mrasbuilt.com/MAB\\_BIM\\_ClashD.html](http://mrasbuilt.com/MAB_BIM_ClashD.html)

Nikolic, D. (2006). *The Virtual Construction Simulator*. Retrieved December 02, 2013, from Penn State University - Computer Integrated Construction : <http://www.engr.psu.edu/ae/cic/vcs/index.aspx?p=4>

- Optimizing Graphics Performance*. (2012, July 29). Retrieved January 03, 2014, from Unity3D.com: <http://docs.unity3d.com/Documentation/Manual/OptimizingGraphicsPerformance.html>
- Peterson, F., Hartmann, T., Fruchter, R., & Fischer, M. (2011). Teaching construction project management with BIM support: Experience and lessons learned. *Automation in Construction*, 115–125.
- Qualcomm. (2012). *Augmented Reality (Vuforia)* . Retrieved October 15, 2013, from Qualcomm Developer Network: <https://developer.qualcomm.com/mobile-development/add-advanced-features/augmented-reality-vuforia>
- Qualcomm. (2012). *Resources - Cylinder targets*. Retrieved September 16, 2013, from Vuforia Developer: <https://developer.vuforia.com/resources/dev-guide/create-targets>
- Quirk, V. (2012, September 17). *The 10 Best Apps for Architects*. Retrieved December 16, 2013, from <http://www.archdaily.com/273823/the-10-best-apps-for-architects/>
- RealVisual. (2011, July 15). *Unity 3d: Hotspots. A presentation by Real Visual*. Retrieved January 07, 2014, from Youtube: [https://www.youtube.com/watch?v=xJXqk4hex\\_o&list=PL7HmpJN3LvQpWYY8AZLzjGMbnywKngffB&index=2](https://www.youtube.com/watch?v=xJXqk4hex_o&list=PL7HmpJN3LvQpWYY8AZLzjGMbnywKngffB&index=2)
- Reinhardt, J. (2009). Appendix C: BIM Tools Matrix. *The Contractor's Guide to BIM*, 57-67.
- Sabol, L. (2008). Challenges in Cost Estimating with Building Information Modelling. *Design + Construction - The power of process in the built environment*.
- Schonfeld, E. (2010, January 06). *Augmented Reality Vs. Virtual Reality: Which One Is More Real?* Retrieved January 10, 2014, from TechCrunch: <http://techcrunch.com/2010/01/06/augmented-reality-vs-virtual-reality/>
- Schwaiger, T. (2013, October 18). *How to use BIM 360 and Navisworks on your projects* . Retrieved December 14, 2014, from Beyond Design - empowering contractors to get the most out of BIM: <http://beyonddesign.typepad.com/posts/2013/10/how-to-use-bim-360-and-navisworks-on-your-projects.html>
- Staub-French, S., & Khanzode, A. (2007). 3D and 4D Modelling for Design and Construction coordination: Issues and Lessons learned. *ITcon*, 382.
- Strecker, T. P. (2013, November 15). *Zombies from Hell and ACC*. Retrieved January 06, 2014, from Stuff.co.nz: <http://www.stuff.co.nz/business/industries/9402179/Zombies-from-Hell-and-ACC>
- SynchroSoftware. (2012, April 12). *Synchro Professional Product Video* . Retrieved January 18, 2014, from Youtube.com: <http://www.youtube.com/watch?v=gL-tjMCwfgg>

- Unity3D. (2013). *Welcome to the Unity Scripting Reference!* Retrieved January 15, 2014, from Unity 3D.com: <https://docs.unity3d.com/Documentation/ScriptReference/>
- Unity3D. (2014). *Reel Profiles*. Retrieved January 10, 2014, from Unity3D: <http://unity3d.com/company/sim/profiles>
- Vicosoftware. (2014). *What Does 4D BIM Mean to YOU?* . Retrieved November 07, 2013, from Vicosoftware: <http://www.vicosoftware.com/what-is-4D-BIM/tabid/88206/>
- Vicosoftware.com. (n.d.).
- Wagner, D., Pinatric, T., Ledermann, F., & Schmalstieg, D. (2005). Towards massively multiuser - user augmented reality on handheld devices. *3rd International Conference on Pervasive Computing* (p. 108). Munich: Pervasive.
- Wammen, T. (2010, June 07). *Part 1 - Building Information Modeling Case Study from the Marshall Space Flight Center*. Retrieved January 08, 2014, from Directions Magazine: <http://www.directionsmag.com/articles/part-1-building-information-modeling-case-study-from-the-marshall-space-fli/122356>
- What is Unity and what can I do with it?* (2013, July 3). Retrieved December 16, 2013, from Unity3D.com.
- Woodward, C., Hakkarainen, M., & Rainio, K. (2010). *Mobile Augmented fo Building and Construction*.
- Yan, W., Graf, R., & Culp, C. (2011). Integrating BIM and gaming for real-time interactive architectural visualization. *Automation in Construction*, 446–458.