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Building Information Modelling:
An Explorative Study

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ABSTRACT

This research was driven by a desire to understand the use of 4D and 5D Building Information Modelling (BIM) tools in medium scale Design and Build (D&B) organisations in Australia.

The utilisation of BIM tools in Australia is still in its infancy despite the reported advantages on the use of BIM methodologies for managing large scale projects. However, there is little information on the value of such methodologies for the management of D&B projects particularly with respect to medium scale construction companies. Furthermore, it was found that there lacked a consensus in the literature on the use of specific BIM tools, and which tools provided the most benefit to an organisation. Accordingly, the aim of this this research project is to examine the feasibility of utilising 4D and 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors.

In order to pursue the above aim, semi-structured interviews and a multiple case study approach was adopted. Semi-structured interviews were undertaken as a means to validate the findings from the literature review. Interviews undertaken with the Construction Manager, Project Manager and CAD Manager of a medium scale D&B organisation demonstrated that the D&B method of contracting improves both budget and timeframe performance on projects. The constructability of designs however, is integral to the level of success achieved.

The first case study for the project utilised a historical project in order to provide a first-hand understanding of the key issues and problems faced by medium scale D&B contractors. The results of the case study identified co-ordination between the design and construction teams are paramount to the D&B contractors' performance. Revised designs on the project due to constructability concerns after the commencement of construction works was both costly and disruptive to the project. The ability to identify constructability concerns prior to commencing construction works ensures project success. Identifying the specific key concern on the project demonstrated the need for research into the use of 4D and 5D BIM for managing and resolving these issues.

The use of a second case study enabled 4D and 5D BIM tools to be retrospectively implemented on the same historical project, enabling a comparative analysis of the performance of the project to be undertaken. The results of the case study demonstrated that the use of 4D BIM tools enables the identification of constructability concerns prior to the commencement of construction works onsite. Identifying these concerns improved the project schedules predicted performance with the use of 4D BIM tools by one week and one day. 5D BIM tools utilised the 3D BIM model to price the alternative designs on the project. Whilst the use of 5D BIM proved advantageous in pricing the design change in a reduced timeframe, the outcome of the case study indicated that the use of 5D BIM in managing and resolving key issues is feasible, when used in collaboration with a 4D BIM tool.

Recommendations are provided to undertake further research on the use of 4D and 5D BIM tools on multiple medium sized D&B projects. The use of multiple projects would be used as a means to provide a consensus in the results, prior to recommending the implementation of 4D and 5D BIM tools in medium scale D&B organisations.

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Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 – INTRODUCTION

1.1 Outline of the study

The use of the Design and Build (D&B) method on construction projects provides a significant advantage to both clients and contractors. Control of the design affords the contractor with the ability to regulate the projects budget and also construction timeframes, improving the overall success of a project.

My current employment is with a successful medium scale Design and Build Organisation. Through the use of the D&B method, the organisation is able to reduce project timeframes, as well as improve budget performance for the client. Issues arise on occasions however; therefore there is an opportunity for continuous improvement. The need for the project was identified from this desire for improvement. For the purposes of this report, the company will be referred to as **"The Organisation"**.

New and emerging Building Information Modelling (BIM) tools are being introduced into the market that are used for the overall management of the project throughout its entire lifecycle. The research was driven by the desire to understand the use of 4D and 5D BIM tools in medium scale Design and Build organisations in Australia, and the feasibility of utilising these BIM tools in managing and resolving key issues.

1.2 Introduction

BIM is a design tool that has been in use in the architectural, engineering and construction industry for some time. The use of the BIM model in the design of a project enables the project team, to utilise the 3D design model as an object database, containing specific information relating to each of the building elements (buildingSMART-Australasia 2012). This information contained within the BIM model, is the key aspect that differentiates the BIM model from other 3D modelling tools.

Autodesk Revit, BIM software has been the principal design software used by the design office in the organisation for approximately ten years for building modelling and design. More recently TEKLA, also BIM software has been in use for approximately two years for structural steel detailing. The current use of both software's in The Organisation are however limited to 3D BIM.

Emerging BIM tools are available for the use by all project stakeholders that aid in the management of construction projects. 4D BIM tools are available according to Mukherjee and Clarke (2012) that aid in construction planning, and also the ability to visualise the construction sequence prior to commencing construction of the project. Through the integration of the 3D BIM model and the projects schedule, 4D BIM tools can then be used to simulate the construction schedule, enabling the construction of the project to be reviewed prior to commencing works onsite (Hardin & McCool 2015).

Furthermore, 4D BIM tools can be used for constructability review processes on project, whereby both site constraints and challenges are able to be identified and resolved prior to commencing works onsite (Hartmann & Fischer 2007). The benefit of implementing 4D BIM tools therefore, is improving both the communication and coordination between the project team, from the commencement of the project in the design phase.

5D BIM tools facilitate the integration of the 3D BIM model and the projects rate schedules. By utilising the information in the 3D BIM model such as material specifications and quantities, the 5D BIM tools are able to combine this information with the rate schedules to produce project estimates (Mubarak 2015). A significant advantage of the adoption of 5D BIM tools, according to Forgues et al. (2012) is the project team is able to undertake estimate comparisons throughout the lifecycle of the project, rather than when the projects designs reach a specific stage.

The use of 5D BIM on projects also enables project team members to price both variations and scope changes, in a shortened period of time. A benefit to utilising 5D BIM therefore is that variations and scope changes can occur when time is of the essence in the project and therefore the estimate updates can be produced almost instantaneously (*Reaching Target Project Costs with 5D BIM Estimating* 2015).

Previous research on the use of 4D and 5D BIM tools has identified significant advantages, improving construction sequencing and project estimate comparisons. This research however, has been limited to use on large scale projects and not specifically used by Design and Build contractors. This research project will therefore investigate the feasibility of utilising these BIM tools to manage and resolve key issues faced by medium scale D&B contractors.

1.3 The Problem

The D&B method of contracting relies upon the accuracy of the constructability of designs. Co-ordination between the design and construction teams is paramount to improving the constructability and also the success of the D&B project (Greenhalgh & Squires 2011). Improved coordination also enables the construction team to increase the construction team members input in the design phase of the project.

As a means to improve areas of the design that prove difficult to construct, constructability reviews should be undertaken. In order to improve the process and also gain valuable construction insight, the construction team must be involved in the process. The constructability review process is an aspect of the D&B method that highlights the significance of the collaboration between the design and construction teams (Cushman & Loulakis 2001).

While the D&B method improves the constructability review process, there are still occurrences on projects where designs are complete, and the review has not identified any areas of concern, problems are therefore only uncovered once construction works have commenced onsite. Changes made to designs after construction works have commenced are therefore both costly and time consuming to resolve. In order to resolve these design changes, the projects overall success can be affected.

Despite the consensus in the research of the benefits in the adoption of BIM tools on projects, research has not previously identified the benefit of using 4D and 5D BIM tools in medium scale D&B organisations. This dissertation therefore focusses on the value that the implementation of BIM tools will provide to medium scale D&B organisations, to aid in the constructability review processes and therefore alleviating the problems that are encountered from time to time.

1.4 Research Objectives

The aim of this research was to examine the feasibility of utilising 4D and 5D BIM tools for managing and resolving key issues faced by contemporary medium-scale Design and Build contractors.

In order to achieve this objective the following sub-objectives have been formulated:

1. Establish risks faced by design and build contractors through an extensive literature review.
2. Undertake extensive literature review to research and evaluate currently available Building Information Modelling software and the developments in the software since its inception, focussing on the integration between 3D and the elements of 4D (Time) & 5D (Cost).
3. Undertake interview with key organisation members in order to validate the findings from the literature review.
4. Undertake a historical case study on one of our Organisations completed projects in order augment these concerns (Historical Case Study 1).
5. Undertake Pilot Case Study using a small scale test project created in Autodesk REVIT and selected 4D and 5D BIM tools, as a means to provide an understanding of the tools and resolve the usage of the tools for the remainder of the research project.
6. Apply selected BIM 4D and 5D BIM tools to the historical project and then undertake a case study (Historical Case Study 2) to resolve the value of using these tools in managing and resolving the issues that are encountered.

1.5 Conclusions

This dissertation aims to determine the feasibility of utilising 4D and 5D BIM tools in managing and resolving key issues faced by medium-scale D&B contractors.

The results of the research are expected to identify that there is an advantage in the adoption of BIM tools in medium scale design and build organisations, for use on projects. 4D BIM tools are expected to improve the constructability design review process, which will result in improved project schedule performance and a reduction in costly design changes. The results of the utilisation of 5D BIM tools is expected to aid in improving the pricing of design changes and cost management on projects. The use of 4D and 5D BIM tools are expected to be a feasible method of managing and resolving key issues faced by medium-scale D&B contractors.

A review of the literature for this research is included in Chapter two. The literature review has been undertaken to establish both the risks faced by D&B Contractors, and also the advantages to the use of 4D and 5D BIM tools. Chapter two will aim to achieve sub-objectives 1 and 2 that have been established for the research project.

Chapter three of the dissertation includes the research methodology that has been implemented to carry out the research project works. The chapter includes both the case study protocol and interview guide that has been used to complete the research for the project.

Chapter four has been included in the dissertation as a software user guide. As the software adopted for use in the project is new, the guide has been included as a means to provide reliability to the research as all processes that were undertaken are included.

Chapter five includes the results and analysis section of the dissertation. The results included in Chapter five are the results from the interviews with key organisation members, the historical case study, small scale test project and the second historical case study with BIM tools implemented. The contents of this chapter will achieve sub-objectives 3, 4, 5 and 6.

Chapter six of the dissertation includes the conclusions and recommendations for the project. The objective of the research is to examine the feasibility of using 4D and 5D BIM technologies for managing and resolving key issues faced by contemporary medium-scale Design and Build contractors. The recommendations will therefore include a determination on the value of the BIM tools, and the benefit of adopting them in the organisation.

The outcomes of this study will be used as a means determine the recommendation to The Organisation, for the adoption of 4D and 5D BIM tools for use on future D&B projects.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

The aim of this literature review is to examine key issues that are faced by medium-scale Design and Build (D&B) contractors. In addition to this, the literature review seeks to investigate currently available Building Information Modelling (BIM software), and the developments of BIM. An evaluation of the integration of the 3D BIM model and the 4D and 5D BIM tools will also be undertaken.

Construction projects are becoming increasingly more complex, with shorter timeframes and reduced budgets. In order to ensure projects success, adequate planning therefore must be undertaken. When appropriate planning isn't undertaken however considerable cost and time overruns can be experienced. A study by Zuppa, Issa and Suermann (2009) highlighted that in the United States in 2008 there was approximately $600 Billion dollars' worth of spending that was considered waste, and could be attributed to poor planning through inefficient communication between relevant parties on the project, poor design, or poor productivity on the project.

BIM is a 3D modelling concept that has been introduced to the Architectural, Engineering and Construction Industry. The concept has enabled the design of a project to be undertaken through the use of a collaborative and digital model, which has provided much benefit to organisations to establish co-ordination in designs between different building aspects (Azhar 2011).

Planning and Scheduling in the traditional method on a project consists of a Project Manager utilising 2D plans to visualise the project to identify and schedule tasks and timeframes in planning methods such as the Critical Path Method or the Line of Balance (Jongeling & Olofsson 2007). While these methods are beneficial on projects and have been successful, they are however subject to differing interpretations based on how the drawings are read. BIM software allows the user to be able to simulate the construction sequence of the project, and then in turn identify any potential clashes on the project ensuring the project schedule produced is accurate and clear to all stakeholders in the project.

Traditional estimating methods utilise 2D drawings to undertake measurements of the project to produce quantity take-offs (Monteiro & Poças Martins 2013). The quantity take offs are then used in conjunction with rates and Bill of Quantities that have been established within the organisation for the various work packages. An issue that estimators face on projects however is the time constraints to undertake quantity take-offs multiple times. The use of 5D BIM tools enables the estimator to utilise the BIM model to undertake numerous estimates as required throughout the design phase of the project (Mitchell 2012).

2.2 Design & Build Construction

2.2.1 Background

The Design and Build (D&B) procurement method in construction projects, enables the client to engage a single firm for the delivery of both the design and construction of the project, reducing the contractual responsibility to one firm (Konchar & Sanvido 1998).

An alternate version of the D&B arrangement is available to clients that reduce the involvement of the D&B contractors in the design phase of the project; however the level of design responsibility remains the same. Novated D&B can be used by clients to engage consultants to complete the design prior to submitting request for tenders. Once a contractor is engaged, the responsibility for the design is then transferred from the client to the contractor (Murdoch & Hughes 2000).

Tenders submitted by contractors on a project using the D&B contract type includes a proposal to be submitted based on the request for proposal procurement method used by the client. The proposal submitted by the contractor can contain preliminary proposal drawings, project specifications or outlines and the tendered price for the project (Ndekugri & Turner 1994).

A key component to the success of a D&B project is the initial clarity of scope by the client. The scope provided by the client includes the established performance criteria which outlines the requirements that are expected to be achieved by the contractor (Cushman & Loulakis 2001). In order for the contractor to successfully interpret the client's requirements for the project however, the performance criteria must be comprehensive and clearly defined.

The basis of the performance specification utilised by the client in the D&B contract determines the overall result that is required from the project, however the specification does not dictate specific materials or methods that must be incorporated into the project which are prescriptive or design specifications. Limiting the specification to performance only, the overall outcome of the project can be improved through innovative ideas and improved efficiencies in the design and construction (Molenaar, Songer & Barash 1999).

The use of the D&B contract type enables the contracted party to undertake the works based on a set of defined deliverables and performance criteria that have been established by the client. The works are undertaken for a set price and a set completion timeframe. The level of detail in the design required by the contractor therefore is required to fit within the contractors proposed budget and the contract completion schedule only to achieve the clients performance criteria (Gransberg & Molenaar 2004).

2.2.2 Advantages to the Design and Build method

As reported by Konchar and Sanvido (1998) in a comparative case study on the performance of D&B projects versus other procurement methods, the D&B project had a construction speed at least 12% faster and 6.1% less costly than that of the Design-bid-Build procurement method which is a considerable advantage in the utilisation as a procurement method.

Results of a historical case study undertaken on 104 completed public sector projects in the United States found that 55% of projects undertaken using the D&B procurement method were completed within 2% of the project budget, a further 8% of projects were under the project budget by 3% or more. Approximately 28% of the projects were within 3 to 5% of the project budget and the remaining 9% of the projects were over budget by 5% or more. The case study further compared three D&B methods based on the status of design completion at the time of the Request for Proposal. The three methods were more than 50% of design completed, less than 35% of design completed and qualifications based with less than 10% of the design completed. The study found that the best performing D&B projects were those that had less than 35% of the design completed at the time of the Request for Proposal. The least performing projects were qualifications based projects which were attributed to lack of competition during the proposal stage of the projects (Molenaar, Songer & Barash 1999).

Results of the same case study also identified that 77% of the projects were also completed within 2% or better of the project schedule, 10% of the projects were under the project schedule by 3% or more, and approximately 10% of the projects were completed within 3 to 5% over the anticipated project schedule. The remaining projects were completed at least 6% over the projects schedule. The study found that the best performing projects in terms of the project schedule were also those had less than 35% of the design completed at the time of the Request for Proposal with the least performing projects being qualifications based projects (Molenaar, Songer & Barash 1999).

A key criterion for the selection of the D&B method is the ability to shorten the timeframe of a project from the commencement of design to completion. This shortened timeframe can happen due to the ability of the design process and construction activities being undertaken concurrently. This enables the contractor to be undertaking works onsite prior to the final design being completed (Ling & Leong 2012).

The D&B method enables the project team to improve coordination on the project. The improved coordination enables the construction team to increase the construction team members input in the design phase of the project. The improved coordination is also a contributing factor to the reduction of project timeframes if the D&B method is utilised (Greenhalgh & Squires 2011).

The potential for claims raised by the contractor can be reduced when utilising the D&B method. Examples of such claims are, extension of time claims that can be raised for the delay in the client providing required information or responses for the project. Due to the contractor assuming all responsibility for completing the project within the specified project schedule as well as the responsibility for the design, the potential for these claims are therefore reduced (Davis, Love & Baccarini 2008). Construct only projects can be subjected to delays which can include claims by the contractor to the client for delays in providing design documentation; these claims however are not experienced on D&B projects.

2.2.3 Problems with the use of Design and Build procurement

a. Increased Financial Risks

D&B projects are tendered by contractors with an amount of uncertainty due to the lack of design information available at the time of pricing the project. As discussed in Section 2.2.2, the best performing D&B projects were those with less than 35% of the design completed at the Request for Proposal stage. Contractors can therefore be expected to provide a fixed price for the project, even with a considerable amount of information lacking. In order for the contractor to price the project to remove potential financial risks associated with the project unknowns must be allowed for (Lam, Chan & Chan 2003).

In order for contractors to allow for unknowns, contingencies can be added to the estimate. A contingency or allowance is utilised to provide an accurate estimate for a project where it is known that information is lacking during the tender stage of the project. Peurifoy and Oberlender (2002) highlight that the contingency amount should be determined in collaboration with the estimating team and the project management team to ensure that the correct allowance has been accounted for. Levy (2012) also highlight that the use of contingency within D&B contracts enables the contractor to reduce potential financial risks.

Murdoch and Hughes (2000) identify that a method utilised by clients to reduce the financial risk associated with the D&B method, is to use guaranteed maximum price (GMP). Utilising the GMP method, the price for the project is capped at a predetermined sum. In order to reduce the final cost of the project the client can include incentives that benefit the contractor should the project be completed under the GMP. The D&B method therefore reduces the financial risk for the client as all risk lies with the contractor to complete all design and construction works to achieve the clients' requirements within the agreed contract sum.

b. Increased Design Responsibility

An inherent risk in a contractor undertaking a D&B project is that the contractor assumes all responsibility associated with the design of the project as well as the construction. The increased risk in design responsibility is a direct cause of utilising the D&B method as the design is undertaken by the contractor which includes the accuracy of the design (Kelleher 2005). The contractor is therefore liable for all costs and potential additional time associated with the rectification or modification of works due to errors within the design (Loots & Charrett 2009).

In comparison to the D&B method, Construct only contracts are contracts where the contractor is engaged to undertake only the construction works for the project. The client engages separate design consultants to complete all design works for the project. Therefore in this method, there is no design responsibility for the contractor. Construct only contracts allow for the contractor to claim additional costs for works that have resulted from errors within design (Loots & Charrett 2009).

D&B projects require the contractor to undertake the design of the project and therefore the responsibility of this design component remains with the contractor. The design responsibility also includes an obligation for the design to be fit for purpose. Fit for purpose extends beyond the design being completed without errors, it is an obligation that when the project is completed, it must meet all of the required and intended purposes (Loots & Charrett 2009).

Brierley, Corkum and Hatem (2010) also agree that in the D&B method, the owner is able to assign all risk associated with the design to a single contractor. However it is noted that for this to be an effective method of contracting, the contractor must be given control over decisions made regarding the design. The owner therefore must rely upon the scope provided to the contractor during the request for proposal stage of the project. As discussed in Section 2.2.1 previously, for project success, the clarity of the scope is critical.

A standard form contract used by clients and contractors engaging in D&B projects includes AS4902 from Standards-Australia (2000), which contains contractual clauses that specifically cover the design obligations of the contractor. Specifically Clause 2.2 of the contract includes details of the contractors warranty to carry out the works on the project so as to ensure that they will be fit for their purpose when completed.

A standard form contract AS4000 from Standards-Australia (1997) is used by clients and contractors engaging in Construct only projects where the contractor undertakes only the construction works for the project. This contract contains contractual clauses that specify the requirement for the contractor to complete the works that are agreed as the works under contract. The contract however does not include fit for purpose obligations for the contractor, only the completion of works for the project that are compliant with the design provided by the client.

c. *Timing of Scope Changes*

The advantage of the overlapping of design and construction in D&B projects, can also lead to potential problems when design changes are requested by the client (Lam, Chan & Chan 2003). If a change of design is directed, and the construction works have already commenced in this area the change will also incur rework costs to enable the change to be incorporated into the design. Pricing of variations of this nature can be difficult, due to the incompleteness of the designs, and the inability for the client to understand construction works are further advanced than the completion of the projects design.

Turner, Jung and Hwang (2012) also agree that there is an increase in costs associated with changes to the design requested by the client in the D&B method. The increase in costs can be attributed to the overlapping of the design and construction phases of the project and the addition costs associated with the modification of works already completed.

d. *Overlapping of Project Phases*

As reported by Chang, Shen and Ibbs (2010) in the case study on coordination in five ongoing D&B projects, issues arise in D&B projects when designs are not appropriately coordinated with the construction schedule for the project. Projects can experience delays in the earlier trades in the construction schedule, where construction works are completed onsite however further design documentation is required to be completed to allow the construction schedule to continue. Without the required design, construction works cannot proceed, therefore the project is delayed. Interviews with the contractors of the projects in the case study highlighted that concurrence or overlapping of the design and construction phases is difficult to schedule on the project, and also hard to control. These coordination issues result in delays onsite, and thereby reducing a key advantage of the D&B method.

Murdoch and Hughes (2000) identify that the fast-tracking in D&B projects by commencing construction works prior to the completion of the overall design for the project has advantages in reducing the construction timeframe, as discussed previously in Section 2.2.2. There is however disadvantages when changes are made to the design that affects the construction works already completed. In order to incorporate the design changes, the works already completed need to therefore be changed which increases both time and costs on a project.

Hashem (2005) also agrees that a problem in the D&B method is when the design and construction activities are overlapped so far that the construction works must halt to enable the design to catch up. The error in overlapping has occurred where the commencement of construction works have been scheduled too early in the design phase of the project, so that the design is unable to maintain the required schedule to meet the requirements of the construction team. The solution however is not to remove the overlapping of the D&B phases of the project, because the removal of this overlapping will also remove one of the key advantages of the D&B method.

2.2.4 Constructability of Designs

Constructability reviews should be undertaken in D&B projects as a means to identify areas of the designs that may prove difficult to construct. The input from the construction team in this process enables the design to be reviewed from a construction aspect. This is an area of the D&B method that highlights the significance of the collaboration between the design and construction teams (Cushman & Loulakis 2001).

In a study undertaken by Ndekugri and Turner (1994) it was reported that the utilisation of the D&B procurement method reduced ambiguity in the constructability of the designs. This reduction can be attributed to the increased involvement in the design process by the construction team. Including the construction team in the initial design of the project enables the design team and construction team to work collaboratively in order to achieve the best design for the project in terms of constructability.

Brierley, Corkum and Hatem (2010) also agree that a key advantage of the D&B process is the ability to undertake constructability reviews of the design. A key factor in completing this review is the early involvement of the construction team in the design review. Improving the constructability of designs also aids in a reduction of the construction timeframes. This identifies the importance of the collaboration between the design and construction teams, in ensuring the constructability of designs.

2.2.5 Summary of Design and Build projects

The use of the D&B method provides many advantages to both clients and construction firms. The D&B method enables the client to engage one firm to complete both the design and construction of the project, reducing the contractual responsibility to one firm. This also aids in the reduction of potential claims made by the contractor to the client.

Studies undertaken on the performance of the D&B method have established that projects are able to achieve shorter timeframes than other methods, which can be attributed to the ability for design and construction activities to be undertaken concurrently. In addition to this, studies have identified the improved performance of D&B projects achieving project completion within the specified budget.

While there are important advantages to adopting the D&B method on projects, the D&B method also raises a number of problems for contractors on projects. Contractors undertaking D&B projects can be required to submit a fixed price for the project, when the design has not been completed and therefore there are a number of unknowns. The financial risk then lies with the contractor to complete the project within the specified budget.

Undertaking the design for the project as well as construction requires the contractor to assume all responsibility associated with the correctness and suitability of the design. This differs from other methods, whereby in construct only projects the design liability remains with the client. This liability can have an effect on both the projects budget, and schedule should there be errors within the design that the contractor cannot claim for compensation from the client.

Scope changes can occur on projects that require variations to be priced. The timing of scope changes on D&B projects can affect the cost of these changes. While the design may still be underway, construction works can be commenced which can affect the overall cost of the change.

The overlapping of the design and construction phases of a project enables the project to be completed in a shorter timeframe than utilising other methods. If the overlapping of the phases is not sequenced correctly and the construction phase is commenced prior to the design being completed to a suitable stage, delays can be experienced onsite while the design is being completed. In addition to this, the cost of scope changes can increase due to the advancement of works onsite requiring rework.

Constructability of designs improves the project schedule performance. Construction team input in the design phase of a project provides insight into the construction scheduling of a proposed design. The use of the D&B method improves the constructability review process; however the collaboration between the design and construction teams of a project is paramount to improving the constructability of designs.

2.3 Building Information Modelling in the Construction Industry

2.3.1 Background

Building information modelling (BIM) is a process that has been introduced to the architectural, engineering and construction industry worldwide. While BIM has been a concept available for a number of years, it is only recently that new software has become available for use for the design and construction industry, moving away from the traditional 2D platforms. As reported by Azhar, Khalfan and Maqsood (2012) BIM as an architectural, engineering and construction process has only been adopted by the industry within the last fifteen years.

BIM is used for the design of buildings including architectural, engineering and services which can be incorporated in one model. According to McGraw Hill as cited in Barlish and Sullivan (2012) BIM is 'the process of creating and using digital models for design, construction and / or operation of projects'.

BIM is used for the design of buildings including architectural, engineering and services where all design elements for a project can be incorporated into a single model. As discussed by Barlish and Sullivan (2012) BIM is used for creating a single digital model that is utilised in the design and also the construction of a project. The model can then also be utilised in the operation phase of a project.

The model produced in BIM is a representation of the completed project, rather than traditional 2D drawings, this enables the project team during the design phase of a project to gain a better understanding of the project at completion. In order to realise this success, the use of the BIM model must be used in collaboration with a number of key management strategies such as audits and reviews, appropriate resource planning and educational development. BIM will therefore not solely prevent design errors from occurring, it will however enable the project team to review the project collectively to improve constructability of the project (Love et al. 2011).

The use of 3D BIM software such as Autodesk REVIT according to Howell and Batchelor (2005) enables the incorporation of all architectural, systems and structural elements in a projects model. A key benefit of the BIM model created in Autodesk REVIT is the automation process whereby any change or revision made to the model will automatically update all associated drawings and views.

The traditional method of design, utilising 2D Computer Aided Drafting (CAD) software required that each individual design element of a building had to be produced and revised individually, such as the plans and elevations. For example a change made to the design in the floor plan, also requires that all other views such as the elevations, are manually updated to suit the design change. This process is therefore both time consuming and potentially error prone. In addition to this, the elements in the 2D drawings don't contain any properties regarding the element in view (Azhar, Hein & Sketo 2008).

BIM software includes data and information regarding building elements and can include information such as height, length; wall type, area of the wall element, and whether the wall is load bearing. In addition to this, the model can include information such as the manufacturer of the material. The use of the BIM model therefore is not just for drawings for a project, it can be utilised as a 3D object database that contains the necessary information pertaining to each element within the model (buildingSMART-Australasia 2012). The information contained within the 3D BIM model, is the key aspect that sets BIM aside from other 3D modelling tools. Figure 2.1 on the following page shows an extract from BIM Software Autodesk REVIT from the 3D model for a block wall element included in a building model. When the element from a specific area is selected from the model the properties of the element that are provided, includes the type of block wall, the length of the wall, the height of the wall, the area of the wall and the structural properties of the block wall:

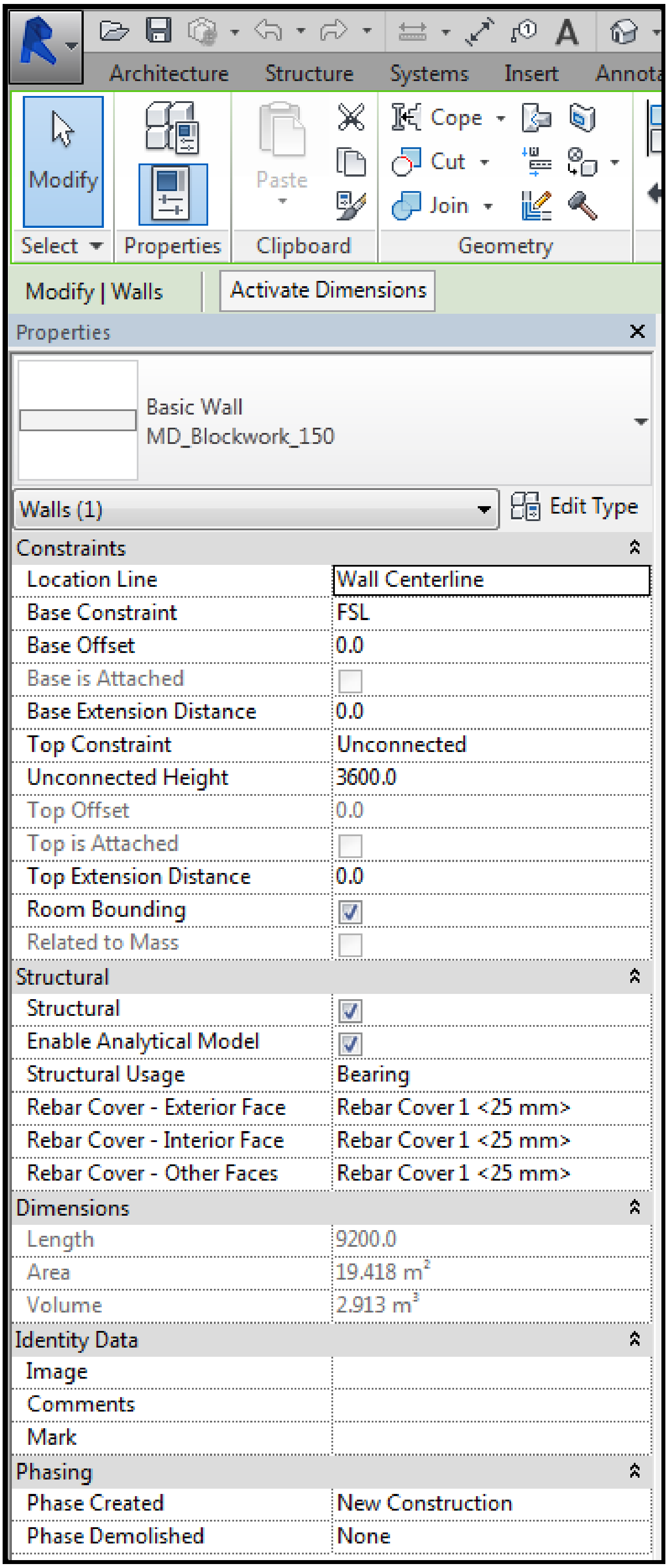


Figure 2.1 - Properties of a building element in Autodesk REVIT (Source - Author)

2.3.2 BIM Tools and Workflows Overview

The growth of BIM in the Architectural, Engineering and Construction industry has also meant changes to the workflow processes on projects. The use of BIM on projects now links all processes in a project which provides a synchronised approach to the management of the project throughout its lifecycle (Weatherford 2014). Rather than each process in the projects lifecycle being undertaken separately, all processes are now linked. The BIM workflow is illustrated in Figure 2.2 below:

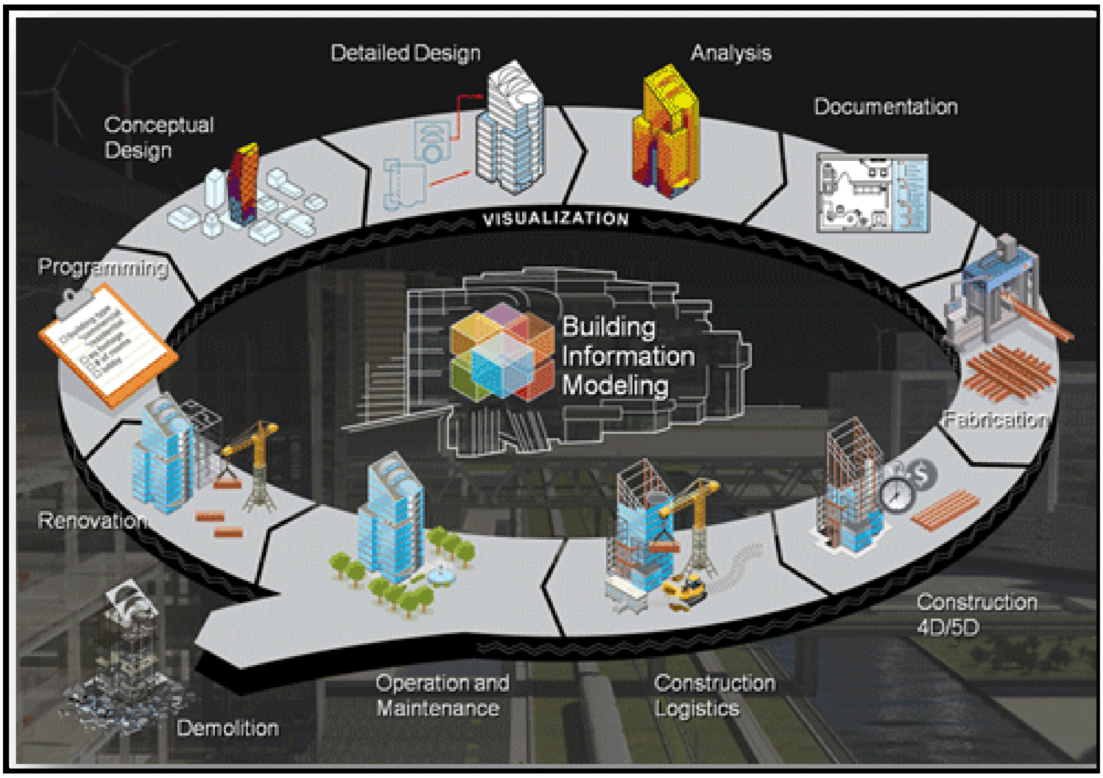


Figure 2.2 - BIM Workflow (Weatherford 2014)

a. Clash Detection

Clash detection is a process of determining potential clashes in design elements, prior to the commencement of works onsite. Prior to the adoption of BIM the methods utilised have been through a combined process of overlaying 2D drawing layers to detect clashes, as well has 3D geometry checks from standard non BIM 3D models and also manual checks. Clash detection in the BIM model however differs from standard 3D model detection, as the design team is able run automatic clash detection in the model utilising predetermined selections. This enables clash detection to be run for example between the electrical and structural systems (Eastman et al. 2008).

In order for the BIM clash detection to be accurate, the BIM model must be a true representation of the project works. A study has been undertaken by Leite, Akinci and Garrett (2009) comparing manual clash detection completed in co-ordination meetings, and the use of automatic clash detection utilising the BIM model. The findings have determined that manual clash detection was able to detect clashes with the cable trays on the project, however automatic clash detection was unable to detect these same clashes as the cable tray was not modelled. The results highlight that if all building elements are not included in the BIM model, manual clash detection will achieve more accurate results.

In contrast to this, the design team on the Aquarium Hilton Garden Inn project that was delivered using the Construction manager at-risk method, implemented clash detection in the design phase. By implementing clash detection the design team uncovered 55 clashes prior to commencing works onsite. The detection of these clashes were estimated to have saved the project $124, 500.00 (Azhar 2011). This highlights the advantages to the use of BIM for clash detection, however the importance for the accuracy and completeness of the BIM model.

b. BIM Collaboration Tools

As a means to resolve the issues faced by project teams that have design and construction teams in different locations, cloud based BIM collaboration has increased in usage. Autodesk BIM360 is one such tool that enables users to upload BIM models for each discipline to the cloud. The models can then be accessed by any team member in any location, either on the construction site or the design office (Hardin & McCool 2015). BIM360 has improved the ability for project teams to utilise the BIM model collaboratively.

BIM products such as Tekla have also established collaboration tools such as Tekla BIMsight that can be utilised as a collaboration and communication tool by multiple design disciplines. For example the tool can be utilised to collaborate the architectural model with the steel detailing model, clash detection can then be undertaken between each of the models. The tool can also be utilised as the central platform for the entire project team to communicate with each of the design models for the project (*What is Tekla BIMsight* 2013).

c. Autodesk Revit Worksharing

The advancement of BIM tools now enable multiple users to be working on a central BIM model file for a project. In order to provide delineations between work zones in the BIM model, BIM tools such as Autodesk Revit establish Worksharing tools. Worksharing is an extension of the collaboration tools, where the 3D BIM design model can be modified simultaneously by multiple users (Vandezande, Read & Krygiel 2012).

d. BIM and Project Lifecycle Workflows

Recent advancements in BIM have seen the BIM model used in new dimensions, surpassing 3D. 4D BIM is a tool that is utilised in collaboration with the 3D BIM model, by the project management team to incorporate scheduling information into the BIM model. The 4D BIM model can be utilised to visualise the schedule of the project prior to commencing works onsite through simulating the construction sequence (Mubarak 2015). 4D BIM is further discussed in Section 2.4.

5D BIM tools are utilised to incorporate cost elements for a project into the 3D model. The 5D BIM model can be utilised to undertake project cost analysis and cost management for the project. New dimensions are able to be added to the BIM model; therefore as the BIM model progresses to the fifth dimension the cost information is added. BIM models created by the separate 4D and 5D BIM tools and used in collaboration with the 3D BIM model are considered part of the overall BIM model for the project (Mubarak 2015). Figure 2.2 provides an overview of each of the functions in nD BIM:

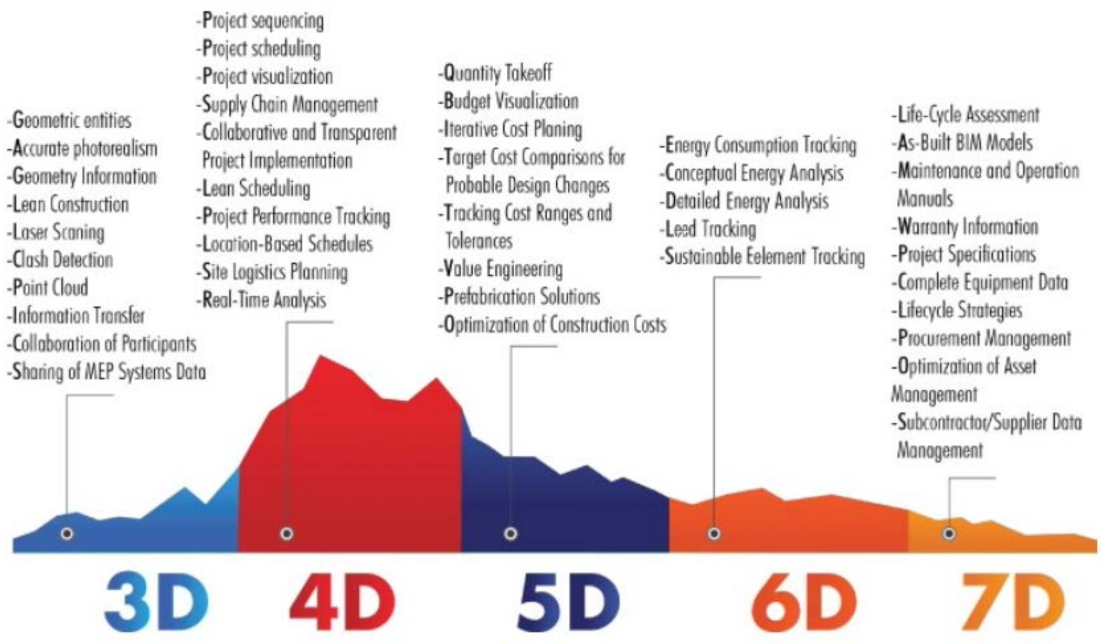


Figure 2.3 - – Summary of functions of nD BIM (Mubarak 2015)

As can be seen in Figure 2.3, additional BIM dimensions are now emerging past 4D and 5D. Due to the early stages of use of the BIM model for these dimensions there are no case studies available examining the performance of these tools, furthermore, there lacks consensus in the literature regarding their use as either sustainability or lifecycle management. As shown in figure 2.3 Mubarak (2015) allocates BIM 6D for use in sustainability, and BIM 7D for facilities management.

In contrast, 6D BIM software is available for use in lifecycle management. The 6D BIM model can be used to replace handover documentation provided to clients at the completion of the project. The model can contain all necessary data pertaining to the operation of the completed facility, and specifically details for each room of the new facility (*6D BIM Models* 2015).

e. Third Party BIM tools

The 3D BIM model is integral to the BIM process and can be considered the authoring tool in the workflow. Third party BIM tools enable analysis of the 3D BIM Model by parties within the project team. The 4D BIM and 5D BIM tools are therefore analysis tools that a distributed environment enables the use of separately from one another. 4D and 5D BIM tools are also therefore considered third party tools in the BIM workflows. The 3D BIM model is able to extract data specifically for the use in each of the analysis tools (Young Jr., Jones & Bernstein 2008). Figure 2.4 shows the integration of the central BIM 3D Design Model with BIM analysis tools:

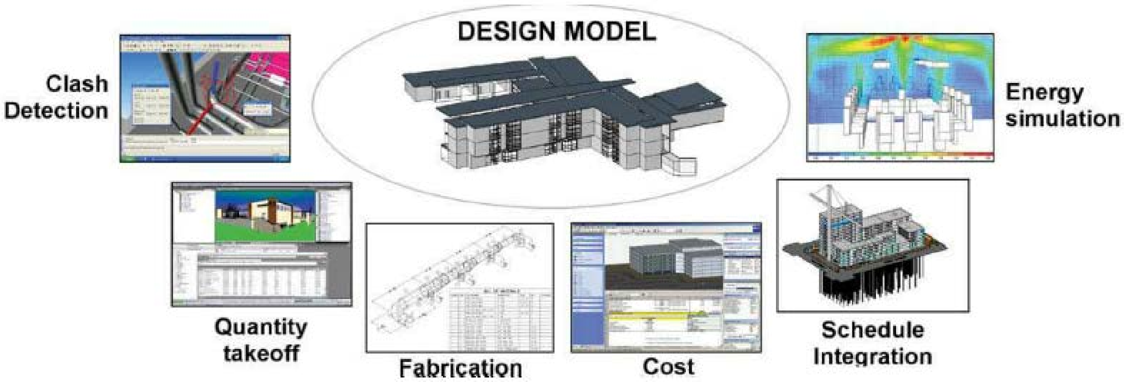


Figure 2.4 - Enabling applications extract data from design models and provide valuable analysis and simulation (*BIM Building Information Modeling A Supplement to New York Construction*)

2.3.3 BIM Global Adoption Strategies

Various authorities around the world have taken steps to increase the usage of BIM on projects, with a goal to improve construction industries. These strategies include mandates implemented by various government departments, as well as government agencies. These strategies indicate that the construction industry worldwide is acknowledging that BIM usage on projects provides a considerable advantage.

A summary is provided of a select number of countries and the strategies that have been implemented.

a. *United Kingdom (UK)*

A country at the forefront of BIM adoption in the construction industry is the United Kingdom (UK). The government has identified the use of BIM to be a key tool to streamline the design and construction process. If team members work from the compatible systems construction costs can therefore be reduced, the Government of the United Kingdom has implemented requirements for the use of BIM on Government funded construction projects, which requires that the use of BIM must include fully collaborative 3D Models by 2016, which is Level 2 BIM (*The Government Construction Strategy* 2011).

There are a number of maturity levels that are used to describe BIM use in the United Kingdom, and the level of detail that they are used for. The use of the levels enables the construction industry to work towards targets with the goal to achieve BIM compliance. The levels are as follows (*BIM levels explained* 2014):

Level 0 BIM – BIM used in this level is limited to 2D CAD drafting, and uses no collaboration between the design teams.

Level 1 BIM – BIM used in this level includes 3D CAD and also 2D CAD, however there is again no collaboration of data between different disciplines. The model used in this level also contains no additional information, they are simply design models.

Level 2 BIM – the key aspect to this level of BIM is the collaboration between each party, and the sharing of the 3D models. Each discipline such as fire services, mechanical services, architectural and structural continues to use their own model, however through the use of common software; the files are able to be shared. The common software that the BIM model must be compatible with is Industry Foundation Class file formats and Construction Operations Building Information Exchange file formats. The use of these file formats enable the project team to combine the data from each of the building models in order to undertake evaluations of the models. This level of BIM also enables the use of 4D and 5D BIM.

Level 3 BIM – the usage of BIM in this level requires full collaboration between all disciplines, including the usage of a single shared model. This enables all disciplines to have access to the shared model, with the ability to modify as required. This level of BIM will also utilise the 4D and 5D BIM aspects of time and cost, which are described later in the literature review.

A BIM maturity model has been created, as a means to provide clarity and also define the Levels of BIM maturity from 0 to 3. The model provides a delineation between each of the levels, showing Level 0 as CAD only, with paper based tools. Level 1, as discussed, introduces 2D and 3D CAD usage, with file based collaboration tools. Level 2, which is the current target for 2016, introduces BIM and Library Management to the maturity level. The future, Level 3 is a fully integrated BIM model utilising a web based BIM Hub. It is this maturity level that introduces Lifecycle Management to the BIM model (*A Report for the Government Construction Client Group: Building Information Modelling (BIM) Working Party Strategy Paper* 2011). The model is shown in Figure 2.5 on the following page.

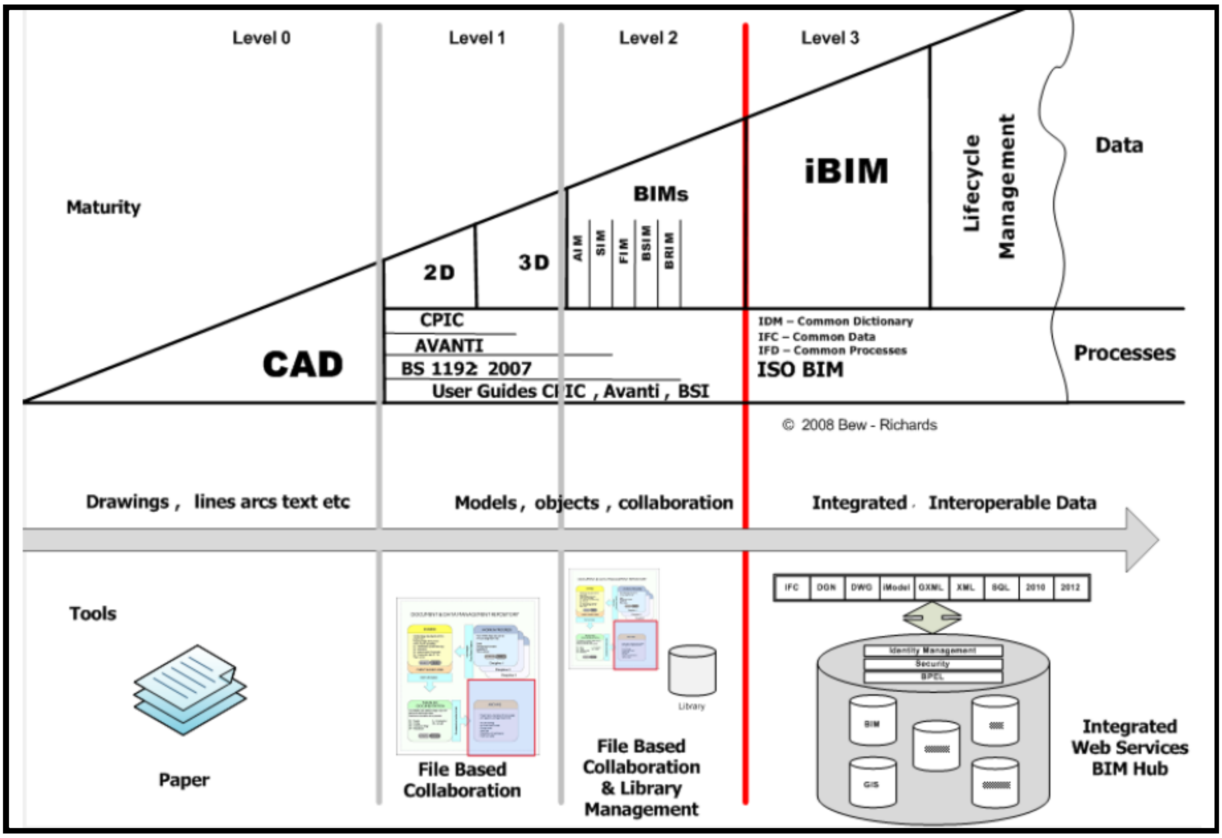


Figure 2.5 - BIM Maturity Model (*A Report for the Government Construction Client Group: Building Information Modelling (BIM) Working Party Strategy Paper* 2011)

The mandate adopted by the UK has seen an increase in BIM usage in the years from 2010 through to 2013, from 13% to 54%. Furthermore, for those organisations utilising BIM, 51% have achieved Level 2 BIM and 7% have achieved Level 3 BIM (*NBS National BIM Report* 2014). UK owners have also been drivers in increasing BIM adoption in the construction industry with a report completed in 2014 identifying that over 65% of owners in both the public and private sector require BIM to be utilised on their projects (*SmartMarket Report The Business Value of BIM for Owners* 2014). This highlights that owners have also identified with the advantages that the BIM mandates will bring to the industry. The mandates are therefore considered a successful strategy in increasing BIM adoption in the construction industry.

b. United States of America

The General Services Administration (GSA) in the United States of America is an agency that provides management to large number of property and construction for the United States Government. In 2003 the GSA implemented the mandatory requirement for 3D models to be utilised in the design phase of all projects that they funded. While the mandatory requirement is for 3D models there is also the expectation that the that the use includes the 4D time parameter also (Zeiss 2013).

The national 3D-4D BIM program was implemented to enable the GSA to provide better management techniques to meet the requirements for the construction projects. The policy has been established as a requirement for BIM to be utilised on all major projects completed for GSA. In addition to this, a requirement of the program is for BIM deliverables at each milestones of the project. A highlight of the GSA program has also been the implementation of a BIM Guide series to be followed (*3D-4D Building Information Modeling* 2015).

In contrast to the UK, BIM adoption in the United States has not been widespread for either owners or organisations. The findings of a report published on the owners requirements for BIM usage on projects in the United States, has identified that only 30% of public and 11% of private owners require BIM to be utilised on the projects (*SmartMarket Report The Business Value of BIM for Owners* 2014). This is significantly less than the UK, and can be attributed to the policy, not mandate, being specifically adopted on GSA projects, with a lack of a widespread mandate being imposed on the industry.

c. Singapore

Singapore is another country that has identified the potential advantages to improve productivity in the construction sector, through the implementation of BIM. Leading the way in the adoption strategies was the Singapore Building and Construction Authority (BCA) which is a department of the Singapore Government. 2010 saw the introduction of a BIM Roadmap, that set out a goal to increase the number of BIM users to 80% in the construction industry by 2015 ('*All Set for 2015: The BIM Roadmap*' 2011).

Mandates have been established in Singapore as a means to aid in the increase of BIM users. By the year 2013, all projects over 20000m2 were required to undertake Architectural BIM model e-submissions for all required regulatory approvals. In July of 2014, this increased to include Engineering BIM models for e-submission for projects over 20000m2. In July 2015, this again increased to require all BIM model e-submissions for projects with a Gross Floor Area over 5000m2 (*BIM Factsheet* 2013).

The Singapore Government has implemented a number of measures in order to promote and also support the adoption of BIM in the construction industry. These have included BIM competitions, seminars and also BIM manager forums. In addition to this, BIM guides and standards have also been published. This has led to an increase in the usage of BIM by organisations, with the findings of a survey undertaken on BIM usage in Singapore organisations showing between the years 2009 to 2013 there was a growth from 25% to 76% (*SmartMarket Report The Business Value of BIM for Owners* 2014)

A further example of the Singaporean Government's move to increase BIM adoption in the construction industry is the establishment of a BIM fund that is utilised to support firms to improve collaboration capabilities. The fund can be used to cover training costs, consultancy costs, software and hardware, in an effort to reduce design errors leading to additional rectification costs (*Technology Adoption: Building Information Model (BIM) Fund V2* 2015).

d. Australia

The adoption of BIM in Australia has somewhat lagged behind other countries. Smith (2014) has reported that the adoption of BIM in Australia has been limited in comparison to other regions. While there has been an increased interest in the adoption of BIM in Australia through the implementation of initiatives, the Australian Government has not yet moved to introduce any BIM mandates to the construction industry.

A report on the adoption of BIM by Australian organisations identified in the year 2014 that approximately 50% of BIM users were utilising BIM tools on projects. Furthermore, the report established that of the BIM users, only 30% were utilising 4D and 5D BIM on projects. The predominant usage of BIM in Australia remains largely with engineering and architecture firms, rather than contractors (*SmartMarket Report The Business Value of BIM in Australia and New Zealand* 2014)

While there have not yet been any government mandates introduced in Australia, there has been significant moves to aid in the adoption of BIM in the construction industry. The National Specification System of Australia (NATSPEC) National BIM Guide has been produced in an effort to provide clarity to the all members of the project team of the BIM requirements for the project and also standardise the adoption of BIM on projects (*NATSPEC National BIM Guide* 2011). The BIM guide has been established in order to provide a standard on how BIM should be adopted and managed by the project team on a project. This includes establishing the BIM management plan, which defines the modelling considerations specific to each project, the responsibilities that are assigned to the Design Team BIM Manager, the author control of the BIM model, and the standards for the collaboration between the project team members with the BIM model. The BIM guide also provides standards on how the BIM file storage folders should be structured, to enable efficient use of the project files.

As a means to facilitate the adoption of BIM in the Australian Industry, a framework has also been established. The framework has identified a number of objectives to be utilised as a guide to further improve the adoption of BIM. The purpose of the framework was a method of resolving Australia's fragmented approach to BIM adoption in Australia (*A Framework for the Adoption of Project Team Integration and Building Information Modelling* 2014).

2.3.4 BIM Contractual Challenges

The increase in BIM adoption has also seen a need for the review of the legal implications associated with its usage. The use of collaborative BIM models, introduces multiple parties that contribute to the BIM process. Therefore in the event of inaccuracies in the design model, identifying the responsible party can be difficult (Azhar 2011). A point of responsibility should be established, and the contractual clauses resolved, prior to the use of BIM technologies on projects.

The advancement of the 3D BIM model to 4D and 5D, also introduces the requirement to identify the responsibility for the accuracy of the information produced with regards to the cost and scheduling information produced by the BIM model (Thomson & Miner 2006). The design parties are responsible for the 3D design BIM model; however the

4D and 5D BIM models can be produced by the project management team, or the estimating team for the project. A contractual assessment must therefore be made prior to the commencement of projects intending to utilise BIM tools such as 4D and 5D on projects.

Ownership of the content in the BIM model is also a contractual aspect to be considered for projects utilising BIM. The BIM model contains not only the design for the project, but a significant amount of content that the design team has developed. Content includes the model elements, as well as the model information. Furthermore the owner pays for the design of a project, with an expectation of ownership of the design. A delineation must therefore be established between the design and the content contained in the BIM model, and which party should retain ownership of this information (Azhar, Khalfan & Maqsood 2012).

2.4 Building Information Modelling (4D – Time)

2.4.1 4D BIM Overview

Construction scheduling is used as a means to define the construction sequencing of a project. A number of tools are available to produce project schedules such as Primavera and Microsoft Project. The use of 4D BIM in project scheduling is a process of integrating the projects schedule, with the BIM model (Hardin & McCool 2015). BIM tools are then able to produce animated videos of the projects construction schedule.

The 4D BIM model is not simply a visualisation tool. The simulation of the project schedule, enables a review of the projects schedule visually, however it contains information relating to the projects schedule, as well as projects resources requirements and quantities (Mubarak 2015). As discussed previously in Section 2.3.2 (e), the use of 4D BIM is reliant upon the information contained in the central 3D BIM model. The results of the third party 4D BIM tools are reliant upon the accuracy of information contained within the 3D BIM model.

2.4.2 4D BIM Advantages

Utilising the traditional CPM method of scheduling and 2D drawings the user is required to schedule the project based on their conception of the building components, which in turn could be interpreted in a different manner by a different reader of the schedule or drawings (Jongeling & Olofsson 2007). With the utilisation of 4D BIM, the sequencing of the activities in the schedule are identified should they be out of sequence, or missed from the schedule all together enabling the user to rectify the schedule during the planning stages. In addition to this the utilisation of construction sequencing and simulation ensures that logic in the sequencing is understood (Koo & Fischer 2000).

As reported by Mukherjee and Clarke (2012) the use of 4D scheduling in construction planning, aids in the ability to visualise the construction sequence prior to commencing construction of the project. The benefits of utilising the 4D model include, improving the scheduling, improving communication and coordination between all stakeholders in the project and improving the use of resources on the project.

Hartmann and Fischer (2007) have reported that one of the main benefits to utilising 4D models is during the constructability review process whereby site constraints and construction challenges can be identified and resolved prior to commencing works onsite. In addition to this it aids in the scheduling of projects due to the ability to view the schedule at certain time periods. The 4D model aids the construction team to undertake collaborative meetings based on the scheduling of the project. The case study of the Fulton Street Transit Centre (New York) as quoted by Hartmann and Fischer (2007) utilised 3D/4D models in order to evaluate different designs and schedules which helped to reduce disruption to traffic around the site.

The case study undertaken by Haymaker and Fischer (2001) that investigated the use of nonspecific 4D BIM software on the Walt Disney Concert Hall project, found that the utilisation of 4D models improved scheduling on projects through improving the creation and analysis of the projects schedule, communication to project team members and team building on the project. Challenges that were encountered however were in the creation of the 4D models and the linking of the schedules to the 3D models, which was attributed to the creator of the 3D model not taking into consideration the requirements of the 4D model.

In a survey undertaken by Gledson and Greenwood (2014) 122 respondents were asked multiple questions on the implementation and use of 4D BIM in organisations. Q22 of the questionnaire asked the respondents whether the implementation of 4D planning in lieu of the traditional planning methods would improve the construction processes, with response categories being visualising construction processes, work winning, improvement of location based planning and validating the projects time schedule. The respondents answered in each of the categories that there would be significant improvements.

Hartmann, Gao and Fischer (2008) have also reported in the case study of 26 projects using a variety of nonspecific 4D BIM software that models that are applied in the construction phase of a project benefits in the fast tracking of construction and design, the coordination of contractor and management of site constraints and the management of schedule constraints. The study also found that the project managers primarily used the model for the planning of the construction operations on site prior to the commencement of construction works.

2.4.3 Overview of available 4D BIM Software

e. Autodesk Navisworks Manage

Autodesk Navisworks Manage (Navisworks) is an activity based scheduling software that enables the user to combine the project schedule with the 3D model for the project. *Navisworks - Project planning and review software for AEC professionals* 2015) have stated that the use of Navisworks Manage enables the user to undertake the scheduling of the project either within the software or imported for programs such as Oracle Primavera, Microsoft Project or Microsoft Excel. Firstly the 3D BIM model is completed, and then using the Timeliner function in Navisworks the 3D model is linked to the schedule, a simulation of the project can then be generated to show real time construction of the project.

Mukherjee and Clarke (2012) have reported that one of the main benefits of using Navisworks software is the ability to import 3D models from a range of software packages, including Revit, AutoCAD and Bentley. The schedule that is to be used for the project however should be completed when the model is at 70-80% completion.

Eastman et al. (2008) have stated that Navisworks Jetstream Timeliner Software has the function to be able to automatically and manually link tasks from the schedule to the elements of the building model, which can benefit the project by giving the user the ability to modify the schedule to determine the best sequence of tasks for the project. The sets of building elements that have been established, has the ability to then be attached to the projects schedule in the Timeliner window through the drag and drop function.

The case study of the University of Colorado Denver Health Sciences Center Research 2 highlights that the use of BIM and more importantly Navisworks, enabled the project to be completed 6 months faster than a similar sized project previously completed by the company. The delivery method for this project was Construction Manager and General Contractor (*Mortenson Construction - Using Autodesk BIM Software Solutions, Mortenson Construction delivers projects faster and more cost-effectively* 2015).

Staub-French and Khanzode (2007) reported that the utilisation of Navisworks software on the $100 Million Camino Medical Group Medical Office Building Project in California, enabled the construction team to gain a better understanding of the sequence of works to be undertaken onsite prior to commencement. In addition to this the use of the 4D model enabled the sequence of works for each of the subcontractors' onsite to be established and defined, ensuring that there was no loss of productivity.

There are no case studies within the literature on the use of Navisworks software on construction projects undertaken by medium sized D&B companies. Previous research has focussed on the use of Navisworks on large scale projects; there is no consensus within the literature providing quantifiable results for understanding the advantages to implementing Navisworks in The Organisation.

f. Vicosoftware Schedule Planner

Vico Software's Schedule Planner software utilises the flow line theory or Line of Balance by utilising the quantities and data extrapolated from the 3D BIM model and applying a sequencing logic (*4D BIM Scheduling* 2015). Rather than utilising external scheduling software and importing to the 4D software, this software incorporates crew sizes, productivity rates and geography-specific pricing to each of the building elements. The software enables the user to define specific locations within the model, with these locations and the building elements within the locations then linking to the schedule. The benefit to this software is the ability to produce flow line schedules to determine the uninterrupted workflow for the trades on the project. Once the schedule has been completed Vico Software can produce a 3D simulation of the project.

Morkos et al. (2012) have reported that the utilisation of the Vico Office Suite of software enables the user to make changes in one module of the software that will automatically change another module, for example should any changes be made to the rates of production in a specific task; the schedule duration will automatically be updated. The findings of the case study presented by Morkos et al. (2012) into the productivity of 4D modelling tools show that on the LPCH Hospitals Utilities Tunnel project, which was a $17 million project that was initially modelled in Revit Architecture 2012 a 4D model using the Vico Office Software was able to be produced and visualised in approximately 5 hours and 26 minutes.

g. Synchro Pro

Synchro Pro is an activity based scheduling software that *Product Overview – Synchro PRO: Advanced Construction Project Management (2015)* states has the ability to complete the scheduling either within the software or imported from either Oracle Primavera, Microsoft Project, Microsoft Excel, PMA Netpoint or Asta Powerproject. The software allows for the 3D model to be imported from a number of CAD platforms including the Autodesk Revit 3D Model. Tasks from the schedule can be linked to the model via a "Drag & Drop" function. Once the tasks have been assigned to the model the 4D Simulation can be played back with multiple views of the 3D model.

The findings of the case study presented by Morkos et al. (2012) into the productivity of 4D modelling tools show that on the LPCH Hospitals Utilities Tunnel project, which was a $17 million project that was initially modelled in Revit Architecture 2012 a 4D model using Synchro Pro was able to be produced and visualised in approximately 6 hours and 14 minutes.

A case study is being undertaken on the Marina Heights Highrise Project that is currently under construction in Arizona by Ryan Companies. Synchro scheduling software for scheduling as well as collaborating with subcontractors and also implementing lean construction methods with the schedule is estimated to be compressing the construction schedule by 4 weeks for every six months that the project is under construction (*Ryan Companies - Marina Heights "Synchro + Lean = Predictable Outcome"* 2015).

h. Innovaya

Innovaya Visual 4D Simulations is an activity based scheduling software that improves project coordination through linking any 3D model that can be saved in a DWG file, with most traditional scheduling software such as MS Project or Primavera. The tasks within the schedule are colour coded enabling the viewer of the simulation to identify any possible conflicts in the schedule (*Innovaya Visual 4D Simulation* 2010). The literature review has been unable to establish any unbiased case studies utilising this BIM tool.

i. Common Point 4D

Heesom and Mahdjoubi (2004) have reported that Common Point 4D software is a scheduling simulator that utilises schedule data that can be produced in Primavera or Microsoft Project. This schedule along with the 3D model file is then linked in the 4D BIM model. A simulation can then be produced Eastman et al. (2008) also report that Common Point 4D software features a drag and drop feature whereby tasks in the schedule can be linked to the elements of the model manually or they are also able to be linked automatically.

The case study of the Cultural Centre in Lulea Sweden by Jongeling and Olofsson (2007) utilised the Line of Balance diagrams with Common Point 4D. Once the scheduling was completed, it enabled errors in the scheduling of resources to be uncovered, which were not uncovered by simply using the Line of Balance diagram. Once the errors in the diagram were found, the tasks were rescheduled with the re-simulation of the 4D model. By doing this, potential delays onsite due to scheduling conflicts were mitigated.

2.4.4 Summary of 4D BIM

There is significant evidence in the literature that highlights the advantages to adopting 4D BIM on construction projects. A key finding of the literature review on the D&B method was the importance of the constructability of the designs, and the coordination between the design and construction teams in an organisation to achieve this. The case studies presented on projects that have adopted the use of 4D BIM has improved the review of the constructability of projects, improving collaborative scheduling of projects and also reducing timeframes on projects.

There are currently a number of 4D BIM tools available, however the case studies presented provide insufficient quantitative results on the benefits of implementing a specific tool to enable an informed decision to be made on which tool an organisation should select.

The focus of previous research has been the advantages of the use of 4D BIM tools on large scale projects. Case studies on the use of 4D BIM tools to manage and resolve key issues faced by medium scale D&B contractors have not previously been undertaken. The goal therefore for this study will be to adopt a 4D BIM tool, Navisworks Manage, and undertake a case study to determine the feasibility of managing and resolving key issues faced by medium scale D&B contractors.

2.5 Building Information Modelling (5D – Cost)

2.5.1 5D BIM overview

5D BIM is a process of including cost information into the 3D and 4D BIM models, to create the fifth dimension. 5D BIM utilises the information contained within the 3D BIM model, with regards to material quantities and specifications and combining it with cost estimations (Mubarak 2015). As discussed previously in Section 5.3.2 (e) the third party 5D BIM tools are therefore reliant upon the information contained within the central 3D BIM model.

The overall 5D BIM model includes the 3D model, as well as the 4D model and the 5D element of cost data for a project enabling estimating to be undertaken (Bryde, Broquetas & Volm 2013). This additional information that is used in collaboration with the 3D BIM model enables the project management team to review different design scenarios and the effect that they may have on both the schedule as well as the cost for the project.

2.5.2 5D BIM Advantages

The use of 5D BIM on projects provides benefits to project managers. According to Forgues et al. (2012) the use of 5D BIM will enable the project team to undertake estimate comparisons throughout the lifecycle of the project. The BIM model allows the user to assign additional information to each object within the project such as the type and cost of the materials in the element.

One of the key elements of the 5D BIM model is the ability to produce instantaneous estimating take offs that can be utilised in costing (Hartmann et al. 2012). This is also reported by Mitchell (2012) as a significant advantage of utilising 5D BIM as the Quantity Surveyor can produce cost take-offs at any stage in the project, enabling different scenarios to be produced and priced to achieve the optimum project within the required budget. Throughout the Design Phase of the project, estimates can continually be completed to ensure that the design is remaining within the budgetary parameters.

Once the required links have been established between the 3D BIM model and the 5D BIM model ensuring that the required information can be extracted from the model, 5D BIM can also be used advantageously for pricing of variations or reviewing any value engineering options that are requested by the owner. The benefit to utilising 5D BIM is that these issues arise when time is of the essence in the project and therefore the estimate updates can be produced almost instantaneously (*Reaching Target Project Costs with 5D BIM Estimating* 2015). The use of the 5D BIM model could therefore be used to alleviate the problems faced by D&B organisations in the pricing of variations that arise during the design phase, when construction works have commenced onsite. The use of 5D BIM is also able to be used to review alternative solutions that can aid to reduce the increased costs associated with changes made in the D&B method.

The results of case studies undertaken by Hartmann, Gao and Fischer (2008) have shown that utilising the 3D models for cost estimating purposes has enabled time savings in the estimating process of 80%, while still achieving an accuracy of within 3% of the detailed estimates. The use of the 3D models as part of the cost estimating process is reportedly much more accurate that the traditional estimating with 2D drawings.

2.5.3 Available Software Packages

a. Exactal CostX

Exactal CostX (CostX) is an estimating software that as reported by *CostX is a Fully Integrated 2D and 3D Estimating Software* (2015) is a 3rd party software that is able to use the 3D BIM model produced by a number of software packages, including Autodesk Revit. Once the 3D BIM model is imported into CostX, the software can automatically read from the model to produce a Bill of Quantities. The workbooks contained in CostX can include in built rates that are taken from a set database, or the rates can be added to the workbook manually.

As reported in *How Collaboration delivered on a Huge Hospital Project* (2013) the use of Exactal CostX on the $1.8 Billion Sunshine Coast Public University Hospital, enabled the project team to produce quantity measurements at various revision stages within 1 – 2 weeks using between 2 and 4 Quantity Surveyors. Using the traditional industry practice of 2D workflow would require approximately 4 – 8 weeks and 15 to 20 Quantity Surveyors, therefore the use of CostX saved the project considerable time and cost. Time and uncertainty was also removed for the projects Subcontractors, whereby a CostX viewer containing all recent information from the 5D BIM model was provided to the subcontractors of the project after any changes were made. In doing this, it ensured that the Subcontractors were able to price the changes accurately, rather than including any contingency for risks due to the difficulty in identifying the changes.

Figure 2.4 on the following page shows an extract from the 5D model showing that any changes to the model are easily identified by showing any areas that are revised, deleted or new:

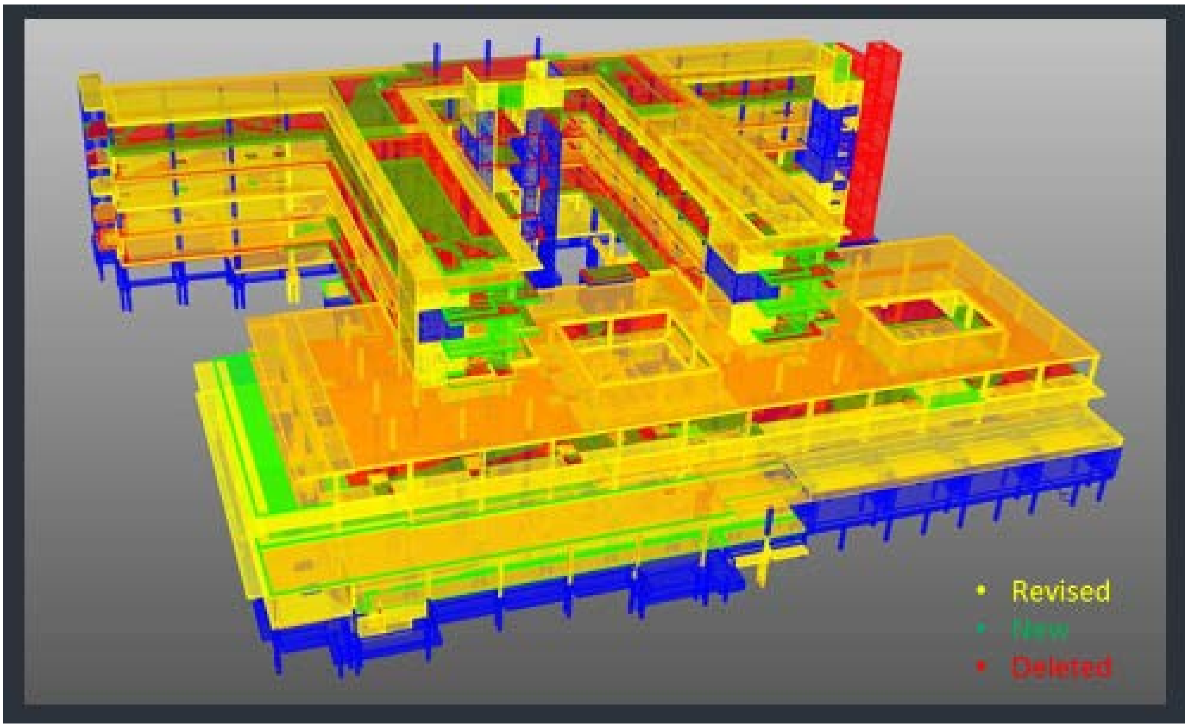


Figure 2.6 – ***How Collaboration delivered on a Huge Hospital Project (2013)***

b. Vicosoftware 5D BIM

The Vico Office suite of software including Vico Take-off Manager and Vico Cost Planner enables the user to utilise the 3D model to undertake quantity take-offs and estimating. Rather than the estimator undertaking the take-off, the software is able to read the quantities from the 3D model. Advantages to this software is the ability to differentiate between the Net Volume which can be a wall element that excludes the volume of a window opening and Gross volumes which can be a wall element that includes the volume of the window opening in quantity take-offs, as well as the ability to integrate the 5D model with the Vicosoftware 4D model to determine the labour that is required for each task (*5D BIM Estimating* 2015).

c. Innovaya Visual 5D Estimating

Innovaya Visual Estimating is estimating software that as reported by *Innovaya Visual Estimating (2010)* utilises 3D BIM models in order to undertake quantity take offs to import into estimating software such as MC2 ICE and Sage Timberline. This software does not contain the workbooks with the projects estimates, however does contain the 3D model with required information.

a. Autodesk Navisworks

Autodesk Navisworks (Navisworks) differs from each of the previously discussed BIM tools, because the primary purpose of the software is not to undertake cost comparison or estimates of the BIM Model. A key advantage however for of Navisworks is the ability to load both cost and time information into the project schedule as a means to improve project analysis. The software however cannot utilise the BIM model to undertake cost analysis, the primary focus is scheduling (*Navisworks Features* 2015). The time and cost information is imported into Navisworks from external software.

2.5.4 Summary of 5D BIM

There is evidence in the literature of the benefits of the implementation of 5D BIM on projects. 5D BIM can be utilised as a tool to aid in cost control during the design phase of projects, due to the ability to produce cost estimates in very short periods of time. Rather than utilising 2D drawings, the 3D model is able to export the required quantity take-offs to the estimating software. The speed, in which an estimate is able to be undertaken, enables the user to be able to undertake a comparison on a number of scenarios which ensures that the most cost effective method can be chosen.

Research has identified that 4D and 5D BIM tools are primarily separate tools that work in collaboration with the 3D BIM model. The 5D models direct link is the 3D BIM model, which is considered the authoring tool. The cost information extracted from the 5D model can then be utilised in the 4D model such as Navisworks to aid in cost scheduling, creating the overall 5D BIM model.

The focus of previous research has been the advantages of the use of 5D BIM tools on large scale projects. Case studies on the use of 5D BIM tools to manage and resolve key issues faced by medium scale D&B contractors have not previously been undertaken. The goal therefore for this study will be to adopt a 5D BIM tool, Exactal CostX, and undertake a case study to determine the feasibility of managing and resolving key issues faced by medium scale D&B contractors.

2.6 The Implementation of Building Information Modelling

2.6.1 Implementation of BIM in an Organisation

It has been suggested by Oakley (2012) that in order to successfully implement BIM in an organisation, time should be taken in the implementation by trialling only a small number of projects specifically chosen. By doing this, it will prevent BIM overwhelming the organisation and ultimately failing in the implementation. This research project will therefore aim to adopt 4D and 5D BIM technologies to one project, engaging a select number of members from the projects team to ensure successful implementation.

A Framework for the Adoption of Project Team Integration and Building Information (2014) also specify that the successful adoption of BIM needs to be led by the Senior Managers of the Organisation, recognising that BIM should be used not only for a design tool but collaboration tool for the organisation.

Another point made by *The route to BIM in 10 Steps* (2015) is to have a clear understanding of where the organisation is operating at prior to implementing any BIM tools. The will ensure that the adoption of BIM will enable the organisation to continually move forward.

By initially undertaking a historical case study as discussed in the Methodology section, a clear guide will be provided on the performance of the organisation prior to the implementation of the BIM 4D and 5D tools. This will ensure that clear goals can be established on what the organisation is to achieve when the BIM 4D & 5D tools are implemented. The implementation of BIM on a single case study project will also ensure that only select members of the organisation are initially involved in the use of the tools. Based on the success of the tools, further projects and teams can be chosen for implementation.

2.7 Literature Review Summary

The aim of the literature review was to examine problems faced by D&B contractors, furthermore to evaluate currently available BIM software focussing on the integration between the 3D BIM model and 4D and 5D BIM tools and the advantages that the BIM tools provide. Although widely regarded as a successful method of contracting, D&B contractors still face challenges in completing projects successfully. The utilisation of BIM tools has proven advantageous on projects; however the main focus to date has been large scale projects and not specifically D&B. There lacked a consensus in the literature on specific BIM tools, and which tools provided the most benefit to an organisation.

There is an advantage to the utilisation of the D&B method, with the research establishing its benefits in maintaining the budgets and achieving the project schedule Molenaar and Songer (1998). Studies undertaken on projects completed utilising the D&B method have identified an improved performance in achieving completion either within the projects schedule, or improving the projects schedule when compared to the Design-bid-Build method. The use of the D&B method also provides significant advantages in terms of the projects budget performance, with projects able to be completed either within budget or improving the budget.

While there are a number of advantages to utilising the D&B method, the findings from the literature review has also established that organisations face a number of problems when the D&B method is used. Contractors are required to price D&B projects, often with limited information which therefore requires unknowns to be allowed for during the tendering process.

The D&B method of contracting requires the contractor to undertake the design for the project. The contractor also has an obligation to assume the responsibility for the design, ensuring that it is both correct and fit for purpose. Errors or omissions in the design are therefore the responsibility of the contractor to rectify. In the event that rectification works are required to modify or correct the design, both cost and time delay claims from the contractor are excluded.

The overlapping of the design and construction phases in D&B projects provides significant advantages to both contractors and clients. The phases can be overlapped in order to reduce the construction timeframe on projects. A problem for contractors identified in the literature was the result that the overlapping of the project phases has on the costs for scope changes. The costs for design changes, whether client or contractor directed can increase based on the timing of the change, due to construction works having already commenced.

An area of great importance identified in the use of the D&B method was the constructability of the designs. A contributing factor of the constructability is the co-ordination between the design and construction teams for the project. While a design may be error free, the ease of construction of the design is imperative in ensuring project success. Due to the contractors increased design responsibility, it ensuring that projects can be completed both on time and also within budget can be improved if the constructability of the designs is also improved.

A summary of the findings from the literature review into the D&B method have identified a number of key areas to be further examined as part of this research project, and they are summarised in Table 2.1. The interview guide included in Chapter 3, section 3.4 is based on the contents of this Chapter:

Table 2.1 – Key Findings of D&B Literature Review

1	Budget and project timeframe improvements using the D&B method
2	The importance of the co-ordination between the design and construction departments in the D&B method to improve constructability
3	Reduction of claims when the D&B method is used
4	Financial risks associated with the use of the D&B method
5	Increased design responsibility associated with the use of the D&B method
6	Overlapping of the design and construction phases and the effect on scope changes

The utilisation of BIM within the construction industry is not a new process, with previous case studies and research highlighting the many benefits for the use of BIM tools. There are currently a number of 4D BIM tools available for organisations to adopt, however there is insufficient unbiased quantitative results on the benefits of implementing a specific tool, specifically in medium scale D&B projects, to enable an informed decision to be made on which tool an organisation should select.

There is a consensus in previous research of the benefits of 4D BIM tools improving the constructability review during the planning phase of a project as well as improving the projects schedule; however this research focuses on large scale complex projects. Previous research on the utilisation of BIM tools to aid in the alleviation of the problems faced by medium scale D&B organisations has not previously been undertaken.

5D BIM tools are implemented on projects to enable project teams to undertake instantaneous estimating take offs for use in costing. The 5D BIM model relies upon the information contained within the central 3D BIM model, however if sufficient information is contained within the model estimates can be undertaken throughout the lifecycle of the project rather than as a design reaches a specific milestone. 5D BIM tools provide a significant advantage in pricing both scope changes and variations, which can provide an advantage to D&B contractors in determining the cost of these changes.

Previous research on the use of 5D BIM tools has identified the benefits such as accuracy of estimating, speed of pricing and cost control when implemented on projects. There is also a widespread agreement in the literature of the advantages in using 5D BIM, however there is insufficient unbiased quantitative results on the use of specific BIM 5D tools particularly on medium scale D&B projects. Case studies on the use of 5D BIM tools to aid in the alleviation of the problems faced by D&B organisations with regards to the understanding of the cost implications on the timing of scope changes and the control of financial risks in medium sized D&B organisations, has not previously been undertaken.

Previous research undertaken on the value and use of BIM tools, specifically 4D and 5D, in organisations, has not focussed on D&B projects and specifically medium sized projects. It will be advantageous to understand the value of BIM tools for the management of key issues faced by medium scale design and build contractors. Previous research findings therefore, are unable to provide a definitive answer on the feasibility of the use of 4D and 5D BIM tools to manage and resolve key issues faced by medium scale D&B contractors. Therefore further research into the use of specific BIM tools on medium scale D&B projects should be undertaken.

Problems faced by D&B Contractors have been identified as scheduling errors in the overlapping of project phases and understanding the cost implications on the timing of scope changes. In addition to this, the importance of the constructability of designs in achieving project success. The goal therefore for this study will be to adopt a specific 4D BIM tool, Navisworks Manage, and a specific 5D BIM tool, CostX and undertake a case study to provide a first-hand understanding on the feasibility of utilising these BIM tools manage and resolve the key issues faced by medium scale D&B organisations.

CHAPTER 3 – METHODOLOGY

3.1 Objectives Overview

The goal of the research project is to examine specific 4D and 5D BIM tools, to determine their suitability for adoption into the organisation.

The objective of this research project is therefore to:

Examine the feasibility of utilising 4D and 5D BIM tools for managing and resolving key issues faced by contemporary medium-scale Design and Build contractors.

In order to achieve this objective the following sub-objectives have been formulated:

Sub-Objective 1:
Undertake an extensive literature review, in order to establish problems faced by D&B contractors.

Sub-Objective 2:
Research and evaluate currently available Building Information Modelling software and the developments in the software since its inception, focussing on the integration between 3D BIM and the elements of 4D (Time) and 5D (Cost), through an extensive literature review.

Sub-Objective 3:
Undertake interviews with key organisation members in order to validate the findings from the D&B literature review.

Sub-Objective 4:
Undertake a historical case study on one of our Organisations completed projects in order augment the concerns from both the literature review and interviews (Historical Case Study 1).

Sub-Objective 5:
Undertake Pilot Case Study using a small scale test project created in Autodesk REVIT and selected 4D and 5D BIM tools, as a means to provide an understanding of the tools and resolve the usage of the tools for the remainder of the research project.

Sub-Objective 6:
Apply selected BIM 4D and 5D BIM tools, Autodesk Navisworks and Exactal CostX, to the historical project and then undertake a case study (Historical Case Study 2) to resolve the value of using these tools managing and resolving the issues that are encountered by medium sized D&B contractors.

A research methodology map is provided in the following Figure 3.1, outlining the steps to be undertaken in the research project.

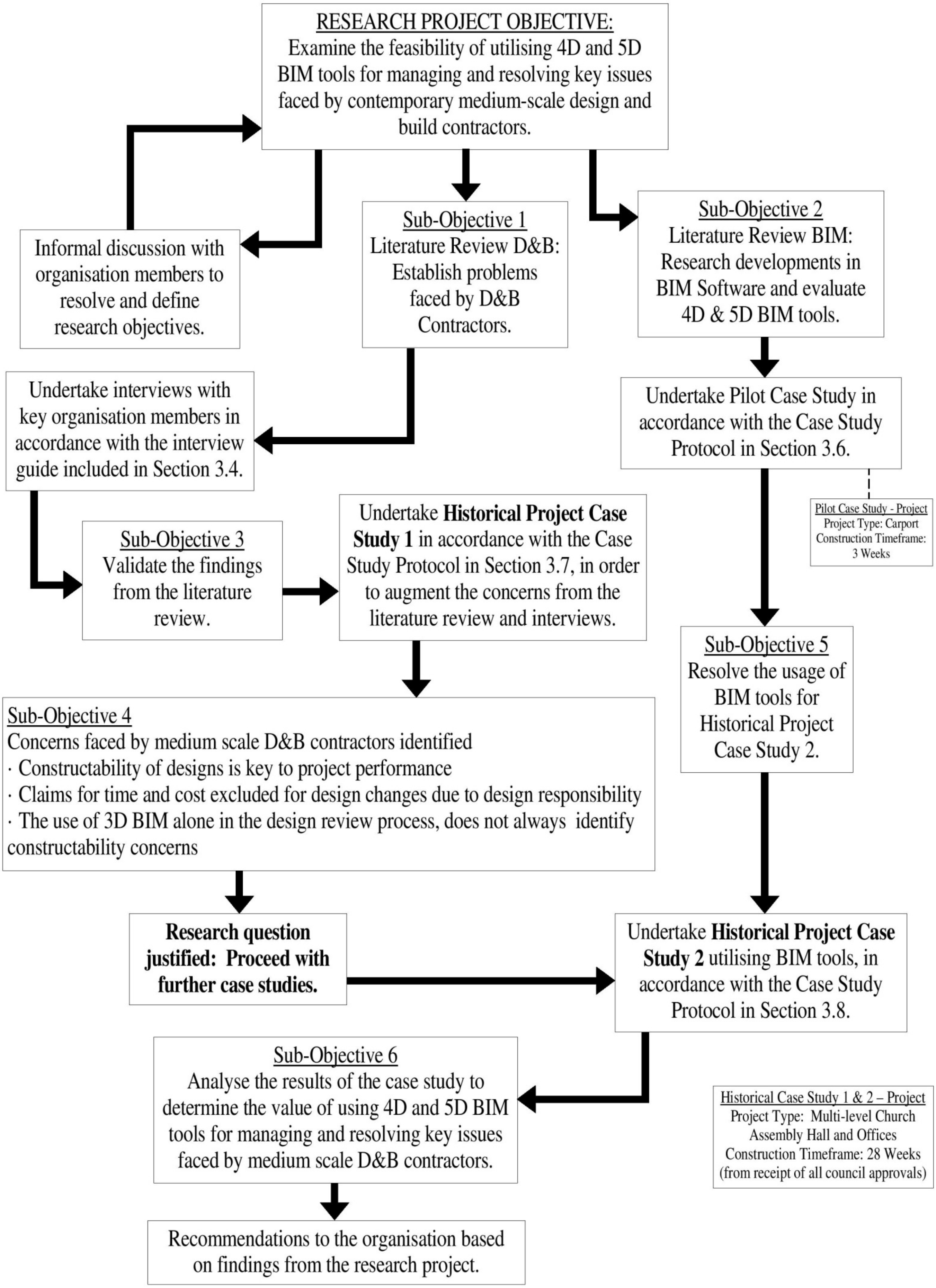


Figure 3.1 - Research Methodology Map

3.2 Organisation Overview

The Organisation used as part of the case study research for this project, is a successful medium-scale D&B Organisation located in South East Queensland that undertakes projects throughout Australia and Asia. Projects primarily consist of Office and Warehouse facilities, Retail Warehouses, and Refrigerated Distribution Facilities.

An internal Design Department undertakes all Architectural, Structural Engineering, Civil Engineering, Hydraulic Design and Structural Steel Detailing design. The Organisations designs predominantly consist of structural steel frame, concrete tilt panel and multi-level offices with concrete mezzanine floors.

The Organisation has operated successfully on numerous projects, with a number of Master Builder awards at both regional and state level. A large portion of the client base is repeat clients, which highlights the organisations success on projects in achieving the client's objectives, there are still however, areas for improvement.

3.3 Selection of BIM Tools

Based on the overview of 4D and 5D BIM tools provided in Section 2.4.3 and Section 2.5.3, the BIM tools that will be used in the case studies have been selected as Autodesk Navisworks and Exactal CostX. These BIM tools have been selected to meet the following requirements:

- Compatibility with current 3D BIM Software used in the organisation
- Availability of Student Licenses
- The scope of the organisations projects and the requirement for activity based scheduling tools
- Previous interest from the organisation in the adoption of these BIM tools

3.4 Interviews

Interviews will be undertaken to provide valuable information on the performance and problems encountered in the organisation (Burns 2000). The use of a semi structured interview enables the researcher to ask specific questions regarding the project topic which are based on the theme that has been determined from the literature review (Gagnon 2010).

3.4.1 Purpose

In order to ensure that there is specific cause for the research project, the purpose of the initial interviews with key organisation members is to validate the findings from the literature review. The results of the interviews will determine the basis for the case studies to be undertaken on specific projects.

3.4.2 Interviewee Selection

Due to the nature of the D&B method including both a design team and a construction team it was deemed relevant to include team members from each team in the interview process. Each of the interviewees will also have significant knowledge about the subject topic (Whiting 2008).

Organisation members to be interviewed will therefore be:

Table 3.1 – Interviewee Selection

Organisation Member	Organisation Team	Period of Service with The Organisation
CAD Manager/Designer	Design Team	12 Years
Project Manager	Construction Team	5 Years
Construction Manager	Construction Team – Includes liaising with the Design Team & Estimating Team	15 Years

3.4.3 Interview Process

The use of open ended questions can be used to reassure interviewees to provide more detailed responses to the questions being asked. To ensure that interaction is continued questions for the interview will be established prior to the interview (Whiting 2008).

The key findings from the literature review of the D&B method as discussed in Section 2.7 were as follows:

Table 3.2 – Key Findings from D&B Literature Review

1	Budget and project timeframe improvements using the D&B method
2	The importance of the co-ordination between the design and construction departments in the D&B method to improve constructability
3	Reduction of claims when the D&B method is used
4	Financial risks associated with the use of the D&B method
5	Increased design responsibility associated with the use of the D&B method
6	Overlapping of the design and construction phases and the effect on scope changes

The interview questions, the same for each interviewee, were established with an aim to validate these findings. The interview questions are therefore as follows:

Table 3.3 – Interview Questions

	D&B Interview Questions
1	In your experience, what are the advantages to the use of the D&B method?
2	In your experience, does the use of the D&B method increase the financial risk for the contractor?
3	If the financial risks are increased, in your experience what are the causes?
4	What are some methods available to reduce the financial risks for the contractors?
5	Does a contractor undertaking a project using the D&B method increase their design responsibility?
6	Although a successful organisation, has The Organisation in your experience, encountered situations on projects where additional costs have arisen due to the rectification of design errors?
7	If they have, can these additional costs be claimed as a variation to the client?
8	Are scope changes requested by clients on projects? If yes, what are some examples?
9	Does the timing of the request for scope change affect the variation cost – eg if the design is still underway, however construction has commenced?
10	Are the design and construction phases of projects overlapped in order to achieve shorter project timeframe and in your opinion is this method successful in achieving the shorter timeframe?
11	Are there cases where the construction phase of a project has been commenced too early, whereby there are delays on site while the remainder of the design is being completed?
12	In your experience can the D&B method increase the contractor's responsibility in achieving the project completion date, because the opportunity to claim for additional time due to design errors is removed?

3.4.4 Data Analysis

The results of the interviews are included in Chapter 5 The purpose of the interview was to validate the findings of the literature review, and therefore determine the viability of further case study research on the topic.

3.5 Case Study Research

In order to achieve the objectives of the Research Project, the best method is undertake a case study, which will include a combination of observations, interviews and document analysis in order to collect significant data to enable the results to be determined. The use of the case study is the best method for this project as it will provide an in-depth understanding of the benefits of 4D & 5D BIM tools. In addition to this, a case study is best utilised in studies where there is a little control over the project (Burns 2000).

The Research Project will require an in depth review of each of the projects, and the problems that are encountered within the organisation. An advantage of utilising the case study research method will be that the case study will enable a closer examination of the projects and the performance of the BIM tools that will be implemented (Zainal 2007).

3.5.1 Multiple-Case Design Case Study

Two case studies will be undertaken in this dissertation in order to determine the best conclusion to the problem. The same historical case project will be utilised for each case study. Historical Project Case Study 1 will be undertaken on the completed project that utilised traditional project management and estimating methods in order to augment the results from both the literature review and the interviews. Historical Project Case Study 2 will then be undertaken on the same project by implementing and utilising 4D and 5D BIM tools to determine the feasibility of utilising BIM tools to manage and resolve the issues identified in Historical Project Case Study 1. It is anticipated that these case studies will present contrasting outcomes, whereby the use of 4D and 5D BIM tools will produce better performance results although it is difficult to say at this stage. If the results do occur as predicted, as discussed in Yin (2014), the use of a two-case design will strengthen the findings.

3.5.2 Case Study Protocol

The establishment and utilisation of a case study protocol will increase the reliability of the case studies (Yin 2014). The case study protocol will include an overview of the case study, procedures for the data collection, and the data collection questions to be undertaken within the case study. The case studies will therefore be undertaken utilising the following protocols in order to ensure that the results at the completion of the case study are deemed reliable:

a. Case Study Objectives

The objectives of the case study must be clearly defined; therefore the protocol for each of the case studies must initially define the objectives of the case study. According to Gagnon (2010), when defining the objectives of the case study, a literature review should also be undertaken in order to provide understanding of previous studies on the subject matter. The first stage in protocol will therefore be to provide clear objectives of the case study.

b. Validity & Reliability

In order to ensure that the results from the case study can be relied upon, construct validity and reliability tests as presented by (Yin 2014) will be used.

i. Construct Validity

To ensure that the case study is not biased by any preconceived notions that the researcher may have with regards to the implementation of 4D & 5D BIM for use in The Organisation, multiple sources of evidence will be used as well as establishing a chain of evidence. This will ensure that that the construct validity of the case study is increased.

ii. Reliability

In order to ensure reliability in the case studies, all methods undertaken will be documented, this will enable the researcher if required, to repeat the case study at a future date. The essence of reliability in case study research is the ability for a future researcher to undertake a similar study to generate consistent results (Gagnon 2010). In addition to this, a review undertaken by peers will ensure the reliability of the data (Gagnon 2010).

c. Case Selection

As this research project aims to understand the feasibility of the use of 4D and 5D BIM tools in managing and resolving key issues faced by D&B companies, the selection of cases for the case studies will be based on their representation of the projects undertaken by *The Organisation* (Gagnon 2010).

Projects undertaken by *The Organisation* consist of Industrial, Commercial and Retail Projects including office, warehouse and distribution centres. Projects range in size to $25 Million, with multiple floor levels consisting of floor areas of up to approximately 20 000m2.

The criteria therefore that will be used in order to select the cases are:

- The project must be undertaken by *The Organisation*
- The project must be undertaken using the D&B method
- Data must be available for use
- Approval for use of the project by the Construction Manager

d. Data Collection

Outlined data collection procedures in the case study protocol enable future researchers to undertake the study, which therefore reaffirms the validity and reliability of the case study (Gagnon 2010).

The sources of data to be used in the case study will consist of a combination of:

- drawings
- estimates and budget comparisons
- project programmes
- minutes of meetings
- site diaries
- various project registers.

Data collection in the case studies will include a number of questions that will be divided into the following levels (Yin 2014):

- Level 1 – these questions will be asked to the various interviewees of the project management team on the projects – specifically the CAD Manager, Construction Manager and Project Manager, using the interview guide as outlined in Section 3.4.
  The use of interviews in the case studies will provide invaluable information as interviewees will also identify possible alternative sources of evidence to be utilised in the case study (Burns 2000).
- Level 2 – these are questions formulated to ask of each of the cases based on the observations made. There are two methods of observation to be used:

i. Participant Observation

The use of participant observation enables the researcher to take a role in the case study itself, which can be detrimental to the results of the case study as the objectivity of the researcher can be hindered (Gagnon 2010). However as noted by Yin (2014) the use of participant observation enables the researcher to gain additional information, that a non-participant role would allow.

ii. Non-Participant Observation

The use of non-participant observation as a means of data collection enables the researcher to assume an observation role only in the case study, there is no direct involvement within the case study (Gagnon 2010).

e. Analysis of the Data

The analysis of the data obtained from the case studies is included in Chapter 5.

As the multiple case study approach is being utilised for this research project, there will be two stages of data analysis. The Historical Case Study 1 results will be utilised to validate the findings from the literature review to determine the merit of implementing BIM tools to overcome the key problems faced by D&B organisations.

Once the data has been collected from the Historical Case Study 2, which is the historical project with the implementation of BIM tools, the data will be interpreted in order to provide justifications for the results. The method that will be utilised for this research project will be to determine explanations for the results (Gagnon 2010). The analysis of the case study results will be undertaken progressively, as the case study is being completed. The results of the case study will then be used to undertake a comparison between both the findings in the literature and also the results from the first case study.

3.6 Pilot Case Study

3.6.1 Pilot Enquiry

A pilot case study will be utilised by the researcher in order to refine the methods by which data and procedures can be followed. The scope for the case study utilised in the pilot enquiry is broader than that used in the final data collection for the case studies (Yin 2014). The utilisation of a pilot case study in this dissertation will enable the final elements in the project case study to be resolved. In addition to this, it will provide the researcher with an understanding of the BIM tools that will aid in the implementation on the larger project in the second case study

3.6.2 Small Scale Test Project

The small scale test project utilised in the pilot enquiry will include the modelling of a carport using Autodesk REVIT, a 3D BIM tool. The design for the carport will consist of:

- footings
- concrete slab
- structure including columns and steel roof framing
- roof and wall bracing
- roof and wall cladding
- blockwork walls
- stormwater drainage
- doors.

The predicted construction timeframe for the small scale test project is 3 weeks.

3.6.3 Method

An activity based project schedule will be written for the carport using Microsoft Project, and a cost estimate will be produced using the current methods in the organisation of 2D Drawing take off and the organisations database of current rates. Autodesk Navisworks will be utilised to review the project schedule and Exactal CostX will be used to produce a cost estimate for the project.

The data collection for the study will be based on the following questions established in accordance with the Case Study Protocol:

Table 3.4 – Small Scale Test Project data collection questions

	Question
1	What cost information can be extracted from the model?
2	Can the schedule information be manipulated to produce different results?
3	Can the project schedule be reviewed at different stages of the project?
4	Can the cost and time information be included in the BIM model to produce a cost loaded schedule?

3.7 Historical Project Case Study 1 – No BIM Tools

3.7.1 Objective

The objective of the historical case study is to understand the problems encountered in the management of the D&B projects within our organisation. The results of the historical case study will be utilised to augment the concerns raised in the interviews with project team members, in addition to the findings from the literature review. The results will also be utilised as a basis of comparison for the results of the case study utilising BIM tools. The case study will be undertaken in accordance with the following case study protocol that has been established based on Section 3.5.2:

3.7.2 Selection of Project

The selected project '***Project A***' was completed in 2013 with a construction timeframe of 28 weeks from receipt of all council approvals. The project consisted of two buildings, a retail building and a church assembly hall and offices. Both buildings included basement car parking and three storeys. The value of the project was $4, 365, 000.00.

The project was selected as it met the criteria as set out in the case study protocol:

Table 3.5 – Case study selection criteria

Case Study Protocol Criteria	**Historical Project**
The project must be undertaken by *The Organisation*	The project was undertaken by *The Organisation*
The project must be undertaken using the D&B method	The project was completed utilising the D&B method. All hydraulic, civil, structural and architectural design for the project was completed by the internal design department.
Data must be available for use	All data is available and accessible for the project, both electronically and hard copy files.
The use must be approved by the Construction Manager	The selection of the project to be utilised in the historical case study was undertaken in conjunction with the Construction Manager for *The Organisation*.

3.7.3 Data Collection

Historical case studies have a significant reliance on records, and therefore in order to undertake the case study effectively there must be access to the required information (Burns 2000). As all records and documentation is available to the researcher for the selected project, as well as relevant project team members for interviews where required, the historical case study method has been selected.

Non-participant observations as discussed in section 3.5.2 (d) will be used as a means of collecting the data in the case study, with the following data to be utilised:

a. Documents

Documents that will be utilised for the historical case study project in order to satisfy the construct validity of the case study include the following:

- Drawings
- Estimates and Budget Comparisons
- Project Programmes
- Minutes of Meetings
- Site Diaries
- Various project registers
-

3.7.4 Data Analysis

A comparison will be undertaken between the results obtained from the case study with the results from the literature review and the interviews with particular reference to the following areas:

- financial risks and the causes encountered on the project
- design co-ordination
- timing of uncovering the design co-ordination issues
- costs associated with the rework of the design co-ordination issues
- client scope changes & costs
- effect of overlapping the design & construction phases.

This analysis will provide clarity on the specific concerns encountered by the organisation, and the potential use for BIM tools in order to manage these concerns.

3.8 Historical Project Case Study 2 – BIM Tools Implemented

3.8.1 Objective

The objective of undertaking a second case study on the same historical project and implementing BIM tools is to resolve whether there is feasibility in utilising 4D & 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors.

The case study will therefore consist of the implementation of 4D & 5D BIM tools on the project at specific milestones to determine whether the tools are able to overcome the problems that have been observed in the previously completed Historical Project Case Study 2.

3.8.2 Selection of Project

As previously discussed in Section 3.7.2, the project that has been selected meets the criteria, as set out in the case study protocol:

Table 3.6 – Case study selection criteria

Case Study Protocol Criteria	**Historical Project**
The project must be undertaken by *The Organisation*	The project was undertaken by *The Organisation*
The project must be undertaken using the D&B method	The project was completed utilising the D&B method. All hydraulic, civil, structural and architectural design for the project was completed by the internal design department.
Data must be available for use	All data is available and accessible for the project, both electronically and hard copy files.
The use must be approved by the Construction Manager	The selection of the project to be utilised in the historical case study was undertaken in conjunction with the Construction Manager for *The Organisation*.

3.8.3 Data Collection

The case study utilises the historical project as a method of providing a direct analysis as to the benefit of implementing BIM tools within the organisation. As part of the case study work, the role of participant observation will be undertaken due to the involvement in the project management team on the project.

The case study will involve one level of data collection as outlined in the case study protocol.

a. Direct Observations

Direct Observations will be undertaken as part of this case study which will include:

- Implementation of 4D and 5D BIM tools on the project
- Performance of the BIM tools

As the case study includes the implementation of new tools, observations of the BIM tools in use will aid in the understanding of how the tools are performing (Yin 2014).

The data collection will be undertaken at two milestones in the projects programme, these being:

- Documentation Issued for Building Approval

As found in the literature review, a key benefit to the implementation of 4D and 5D BIM tools, is the ability to analyse the project prior to commencing any works on site. The milestone has therefore been selected, at a stage that the project is still within the design phase of the project.

3.8.4 Data Analysis

A comparison will be undertaken between the results obtained from the historical case study and the interviews with key organisation members, and the performance of the 4D and 5D BIM tools on the project. In particular an analysis will be undertaken based on the results of the following areas:

- financial risks and the causes encountered on the project
- design co-ordination
- timing of uncovering the design co-ordination issues
- costs associated with the rework of the design co-ordination issues
- scope changes & costs.

This analysis will provide clarity on the specific concerns encountered by the organisation, and the potential use for BIM tools in order to manage these concerns.

3.9 Resource Requirements

The works undertaken as part of this dissertation will require access to the software are outlined in Table 3.7. All software licenses have been obtained from the required providers. No other resources will be required to complete the study.

Table 3.7– Research project resource requirements

Resource	Required Timeframe	Source	Priority	Cost
Exactal – CostX	Permanent	Student Version – Exactal Technologies Pty Ltd.	Critical	NIL
Autodesk – REVIT	Permanent	Student Version – Autodesk	Critical	NIL
Autodesk – Navisworks	Permanent	Student Version – Autodesk	Critical	NIL
Microsoft Excel	Permanent	Student	Moderate	NIL
Microsoft Word	Permanent	Student	Critical	NIL
Microsoft Project	Permanent	Student Version	Critical	NIL
Endnote	Permanent	USQ Library	Moderate	NIL

3.10 Risk Analysis

Risk Management Chart for Works undertaken Preparing Dissertation:

Table 3.8 – Risk Management chart for works undertaken preparing dissertation

Description of Hazard	People at Risk	Risk Level	Control Measures	Completion Details
Eye and muscle strain from prolonged periods working at the computer	Myself	Low	Take regular short breaks away from the computer	Employer: USQ Prepared by: Melanie Patterson Date: 02/06/15

3.11 Project Timeline

A project timeline has been produced in order to provide completion timeframes for each phase of the research work. The Project Timeline is included within Appendix A.

CHAPTER 4 – BIM SOFTWARE USER GUIDE

4.1 Introduction

Case studies will be undertaken in the research project utilising 4D and 5D BIM tools. The 4D and 5D BIM tools that have been selected for use are Autodesk Navisworks (Navisworks) and Exactal CostX (CostX), and have been selected based on the criteria discussed in Section 3.3. As the BIM tools that have been selected are not currently in use by the organisation, and therefore the use of them is unfamiliar, this BIM user guide has been established as a means to outline the steps taken to undertake the case studies utilising the BIM tools. Furthermore, the documentation of the guidelines will be used as a means to ensure reliability in the case studies.

4.2 Autodesk Navisworks Manage 2016

Navisworks Manage 2016 has been selected in accordance with the requirements outlined in Section 3.3. The current 3D BIM software utilised by the organisation is Autodesk Revit, with which Navisworks is compatible. In order to upload the BIM model into Navisworks, the Autodesk Revit model must be exported into an .NWC file. Once the 3D BIM model is complete, export .NWC file from Autodesk Revit

The following procedures for creating the 4D BIM model have been formulated in accordance with the instructions as provided by Mubarak (2015) and Jarvis (2013), using the Small Scale Test Project as the example.

4.2.1 Opening Navisworks Manage software

Open Navisworks Manage software. The default screen when opening Navisworks Manage is as shown in Figure 4.1:

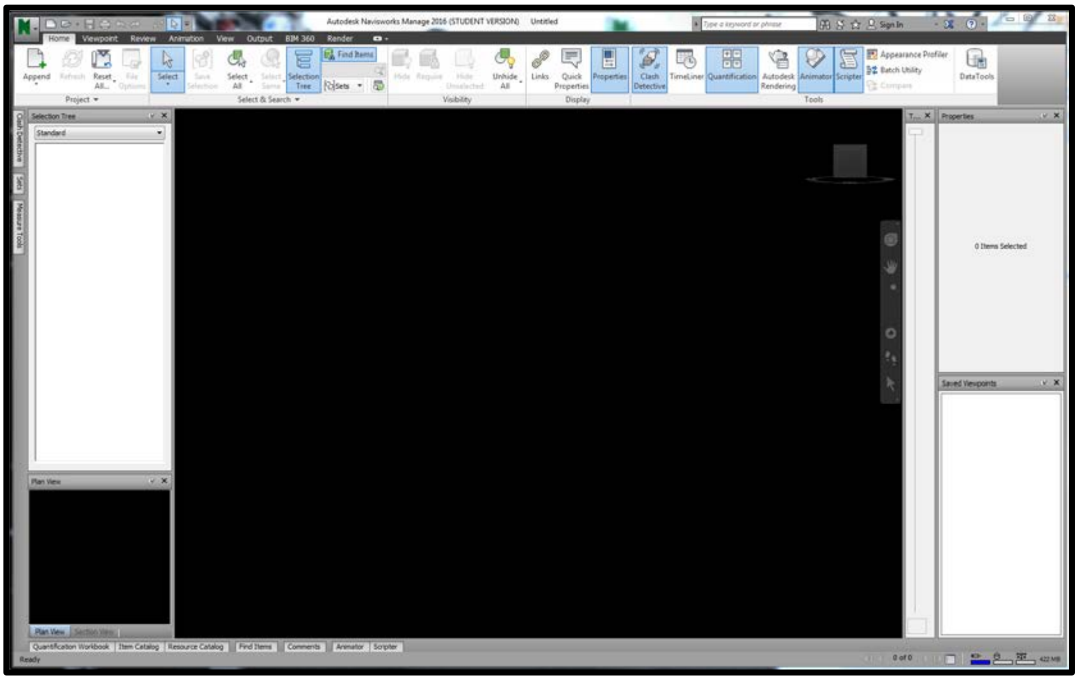


Figure 4.1 - Naviswork Manage default opening screen

4.2.2 Import Project 3D BIM Model

The first step in using Navisworks Manage to aid in the project schedule to is to import the compatible 3D BIM model file.

Using the Open Command from the File Menu in Navisworks, open the saved .NWC File. The 3D Model is then imported into Navisworks as shown in Figure 4.2:

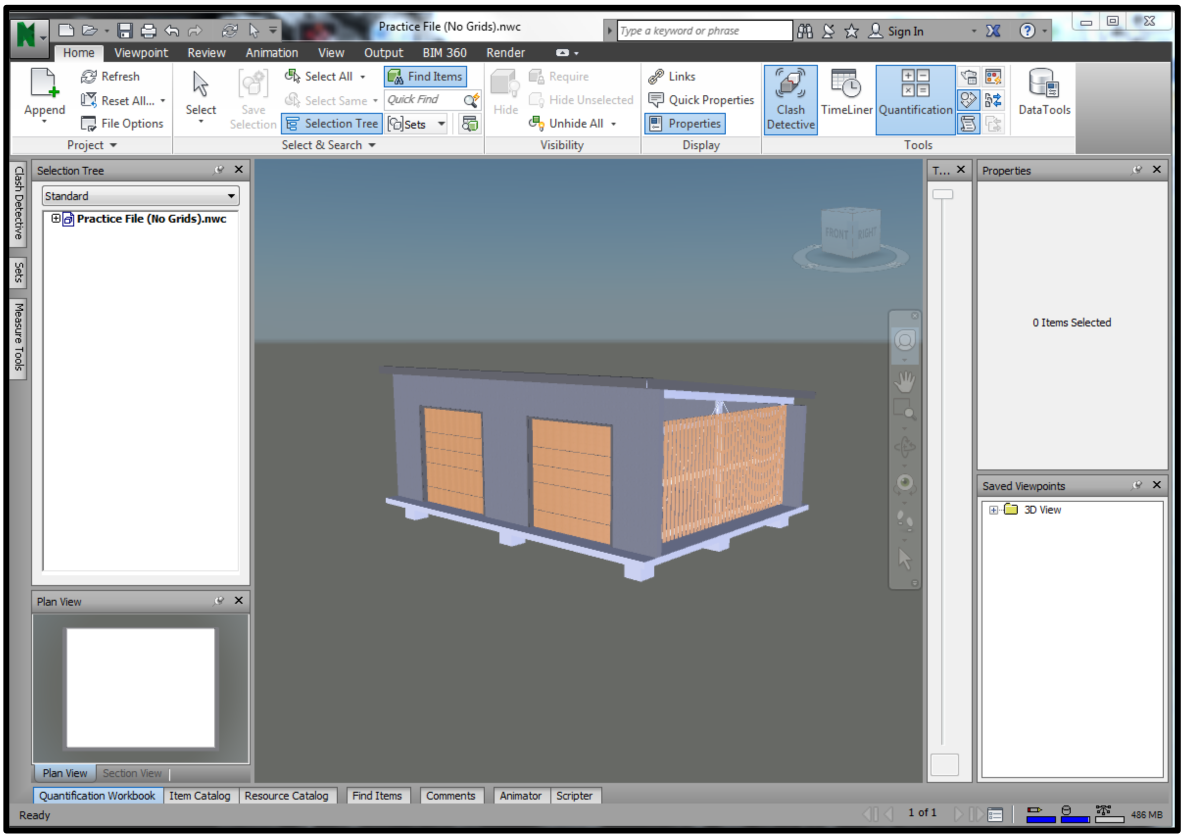


Figure 4.2 - 3D BIM model imported into Navisworks Manage

4.2.3 Import Project Schedule

The Timeliner function in Navisworks Manage is utilised to manage the projects schedules and activities.

Project schedules can be written either manually in Navisworks Manage utilising the Timeliner function, or other project scheduling software such as Microsoft Project. Microsoft Project files can be linked directly to the Navisworks Manage file.

Select the Timeliner Tab from the 'Home' Ribbon:

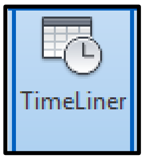


Figure 4.3 - Navisworks Manage Timeliner Tab

To import the project schedule from a Microsoft Project File, select 'Add' from the Data Sources Tab from the Timeliner function and select the relevant file:

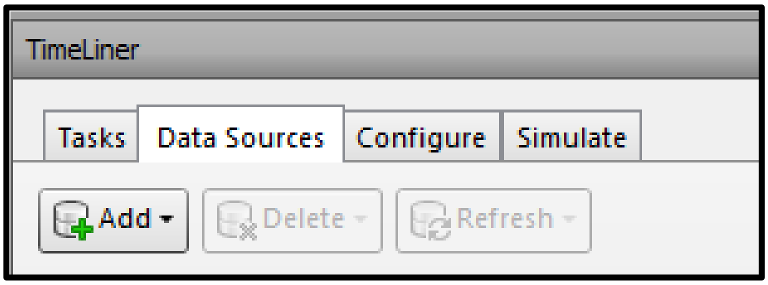


Figure 4.4 - Navisworks Manage Data Sources Tab

Once the link has been created, the Field Selector dialog box is displayed, which requires the Microsoft Project field names to be linked in the 'External Field Name' column to the Navisworks Manage field names in the 'Column' column.

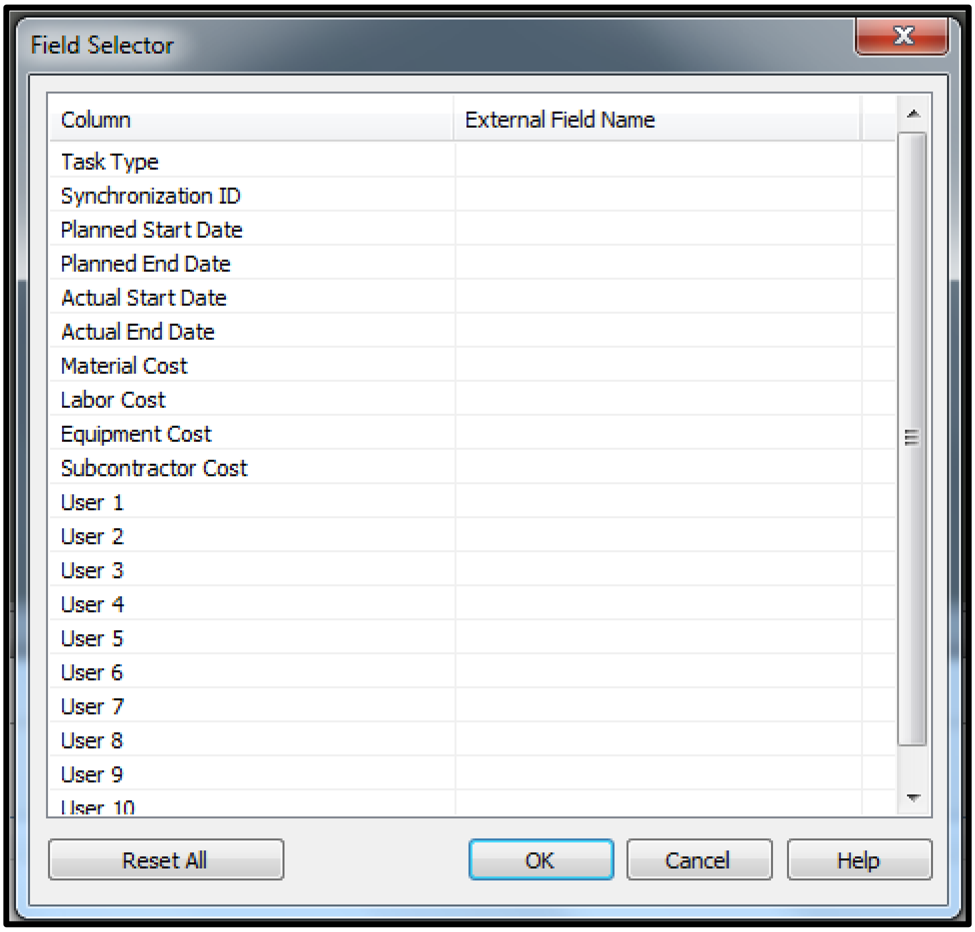


Figure 4.5 - Navisworks Manage Field Selector

In order to view the tasks from the project schedule in Timeliner right click on the File in the Data Sources Tab in Timeliner, and select 'Rebuild Task Hierarchy'. Select the Tasks tab in the Timeliner. As shown in Figure 4.6 tasks from the Microsoft Project schedule are now able to be viewed in the Timeliner:

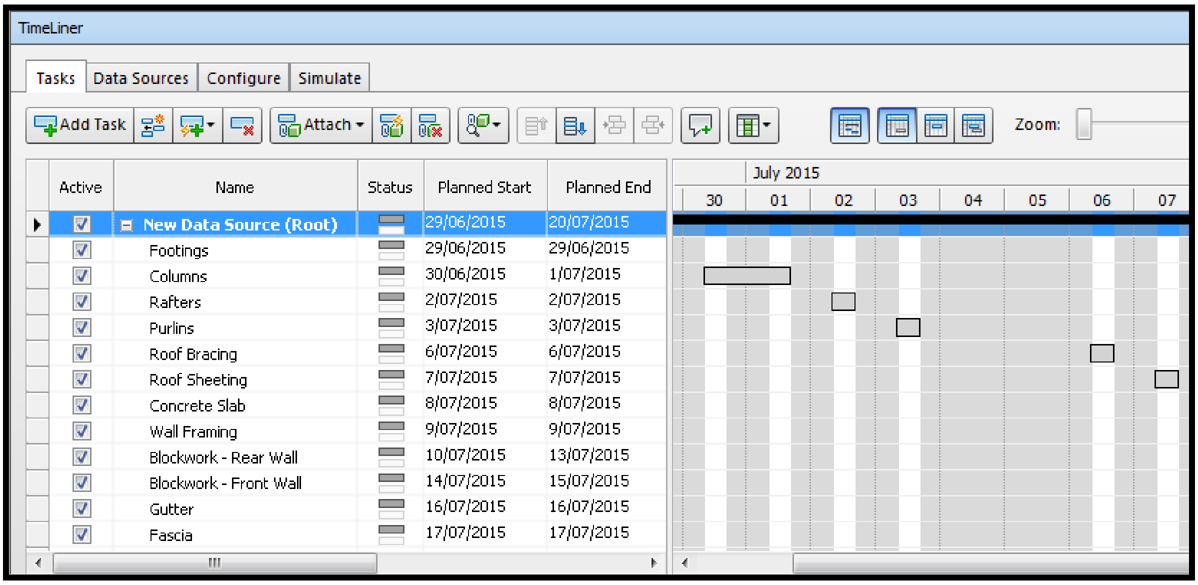


Figure 4.6 - Navisworks Manage Timeliner project schedule

4.2.4 Assigning Task Types

Assigning types to each of the tasks in the Navisworks Timeliner function, determines the tasks view in the simulation function for the project. The types available are:

- Construction
- Temporary
- Demolition

In the schedule under the 'Task Type' column, assign the task type to each of the tasks.

4.2.5 Selection Sets

In order for the project simulation to be run, the 3D model elements must be linked to the tasks in the Timeliner schedule.

The Selection Tree function lists each of the model elements used to link to the tasks in the Timeliner Schedule with the model elements.

The following Figure 4.7 is an example of the Selection Tree in Navisworks:

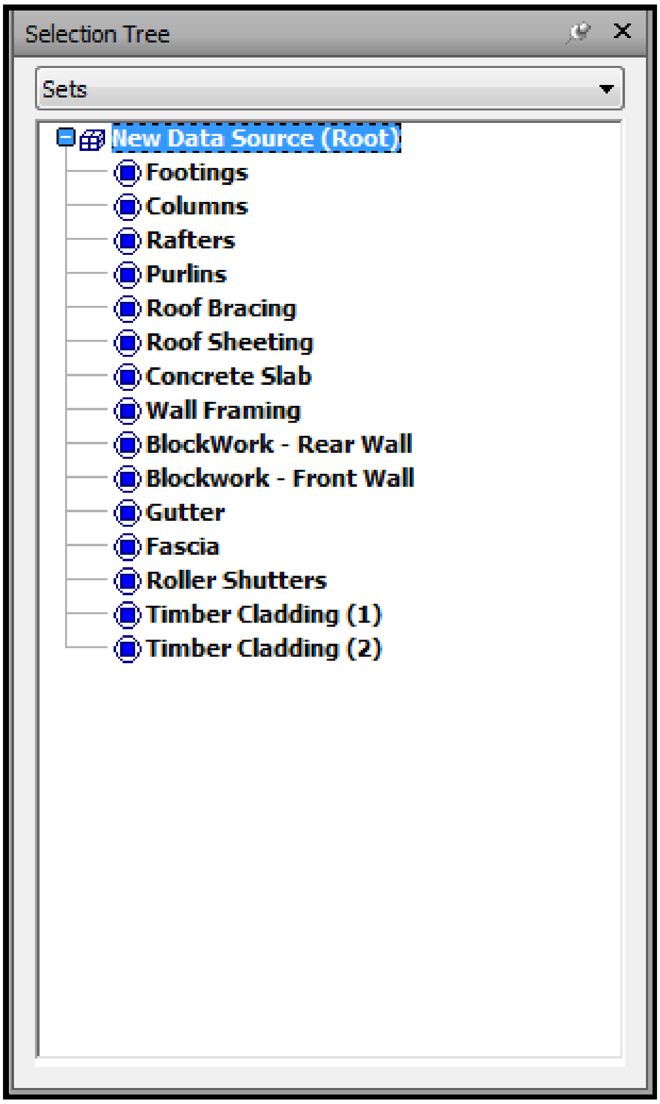


Figure 4.7 - Navisworks Manage Selection Tree

To assign tasks in the Selection Set with model elements:

Right Click on “New Data Source (Root)” in the Timeliner and Select “Export to Sets” as shown in Figure 4.8:

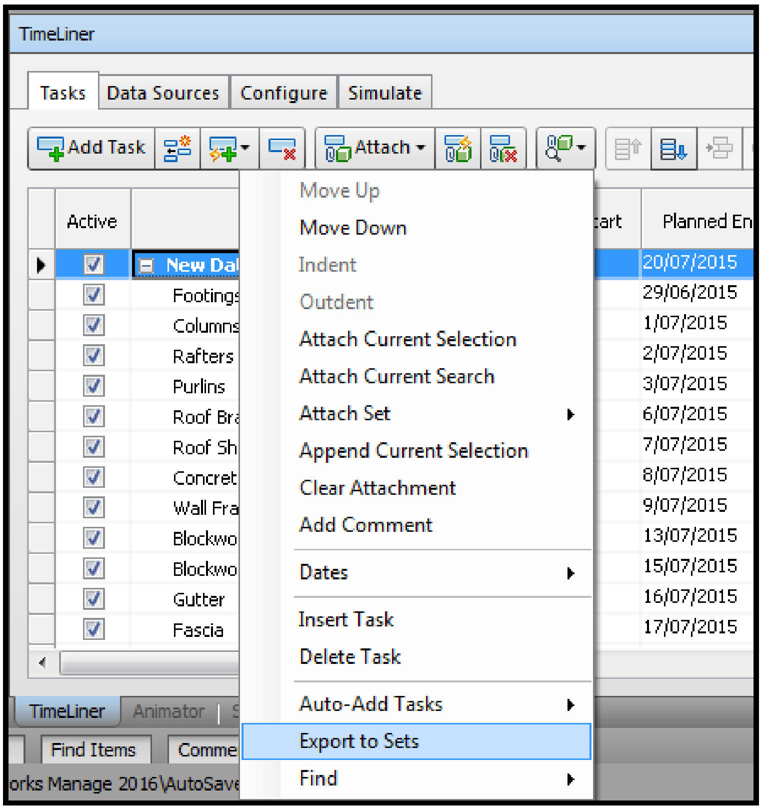


Figure 4.8 - Navisworks Manage assigning tasks in the Selection Set

From the Select & Search Tab under “Find Items” type in the model element to be searched for, such as “Footing” as shown in Figure 4.9:

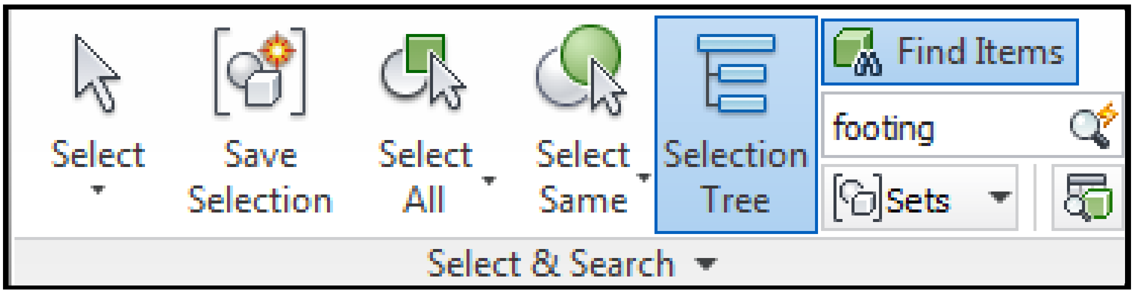


Figure 4.9 - Navisworks Manage Selection Tree search

This will highlight all model elements that correspond to "Footing" in the model as shown in Figure 4.10:

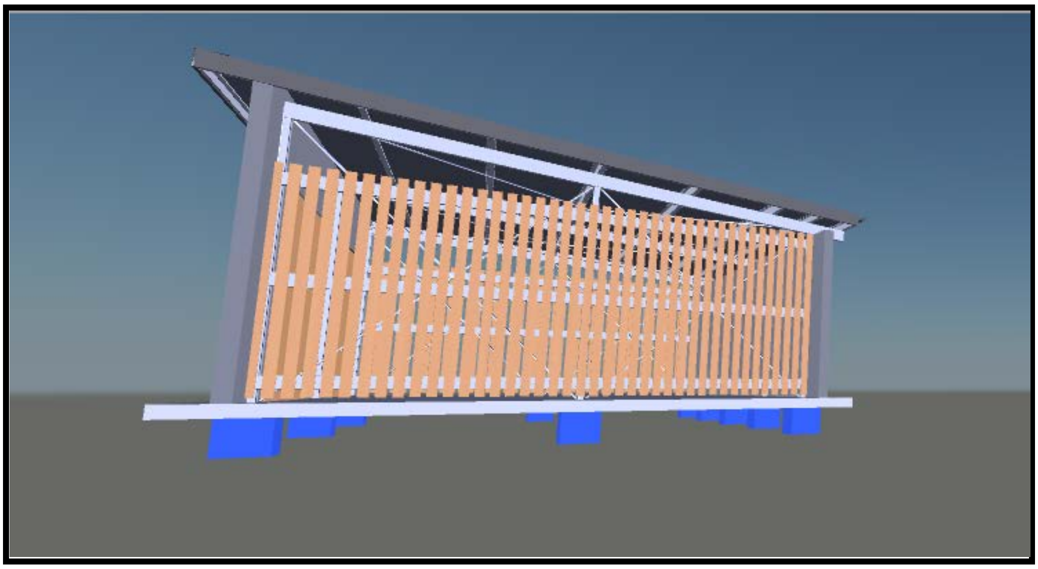


Figure 4.10 - Navisworks Manage Selection Tree model search

The 3D Model however must be set up with the appropriate structure to enable these searches to be undertaken.

Once the model elements have been selected, right click on the element from the Set for example "Footings" and update as shown in Figure 4.12, this will assign the model elements to the Sets:

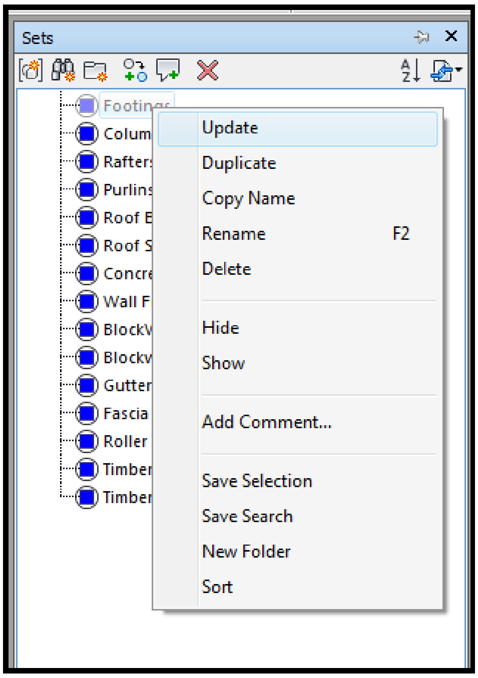


Figure 4.11 - Navisworks Manage Selection Tree task assignment

In order to link the Selection Sets to the Timeliner tasks, in the Tasks tab in Timeliner select “Auto Attach using Rules” and select “Map Timeliner Tasks from Column Name to Selection Sets with the same name, Matching case” as shown in Figure4.12 and Select “Apply Rules”.

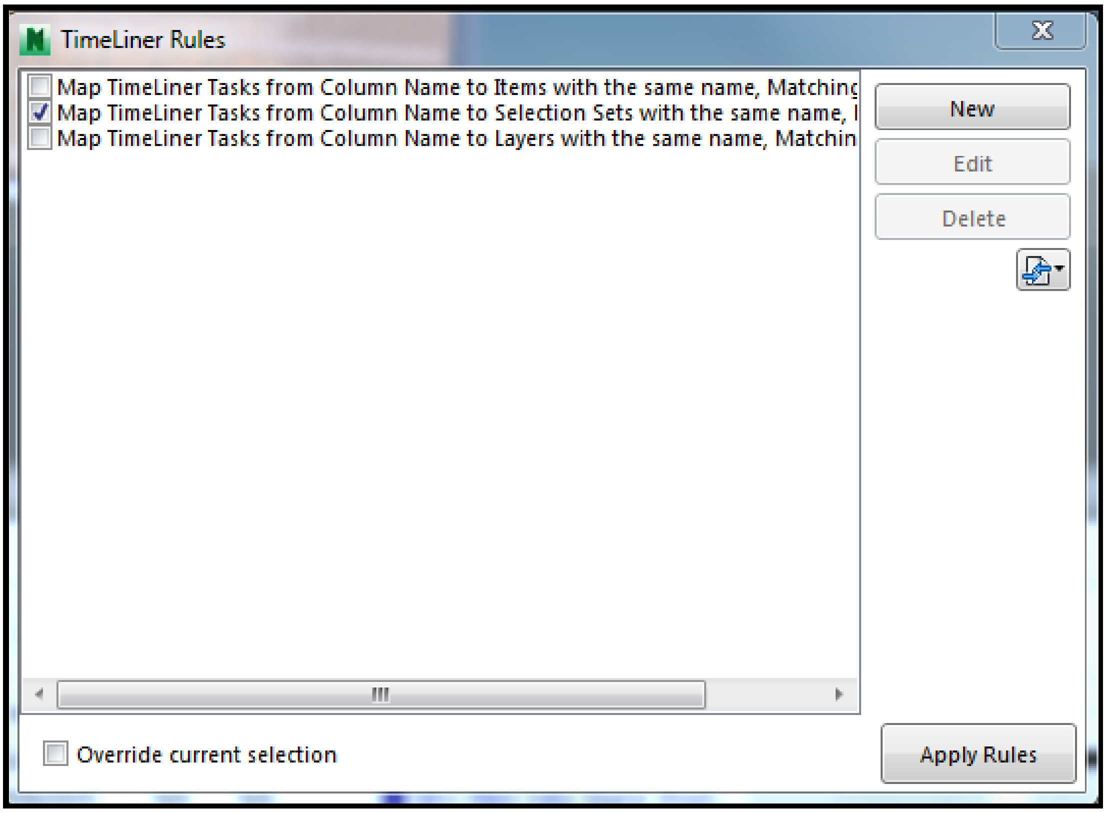
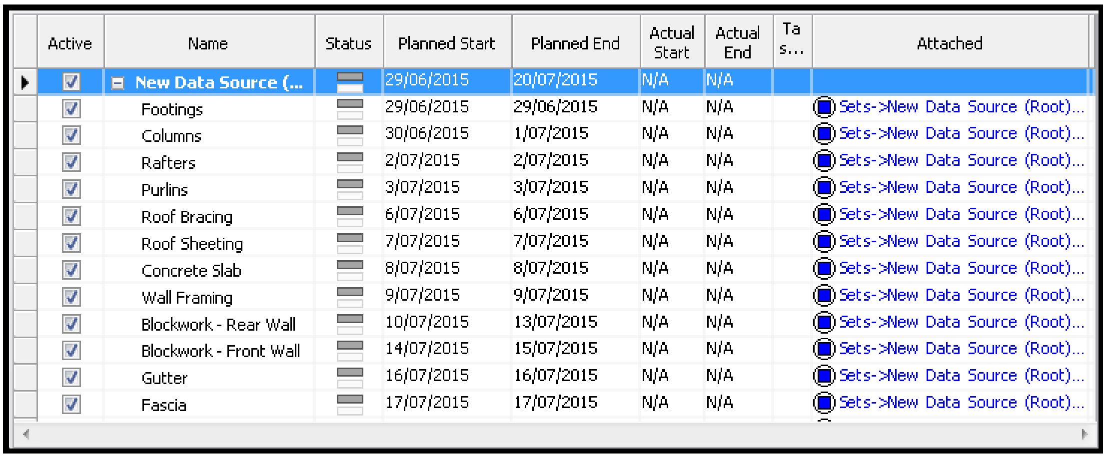


Figure 4.12 - Navisworks Manage Timeliner Selection Set link

The model elements are now shown in the Attached column of Timeliner as shown in Figure 4.13:



Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Ta s...	Attached
☑	New Data Source (...		29/06/2015	20/07/2015	N/A	N/A		
☑	Footings		29/06/2015	29/06/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Columns		30/06/2015	1/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Rafters		2/07/2015	2/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Purlins		3/07/2015	3/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Roof Bracing		6/07/2015	6/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Roof Sheeting		7/07/2015	7/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Concrete Slab		8/07/2015	8/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Wall Framing		9/07/2015	9/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Blockwork - Rear Wall		10/07/2015	13/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Blockwork - Front Wall		14/07/2015	15/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Gutter		16/07/2015	16/07/2015	N/A	N/A		Sets->New Data Source (Root)...
☑	Fascia		17/07/2015	17/07/2015	N/A	N/A		Sets->New Data Source (Root)...

Figure 4.13 - Navisworks Manage Timeliner – Attaching model elements to the project schedule

Linking the model elements from the Selection Tree to the Tasks in the Timeliner schedule can also be completed using 'drag-and-drop'. Select the element from the selection tree and then 'drag-and-drop' to the 'Attached' column in Timeliner.

The 3D BIM model has now been linked to the schedule, which has completed the creation of the 4D BIM model.

4.2.6 Project Schedule Simulation

Once the 4D BIM model has been created, the schedule can be simulated. On the Simulation Tab in Timeliner, select "Settings" and modify the settings as required as shown in Figure 4.14. Once the settings are finalised select "Play" on the Timeliner.

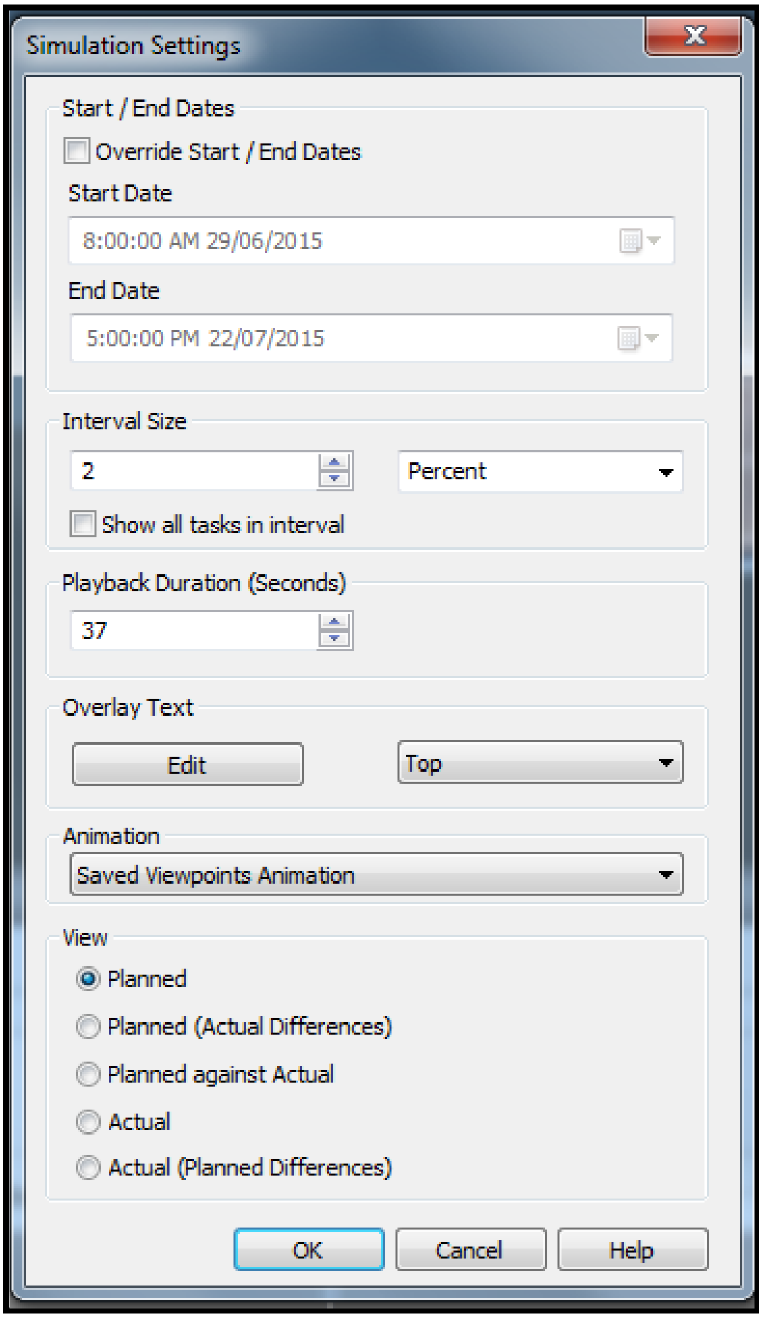


Figure 4.14 - Navisworks Manage project schedule simulation settings

The following figures 4.15, 4.16, 4.17, 4.18 show the 4D BIM Model being simulated:

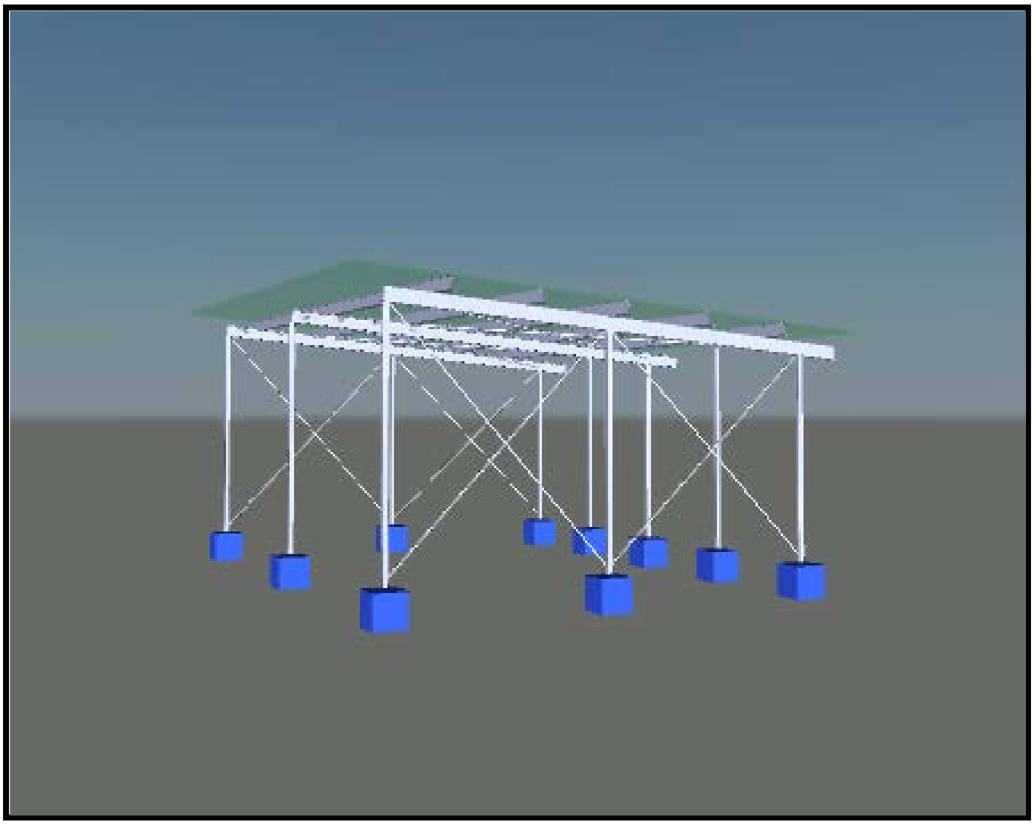


Figure 4.15 - Navisworks Manage Simulation – “roof under construction”

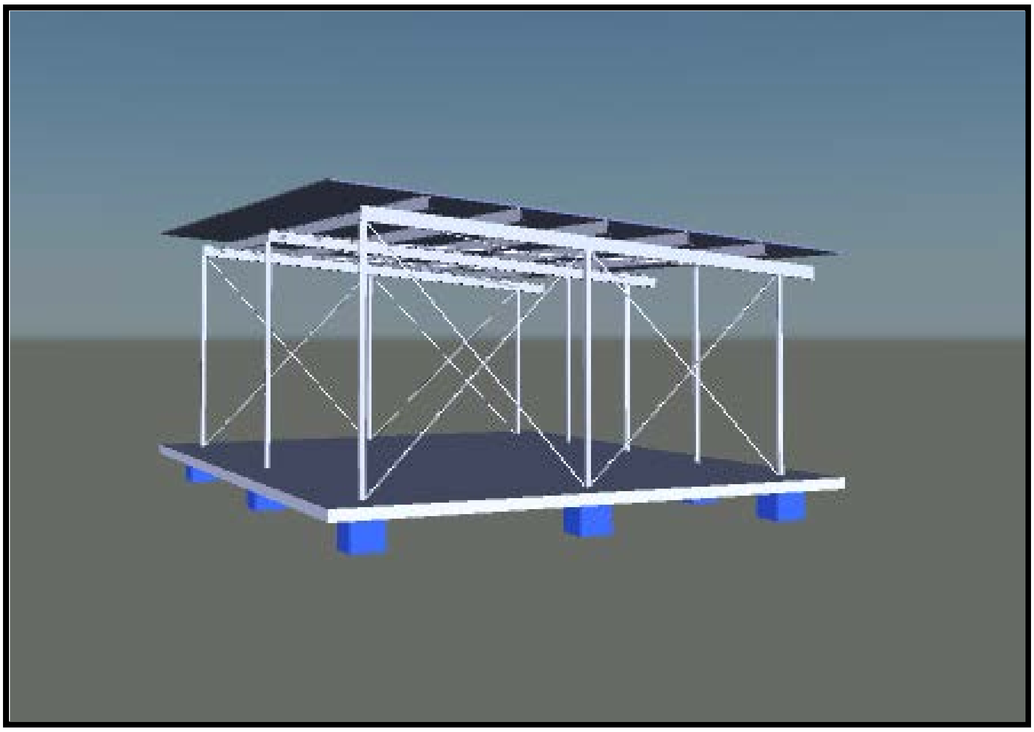


Figure 4.16 - Navisworks Manage Simulation – “roof complete”

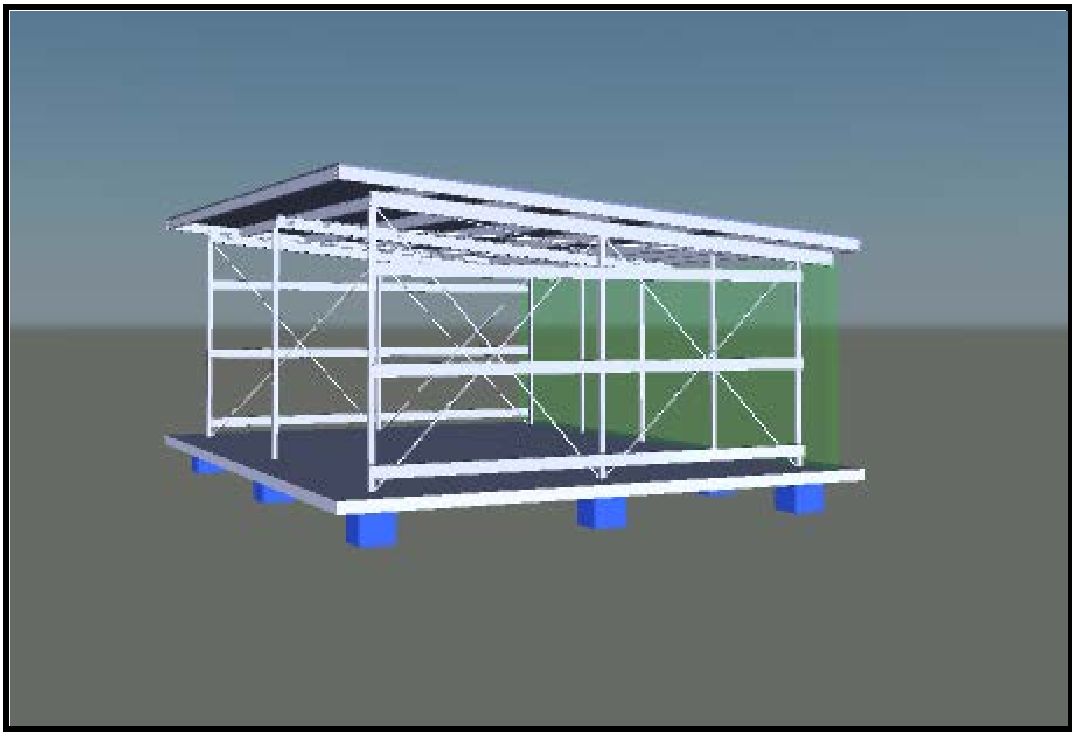


Figure 4.17 - Navisworks Manage Simulation – "wall under construction"

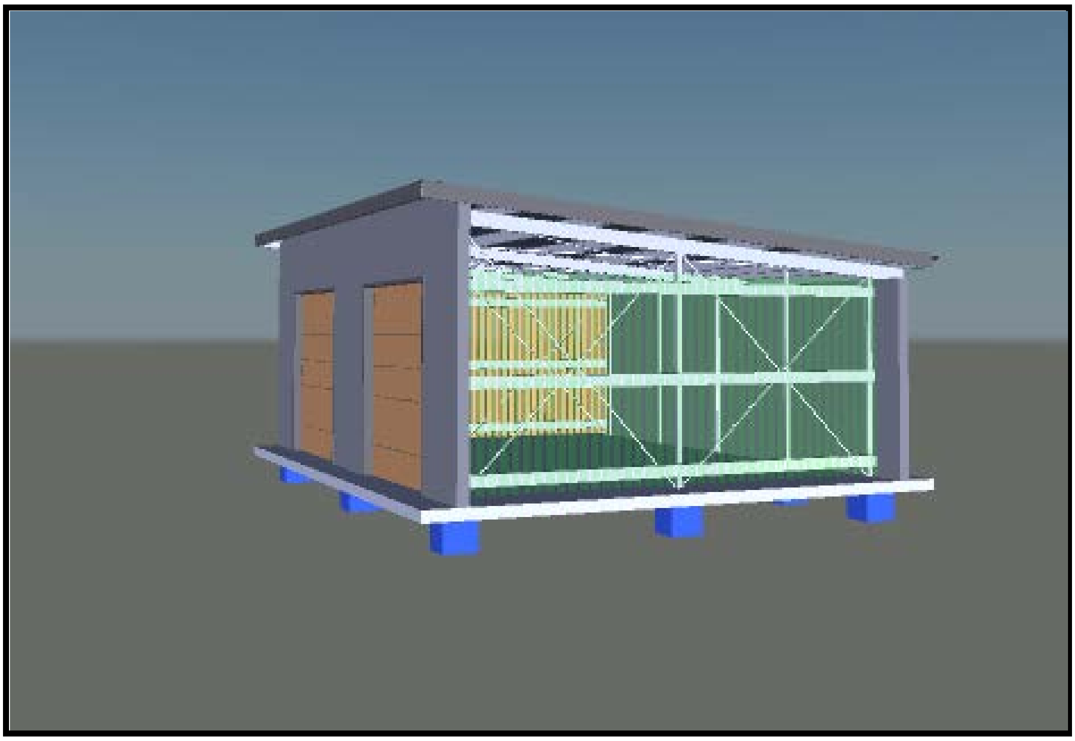


Figure 4.18 - Navisworks Manage Simulation – "wall complete and cladding under construction

4.3 Exactal CostX 2016

CostX has been selected for use in accordance with the requirements outlined in Section 3.3. The current 3D BIM software utilised by the organisation is Autodesk Revit, with which CostX is compatible. In order to upload the BIM model into CostX, the Autodesk Revit model must be exported into a .DWF file. Once the 3D BIM model is complete, export the .DWF file from Autodesk Revit

The following example procedures for creating the 5D BIM model have been formulated in accordance with the instructions as provided by *CostX 5.0 Advanced Manual* (2015).

4.3.1 Import Project 3D BIM Model

When opening CostX software, the default screen is as shown in Figure 4.19:

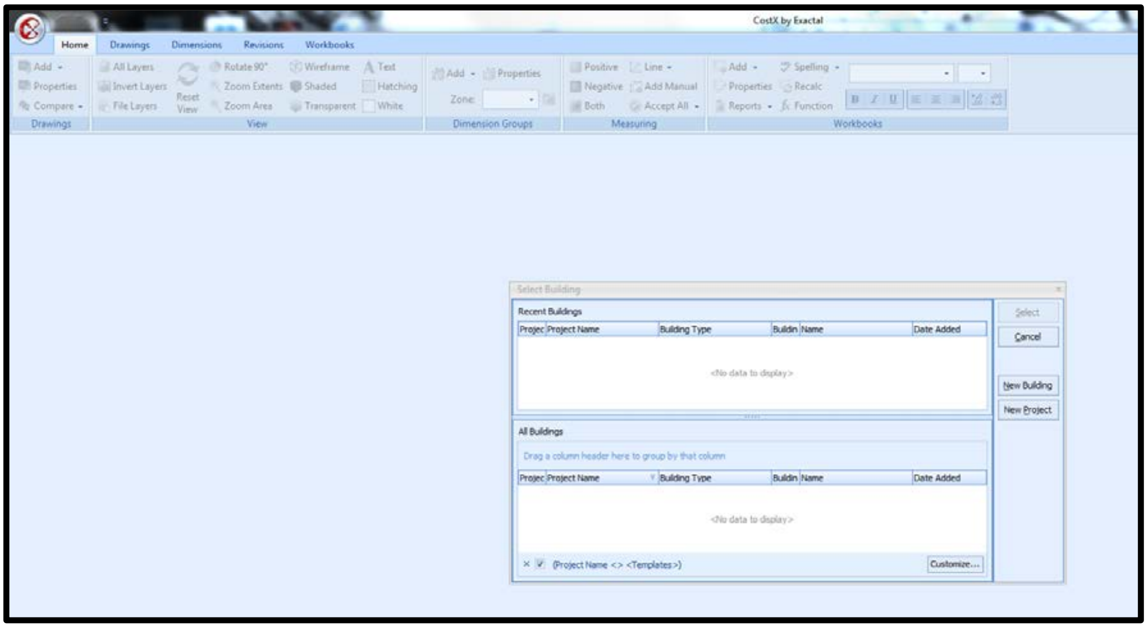


Figure 4.19 - CostX default screen

To commence works on the new project, click the ‘New Project’ tab to complete the details.

From the Drawing Ribbon click Add / New Drawing. Select the .DWF File

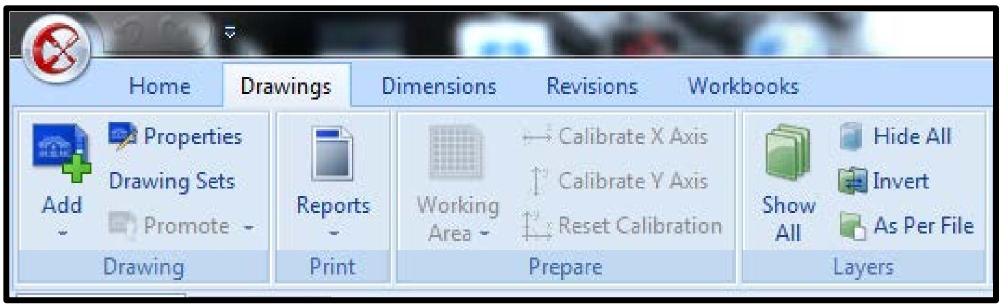


Figure 4.20 -CostX Drawing Ribbon

The 3D BIM model is open in the CostX programme as shown in Figure 4.21

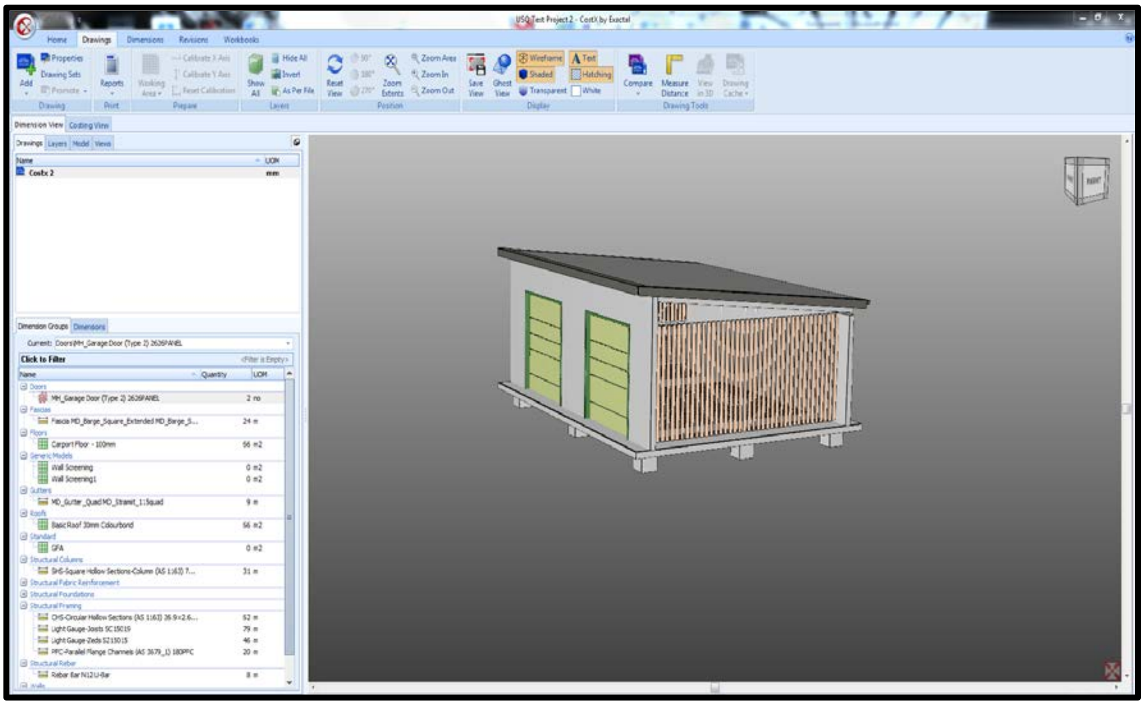


Figure 4.21 - 3D BIM model imported into CostX

Each of the model elements can be selected to review the properties – Right Click on the model Element and select ‘Object Properties’. This is the data that has been extracted from the Revit BIM model, as shown in Figure 4.22 on the following page:

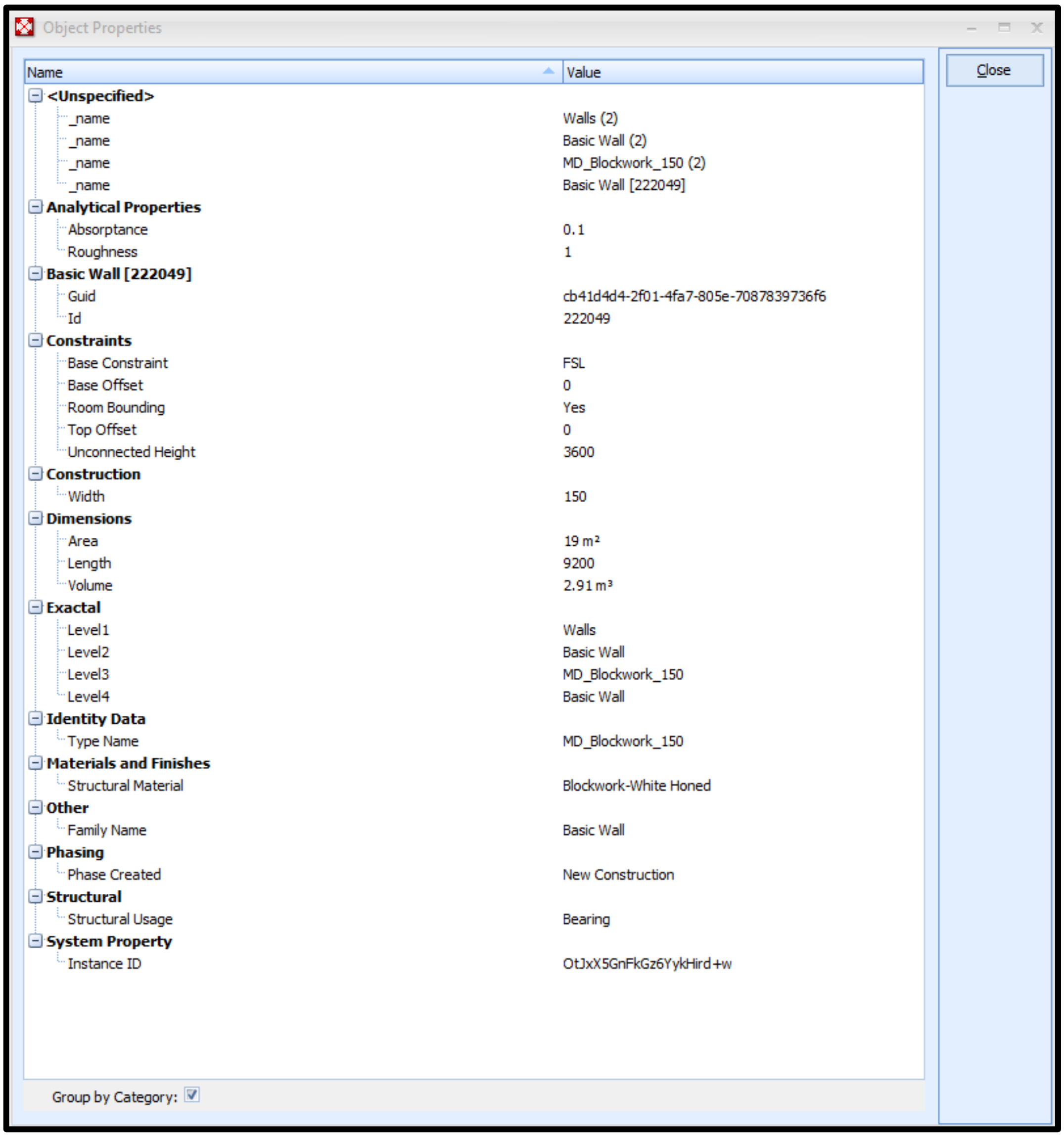


Figure 4.22 -CostX Object Properties

4.3.2 Dimensions from 3D BIM Model

CostX is able to complete automatic measurements for each of the BIM model elements through the use of a BIM template that is provided with the CostX software installation.

From the BIM tab in the Dimensions Ribbon – select Import / Import Dimensions using BIM Template as shown in Figure 4.23:

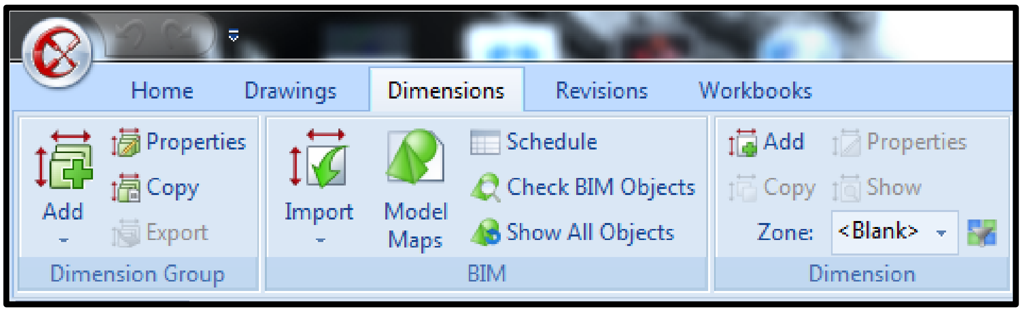


Figure 4.23 - CostX Dimensions Ribbon

Select the Revit General XLST program file.

Based on the Revit 3D Model hierarchy, dimension groups are established from the model in CostX with take-off quantities for each of the model elements in the hierarchy as shown in Figures 4.24:

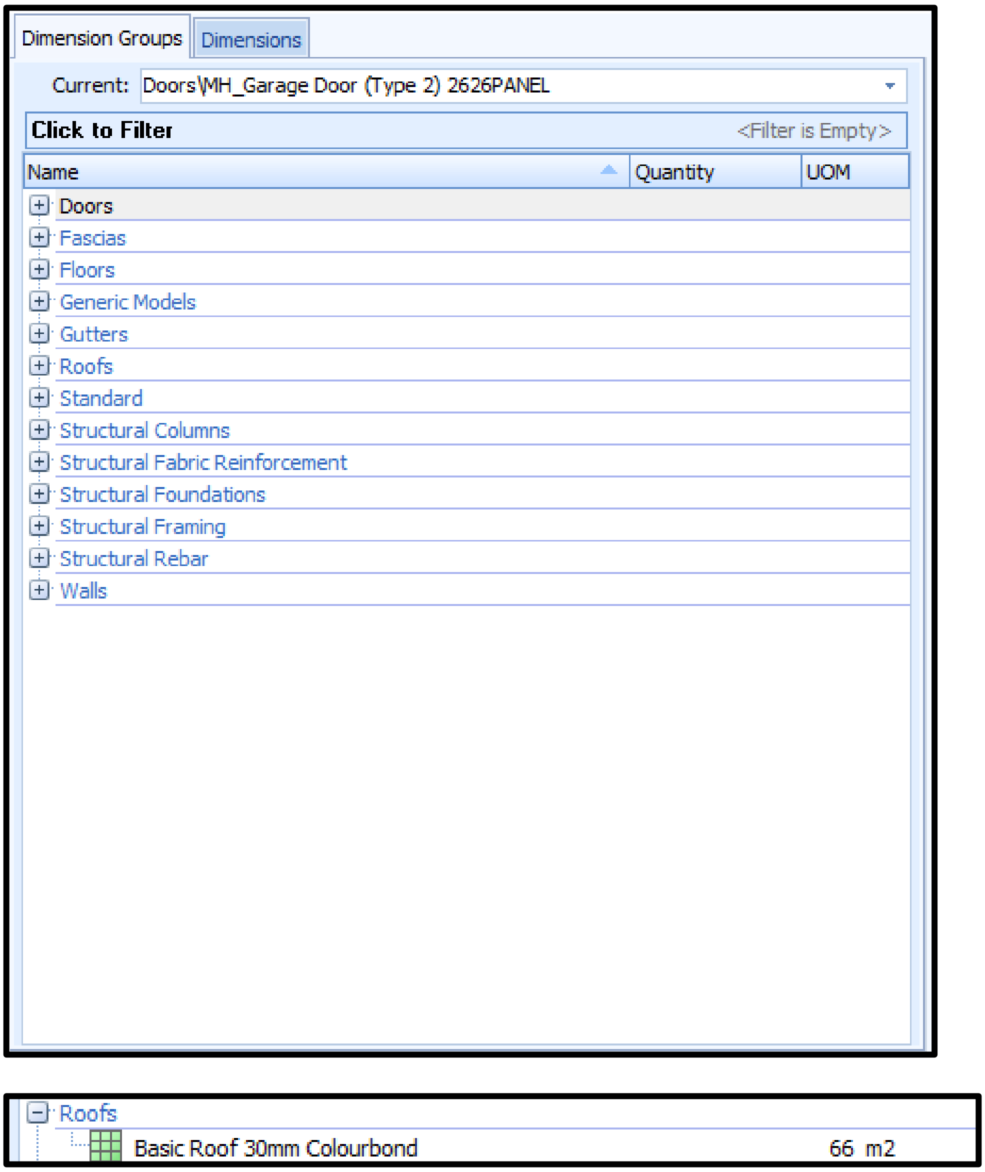


Figure 4.24 - CostX Dimension Groups

To undertake checks on the model elements used in the take-off, select the model element in the Dimension Group and from the Drawing Ribbon select 'Transparent' as shown in Figure 4.25:

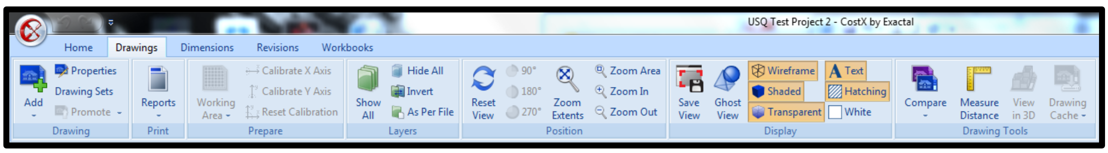


Figure 4.25 - CostX Transparent Display selections

The columns that were selected in the Dimension Group are then visibly highlighted Green in model in Figure 4.26:

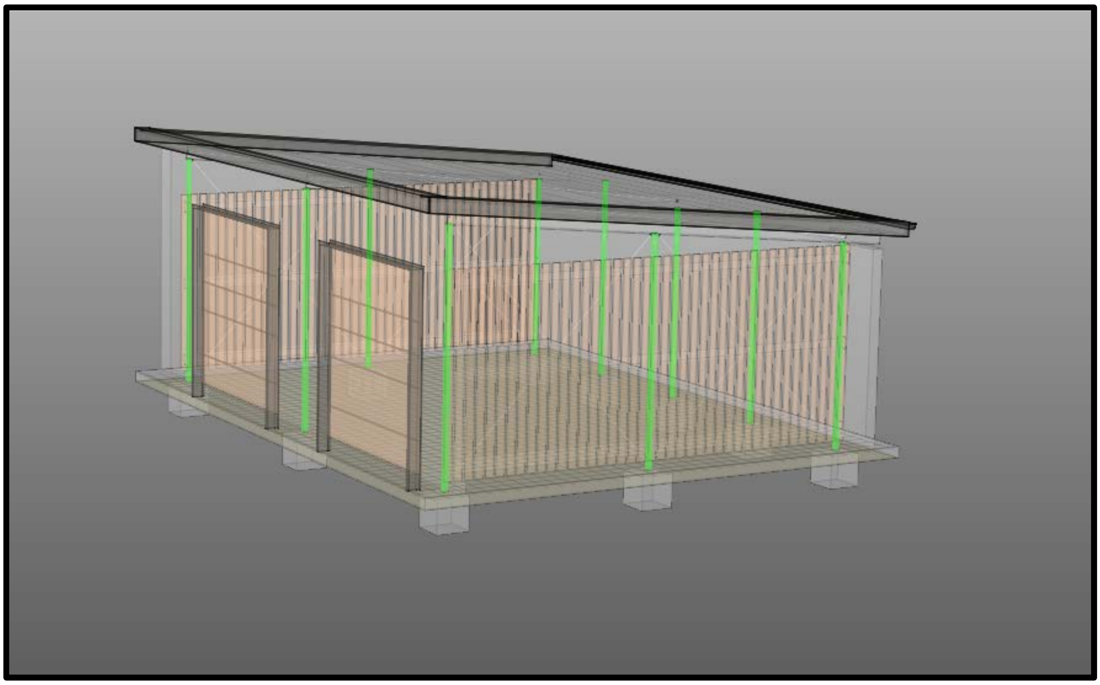


Figure 4.26 - CostX BIM model Dimension Group selections

4.3.3 Importing Rate Libraries into CostX

Rates are able to be added into CostX from different estimating packages, such as Buildsoft and .CSV files from Microsoft Excel, in addition to this, rates can be manually inserted into libraries. For the purposes of this research project, the rates have been imported from a .CSV file from Microsoft Excel. The rates that are used for import are approximate only, and a sample from the company's database.

To import the rate library, select System Administrator / Costing / Rate Libraries as shown in Figure 4.27 on the following page:

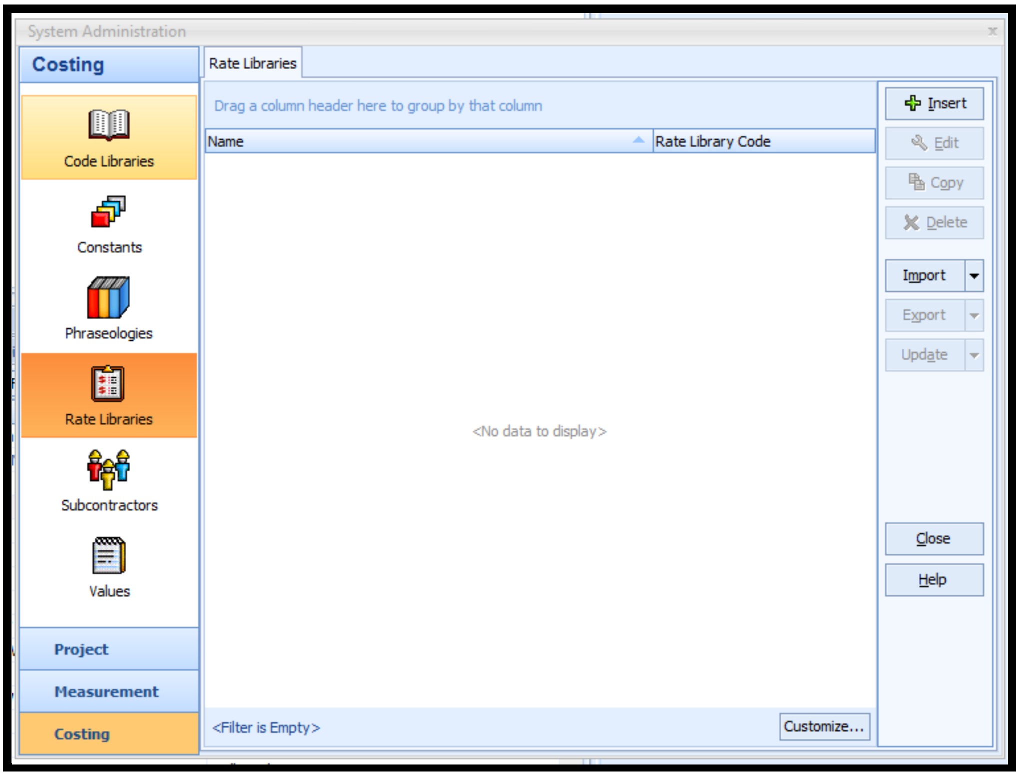


Figure 4.27 - CostX Import Rate Library selections

Select Import – and select the .CSV File and name the Rate Library as shown in Figure 4.28:

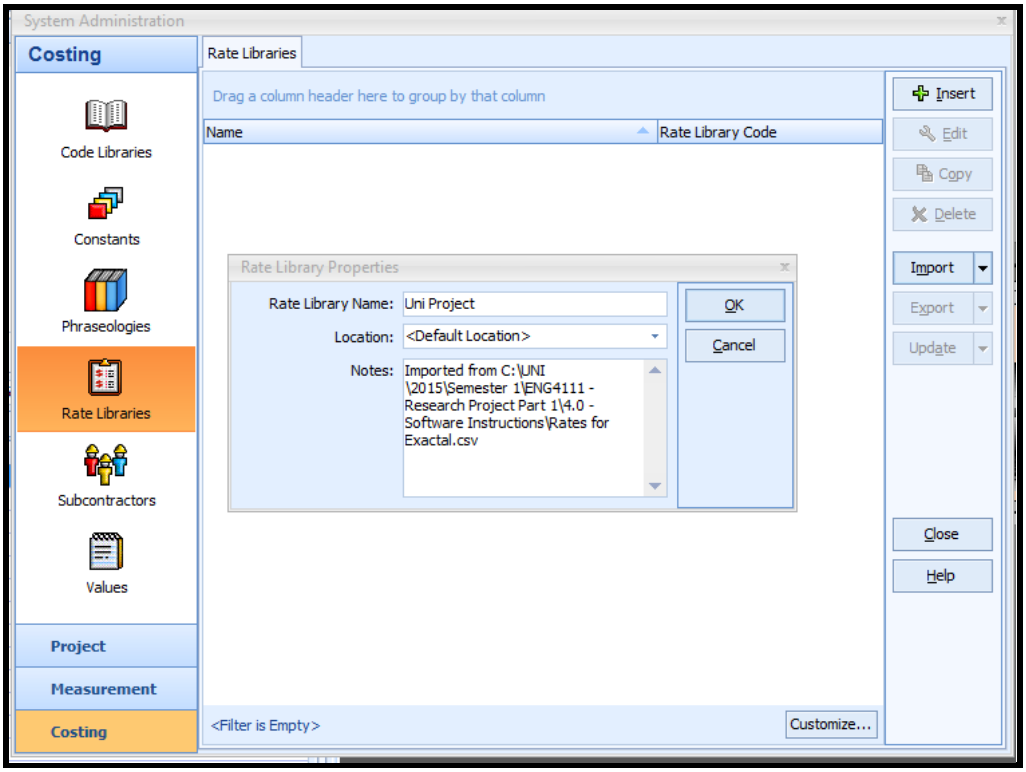


Figure 4.28 - CostX Rate Library Properties

The rate library properties are now included based on the information that has been uploaded, as shown in Figure 4.29:

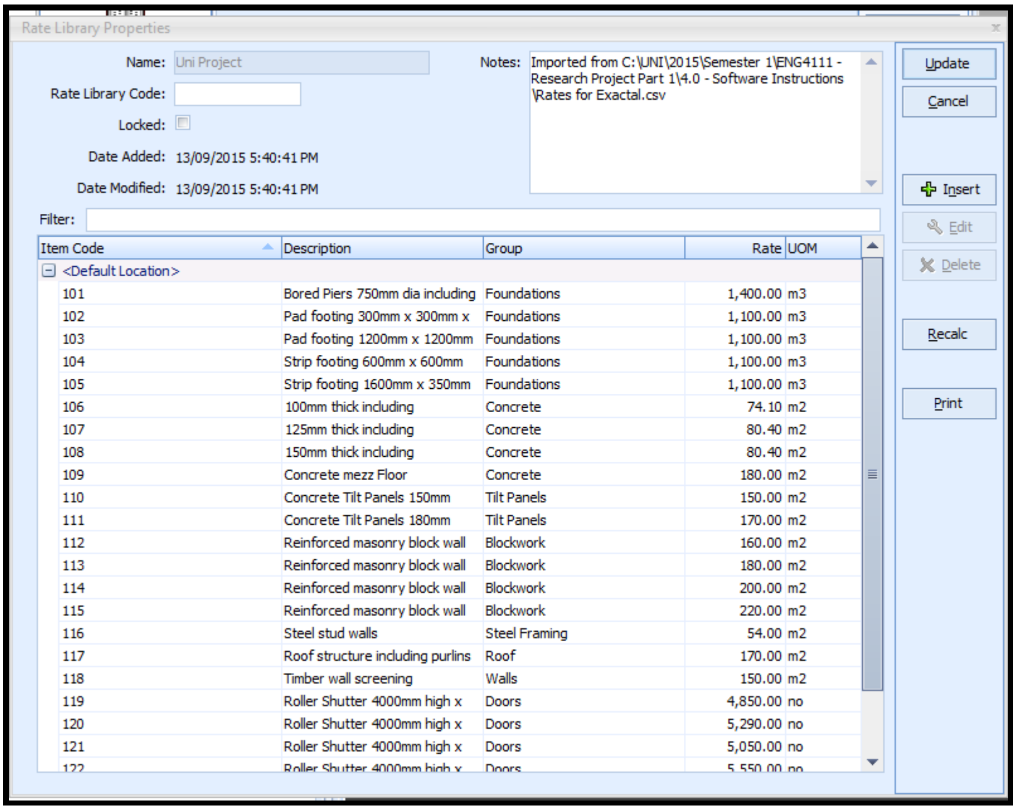


Figure 4.29 - CostX Rate Library import

4.3.4 Workbooks

The workbooks in CostX are linked to the BIM model and rate libraries, and are used to produce reports and estimates from the model.

To import the quantities to the workbook from the BIM model, select Generate Workbook from Dimension Group from the Workbook Ribbon. Complete the Workbook Properties as shown in Figure 4.30:

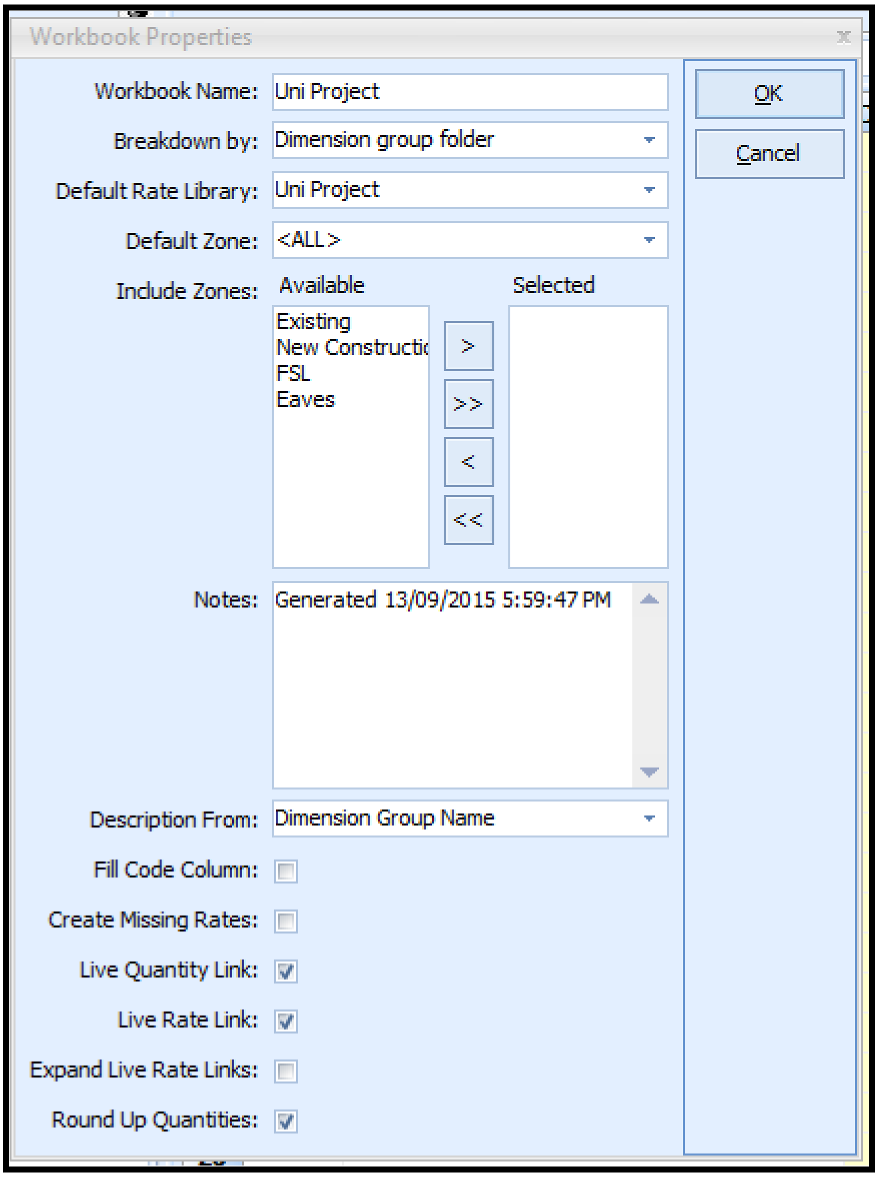


Figure 4.30 - CostX Workbook Properties

The dimension groups are now shown in the workbook, as shown in Figure 4.31. The workbook initially shows the Level One dimension groups; however by Double Clicking on the Cell in the "F" column, the Level Two groups will be shown.

	A:Code	B:Description	C:Quantity	D:Unit	E:Rate	F:Subtotal	G:Factor	H:Total	I:User1
1		Doors				9,700		9,700	
2		Fascias				0		0	
3		Floors				4,891		4,891	
4		Generic Models				0		0	
5		Gutters				0		0	
6		Roofs				0		0	
7		Structural Columns				0		0	
8		Structural Fabric Reinforcement				0		0	
9		Structural Foundations				0		0	
10		Structural Framing				0		0	
11		Walls				0		0	
12									
13									

Figure 4.31 - Dimension group import to workbooks

If the BIM model that has been provided has been established with the codes as specified in the rate library, the workbook will automatically establish costs against the elements in the BIM model and update the workbook. For the purposes of this Research Project, the 3D BIM model will not be altered; therefore the rates can be added as follows:

Select the Level Two of the Workbook for the roof as shown in Figure 4.32:

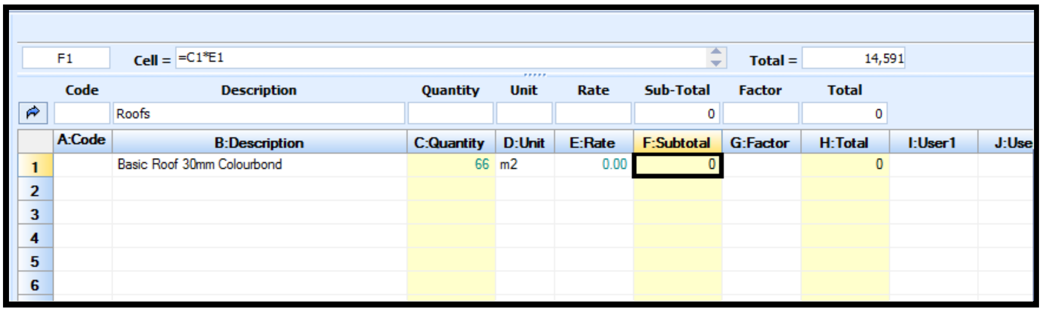


Figure 4.32 - CostX Workbook Level 2

From the rates Tab as shown in Figure – Drag and Drop the rate into the workbook rate column:

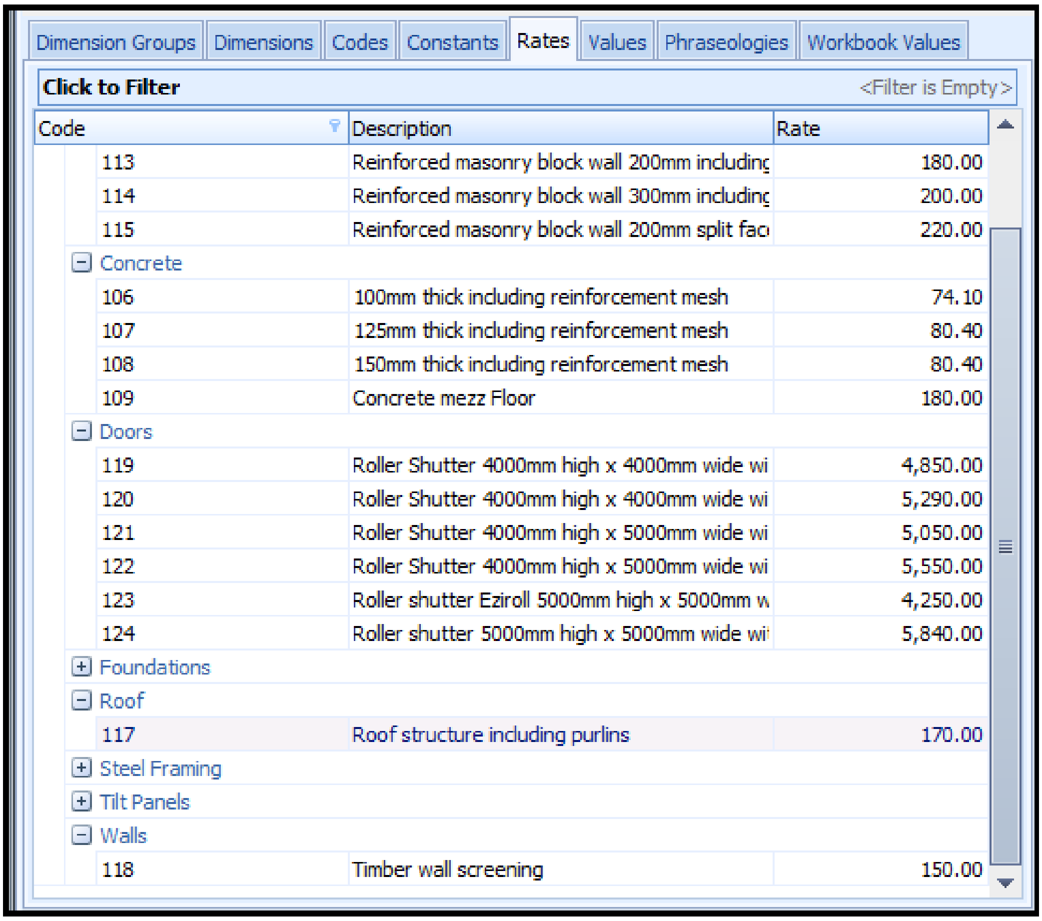


Figure 4.33 - CostX Rates Tab

The rate has been added to the workbook as shown in Figure 4.34. This process is continued until all rates have been updated to the workbook.

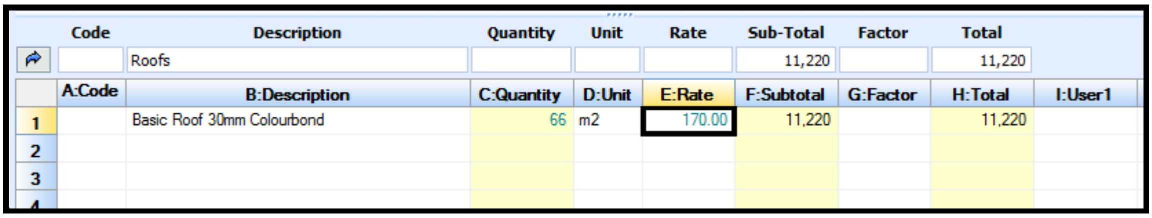


Figure 4.34 - CostX Workbook with rates inclusion

When all rates have been linked to the model elements in the workbook, the 5D BIM model has been created. From this model reports can be created for export from CostX.

Form the Workbook Ribbon select Reports and Print Workbook to Report, a list of reports available are then available, as shown in Figure 4.35. Determine the required report and select Generate.

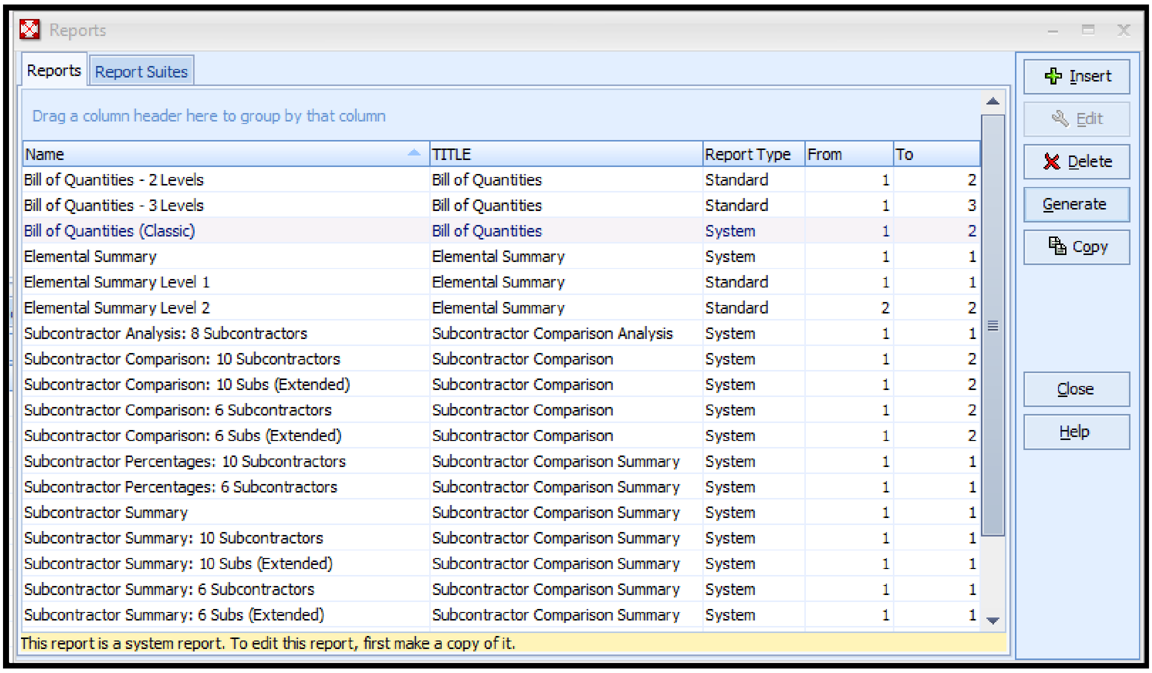


Figure 4.35 - CostX Report selections

4.4 Summary

4D and 5D BIM tools will be used in the Pilot Case Study and Historical Project Case Study 2. The guide has outlined the steps that will be undertaken when utilising Navisworks and Exactal CostX in the case studies, which will ensure reliability in the case study results.

CHAPTER 5 – RESULTS & ANALYSIS

5.1 Introduction

The foregoing literature review identified the use of 4D and 5D BIM has improved the performance of contractors on construction projects, however the studies into the use of these BIM tools has focussed on large scale projects. This chapter therefore includes the results of interviews and case studies undertaken as a means to examine the feasibility of utilising 4D and 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors.

Chapter 3 previously outlined the Research Project Objectives and sub-objectives for the project. Chapter 3 also included the methodology to be utilised as a means to achieve the projects objectives. This chapter provides the results and analysis for sub-objective 3 - Interviews, sub-objective 4 - Historical Project Case Study 1, sub-objective 5 - Pilot Case Study, and sub-objective 6 – Historical Project Case Study 2.

The results obtained from the Interviews conducted with key organisation members in Section 5.2 validated the findings of the literature review and achieved sub-objective 3 of the research project. Historical Project Case Study 1 augmented the concerns from the literature review and the interview findings. Specific issues were identified in the Building B basement that provided a focus for the second case study.

The Pilot Case Study was completed successfully, resolving the usage of 4D and 5D BIM tools; however the simplicity of the project in the Case Study therefore meant a definitive answer was unable to be determined on the feasibility of 4D and 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors.

Historical Project Case Study 2 was completed using the same historical project; however BIM tools were retrospectively adopted. The results of the case study indicate that Autodesk Navisworks (Navisworks) is a feasible BIM tool for managing and resolving key issues faced by medium scale D&B contractors, however further research needs to be undertaken on the feasibility of using of Exactal CostX (CostX).

All results included in this chapter have been obtained in accordance with the methodologies set out in Chapter 3.

5.2 Interviews

5.2.1 Introduction

The interview guide established in Section 3.4 was used as a basis for the interviews conducted with key organisation members. The interviews were completed, as a means to achieve sub-objective 3 of the Research Project, to validate the findings from the D&B literature review which were previously discussed in Section 3.4.3 Table 3.2, and are again provided in Table 5.1 on the following page:

Table 5.1 – Findings from D&B Literature Review

1	Budget and project timeframe improvements using the D&B method
2	The importance of the co-ordination between the design and construction departments in the D&B method to improve constructability
3	Reduction of claims when the D&B method is used
4	Financial risks associated with the use of the D&B method
5	Increased design responsibility associated with the use of the D&B method
6	Overlapping of the design and construction phases and the effect on scope changes

5.2.2 Response from Interviewees

The interviewee selection process was undertaken in accordance with the methodology Section 3.4.2, with the selected interviewees provided in Table 3.1. The questions have been previously provided in the Interview Guide in Section 3.4.3, Table 3.3 with a summary of the responses received for each of the questions from the Interviewees as follows:

Question 1
In your experience, what are the advantages to the use of the D&B method?

The literature review identified a number of advantages for the use of the D&B method. The aim of this question was to identify specific advantages for the organisation.

The construction manager identified that the use of the D&B method was advantageous for the organisation due to the ability to provide

'input from both sides, so as to avoid non practical design only approaches to the project, as well as reduced construction timeframes'.

The input from the design and construction team was identified as an area to improve constructability, as well as ensuring the project is completed on time and within budget.

The CAD manager also acknowledged that the use of the D&B method aided the design phase through the *'input from the construction team'*. In addition to this design co-ordination changes are able to be made from an *'informed position'*.

The D&B method was also identified as a way for the organisation to review alternatives during the construction phase which would, according to the construction manager,

'achieve the same end result and is a cost saving approach to building. These options can be construction techniques and materials and also finishes types and materials'.

This approach enables the organisation to undertake reviews throughout each phase of the project, and make alterations however still meet the project requirements upon completion.

The responses therefore suggest that there is a significant advantage to the use of the D&B method. The D&B method is able to achieve both reduced construction timeframes, as well as improved budget performance which was also identified in the literature review as an advantage to the D&B method. Key to this success however, is the collaboration between the design and construction teams to improve constructability on the project.

Question 2

In your experience, does the use of the D&B method increase the financial risk for the contractor?

The literature review identified that the use of the D&B method increased the financial risk for the contractor, due to the requirement to tender on projects when the design has not been completed. In addition to this, the D&B method reduces the possibility for the organisation to make claims for changes to the design, unless they are changes as requested by the client.

The construction manager however disagreed with these findings, noting that if the contractor is experienced and has an *'in house design team'* the ability to control the design and ultimately the costs on the project is improved. It was noted that the structure of our organisation, with a full in house design team enabled a higher level of control; therefore reducing the risk, however key to reducing the financial risks was the constructability in the design.

The project manager also identified that the D&B method can be a method to reduce possible financial risks, as the method can be used to

'reduce timeframes for requesting information, which reduces delays onsite as well as increasing the potential for value engineering'

Question 3

If the financial risks are increased, in your experience what are the causes?

There were areas that were identified by the construction manager as potential causes of increased financial risks for the contractor. Causes such as a

'lack of understanding of the clients requirements, poor communication between the builder and the client and potential ground issues if sufficient investigation has not been undertaken by the contractor prior to submitting the price'.

Question 4

What are some methods available to reduce the financial risks for the contractors?

Following on from the possible causes of the risks identified in Question 3, the construction manager acknowledged a number of methods available to the contractor to reduce the financial risks:

'Ensure clarity with the inclusions and exclusions, and explain why. Undertake geotechnical investigations prior to confirming the final price. Review available infrastructure for the project to ensure the price covers the costs associated with providing infrastructure if required'

The Project Manager also agreed that the ability to reduce delays during the design phase is a key advantage to reducing the contractor's financial risk.

The result of Questions 2, 3 and 4 therefore suggest that the findings from the literature review regarding increased financial risks are not replicated in the organisation. This is in part due to the ability for the organisation to control the design of the project. It should be noted however that there was an agreement that in the event of, for example the misunderstanding for of the client's requirements, the financial risks can occur. In order to alleviate this risk, clarity in the tender submissions is the key.

Question 5

Does a contractor undertaking a project using the D&B method increase their design responsibility?

The aim of this question was to validate the findings from the literature review that the contractor does increase the design responsibility on D&B projects.

The construction manager confirmed that the as a D&B contractor the organisation was responsible for the entire design projects, however he identified that this was not necessarily a disadvantage to the use of the D&B method. The use of the D&B method provides the contractor with a level of *'control'* over the project enabling changes if required, while still ensuring that the project requirements are met.

The project manager agreed that the contractor does assume a greater level of design responsibility however identified that one of the key advantages to our organisation is the *'right design team setup'*, whereby having the design team in house significantly reduces the response timeframes that can be encountered when utilising external design consultants.

The results suggest that the findings from the literature review that the organisations design responsibility is increased under the D&B method is correct. The responsibility for all design work for projects that the organisation undertakes, the design remains solely their responsibility.

Question 6

Although a successful D&B organisation, has The Organisation in your experience, encountered situations on projects where additional costs have arisen due to the rectification of design errors?

The aim of this question was to provide an understanding of the link between the findings of the literature review and the organisation.

The construction manager identified in the organisation there had been situations where rectification works were required; however these rectification works were minimal and required on an infrequent basis. A key comment here was that:

'each time that this arose, the client was favoured at all times, this is related to the increased design responsibility that the contractor undertakes. If you don't take responsibility and give the design the full attention and input it needs, it will cost you'

The project manager also agreed that the occurrences were few and far between, however when they did occur *'they were there the result of constructability issues'*.

Question 7

If they have, can these additional costs be claimed as a variation to the client?

A finding from the literature review was the reduction of claims made by contractors. The aim of this question was to validate these findings, by understanding the claims that are made by the organisation when these works occur.

The construction manager identified that due to the increased responsibility for the design, in the event that the costs are incurred due to design co-ordination changes, costs are not claimed.

'If the costs relate to changes required due to requests from the client, these costs are claimed as a variation.'

The general agreement between respondents was that one of the key areas that can aid in reducing the costs that cannot be claimed from the client is to improve the constructability of the designs. Changes to the design after construction works have commenced cause not only, time delays due to disruption of trades, but also potentially additional costs. The constructability of a design however is not a design error, but how easy the design will be to construct. Improving the constructability will not only save time, but also costs.

The findings of Question 6 and 7 suggest that the increased design responsibility does require the contractor at times to undertake rectification works, these costs are also the responsibility of the contractor and variations cannot be claimed.

Question 8

Are scope changes requested by clients on projects? If yes, what are some examples?

The construction manager identified that changes requested by the client are primarily internal changes to the design,

'not often are they large structural changes such as building size and height etc. Examples of changes are fitout, partition locations, change to windows, and changes to finishes such as flooring'

The CAD manager also acknowledged that the changes requested by clients on projects were *'primarily office fitout changes'* and occurred throughout the design phase, as well as the construction phase.

Question 9

Does the timing of the request for scope change affect the variation cost – eg if the design is still underway, however construction has commenced?

A finding from the literature review was the increased costs associated with scope changed when the D&B method is used. The aim of this question was to validate whether there are cost impacts to scope changes.

The CAD manager confirmed that scope changes are requested by clients *'when the design phase of the project is nearing completion'.*

The construction manager also confirms that this does have a significant impact on the cost of the variations.

'Scope changes during construction will always cost the client more, if items are already under construction and require modification. A contributing factor is that the client does not always understand what they are getting until the project is constructed'.

The findings from Question 8 and 9 have identified that scope changes are requested on projects, and the costs for these changes are impacted based on the phase of the project. However, ensuring that there is significant co-ordination with the client on the project from commencement, reduces the requests for scope changes form clients.

Question 10

Are the design and construction phases of projects overlapped in order to achieve shorter project timeframe and in your opinion is this method successful in achieving the shorter timeframe?

The literature review identified that the overlapping of the design and construction phases of the project were a significant advantage to the use of the D&B method.

The construction manager agreed that this approach was used in the organisation.

'This is successful if appropriate forward planning is undertaken and successfully managed'.

The project manager agreed that one of the key advantages to commencing construction works was

'*it speeds the design phase up considerably. By reducing the design time, coordination is improved on the project as decisions are made quickly.'*

Question 11

Are there cases where the construction phase of a project has been commenced too early, whereby there are delays on site while the remainder of the design is being completed?

The literature review identified that while the overlapping of the design and construction phases provided advantages to organisations due to reduced timeframes, if the phases were overlapped too far, delays could occur. The aim of this question was to validate whether this was an occurrence in the organisation.

The construction manager confirmed that while there are instances where certain areas of the design aren't complete, works are still able to continue therefore delays are not an occurrence in the organisation due to the overlapping of the design and construction phases.

'A benefit to having the design team in house enables works to be prioritised based on what designs are required onsite, this ensures that site works aren't delayed'

The project manager was of the same opinion as the construction manager with regards to this question. There are instances where projects have had to stop works due to the design and or approvals for the project not being complete; however these were not regular occurrences.

The results of Questions 10 and 11 show that while the overlapping of the design and construction phases was identified in the literature review as a disadvantage due to the potential for delays to be encountered, this is not an issue that occurs within the organisation. The problem is alleviated in the organisation due to the ability to prioritise design works as required onsite with the in house design team.

Question 12

In your experience can the D&B method increase the contractor's responsibility in achieving the project completion date, because the opportunity to claim for additional time due to design errors is removed?

The literature review identified that the use of the D&B method, reduced the possibility for claims, such as delays due to the late response for additional information from the client.

The construction manager was in agreement that the contractor undertaking the D&B method does undertake an increased level of responsibility in ensuring the project completion dates are met.

'Any delays that occur during the design phase of the project are the contractor's responsibility and therefore claims cannot be made'.

There was an agreement with the project manager that

'*the contractors responsibility is increased on D&B projects, however the key is having a clear indication of the performance with regards to design parameters, as well as building in stages such as obtaining staged building approvals to commence works to a certain point while the design and approvals as progressing. Also, to lessen the risks ensure the constructability of the designs*'.

The results of this question have confirmed the findings from the literature review, that the contractor's responsibility to achieve the project completion date is increased when undertaking the D&B method.

5.2.3 Summary - Interviews

The interviews with key organisation members were undertaken as a means to validate the findings of the literature review as outlined in sub-objective 3 in the Research Project Objectives, included in Section 3.1. The interview process has identified that there are areas where the findings from the literature are validated. A key finding of the literature review was the budget and timeframe improvements when using the D&B method. Furthermore the literature review identified the importance of the constructability of the designs relying upon the co-ordination between the design and construction teams of the project. There was an agreement in the responses to Question 1, that the use of the D&B method reduced construction timeframes and also improved budget performance on projects. The use of the D&B method was also identified as a key method to improving the coordination between the design and construction teams, this validated the findings from the literature review.

Increased financial risks for contractors undertaking projects utilising the D&B method due to pricing projects when the design is incomplete, was a key finding of the literature review, however the responses from interviewees to Questions 2 and 3, contradicted this finding. There was an agreement in the responses, that the control the organisation has over the design of the project, improved financial performance rather the increasing the financial risk.

The increased design responsibility is a key component of the D&B method, and this was identified in the literature review. There was a consensus in the interview responses for Questions 5, 6 and 7 that the contractor does have an increased design responsibility in the D&B method. In the event that there are errors, or modifications required to the design that are not at the request of the client, the costs are at the expense of the contractor which is a financial risk associated with the increased design responsibility. A trend in the interview findings was the importance of the constructability of the designs, due to the increased design responsibility. Changes to the design, can cause disruption to the trades as well as the project schedule which ultimately affects the costs incurred.

The timing of scope changes also was raised as an area that significantly affects the costs of the works. When works have commenced, there are additional costs to make the required changes. There was an agreement in the responses to Questions 8 and 9 that requests for scope changes do occur while the design is still underway, however due to the overlapping of the design and construction phases, construction works have also commenced which validated the findings from the literature review. The timing of scope changes therefore does have an effect on the costs required to undertake the change.

The overlapping of the design and construction phases of a project was identified as both an advantage and also disadvantage in the literature review. Timeframes are able to be shortened, however at the same time there is a potential for delay in the event that the design is overlapped too far. There was an agreement in the results of interview Questions 10 and 11 that this issue does not occur within the organisation. The problem is alleviated in the organisation due to the ability to prioritise design works as required onsite with the in house design team, therefore delays are avoided.

The findings from the literature review have been validated, and therefore sub-objective 3 from the Research Project Objectives has been achieved. A trend in the interview findings was the importance of the constructability of the designs. The constructability of designs has an affect not only on the projects programme performance, but also the budget performance. Furthermore, when the designs have to be modified due to constructability concerns, additional costs are not recoverable from the client. The constructability of designs is therefore integral in the success of D&B Projects, and is a key issue in the management of D&B projects. Further investigation with therefore be undertaken on the use of 4D and 5D BIM tools in managing and resolving these concerns.

5.3 Historical Project Case Study 1 – Commercial Development

5.3.1 Introduction

The historical project case study was completed as a means to augment the concerns identified in both the literature review and interview results, and therefore achieve sub-objective 4 of the Research Project Objectives. The historical project case study was undertaken in accordance with the case study protocol as outlined in Section 3.7.

5.3.2 Overview

The selected project '***Project A***' was completed in 2013 and consisted of two buildings, a retail building and a church assembly hall and offices. Both buildings in the development included basement car parking and three storeys, with a central external car park area. The foundation design for the project included strip footings to the perimeter blockwork walls, pad footings to the base of the columns and localised bored piers in building B basement. The design included a structural steel frame, and a combination of blockwork, concrete tilt panels and soldier pile constructions. The project was selected in accordance with the project selection requirements included in the case study protocol included in Section 3.7.2.

The project had a combined floor area of 2578m2 on a site of 3323m2, located within the central business area of a Sunshine Coast township between a motel and business offices. The site works consisted of an in ground stormwater treatment device, as well as landscaping internally and to the street frontages in accordance with the Development Approval Requirements.

All architectural, structural, hydraulic and civil design was undertaken internally, with Design and Construct Electrical and Mechanical subcontractors engaged on the project.

5.3.3 Contract

The contract utilised on the project was an amended version of AS4902-2000. The following clauses relevant to this research project were included within the contracts general conditions:

Design and documentation development

The Contractors obligation under this condition was to complete all design works and required statutory approvals, so as to ensure that the completed works met all principal project requirements.

The contractors design obligation was also covered by a contractors default clause, which enabled the principal to take further action such as terminate the contract, if the contractor failed to perform the design obligations.

The inclusion of this condition within the contract aligns with the findings of the literature review in that the contractor assumes all design responsibility for the project in D&B projects.

Time and Progress

Claims for delays on the project were limited to:

- inclement weather
- a force majeure event
- acts, omissions or defaults by the superintendent or principal.

Delays caused due to design changes and or omissions on behalf of the contractor are excluded. The project timeframe for the work under contract was set as 28 weeks from the receipt of all council approvals.

In the event that the project timeframe exceeded 28 weeks, a clause for liquidated damages was included in the contract whereby the principal was entitled to claim $1000.00 for every day after the 28 weeks that the project was not complete.

The inclusion of this clause within the contract provides a level of certainty for the client regarding the completion timeframe. Regardless of the delays that the contractor may encounter within the design of the project, and any possible co-ordination issues that may arise whilst works are being undertaken onsite, the project timeframe does not change without financial penalties.

Contract Sum

The contract was entered into with a lump sum of $4, 365, 000.00 for the works, which did not include any provisional sum amounts. The principal's project requirements included preliminary design documents

- design brief
- site survey plan
- amended negotiated decision notice
- acoustic report.

The principal's project requirements also included the Contractors Design Proposal and Project Outline.

The tender for the project was provided by the contractor, based on minimal documentation which has been identified in the literature as a disadvantage of the D&B method for contractors. A contingency sum for use against unknowns was not allowed for in the contract, which increased the financial risk for the contractor.

5.3.4 Subcontractor Variations

As identified in the literature review, the use of the D&B method increases the financial risks for the contractor which is primarily due to the contractor pricing the project with minimal design and documentation information available during the tender. In addition to this, the increased design responsibility requires that the responsibility for any costs associated with changes or omissions in the design documentation is the responsibility of the contractor if it is not a scope change requested by the client.

Site instructions were issued by the contractor to subcontractors for instructions and approvals to undertake additional works onsite. Subcontractor variations are claims by subcontractors for additional works outside their scope of works. The site instruction register maintained by the contractor provided the following information regarding subcontractor variations:

- date
- site instruction number
- subcontractor
- scope of additional works
- reason for change
- approved cost of works

A total of 43 site instructions were issued as a result of subcontractor variations for the project, with a summary of these variations provided in Appendix C. The variations have been analysed, and summarised into three groups, these being Design, Site Works and Client Scope Changes.

Design Costs

Design costs include information excluded from the tender documentation provided to the subcontractors and design co-ordination errors. The costs of design errors are unrecoverable from the client, which is attributed to the increased financial risk for the contractor undertaking D&B projects.

Site Works

Site works costs, are costs associated with additional works that arose onsite. The changes were not related to design errors or requests from the client. Works include construction of temporary services for use during the construction phase of the project, as well as increasing the scope of works of the subcontractor not previously allowed for in the subcontract agreement scope of works. The costs of site works subcontractor variations are also unrecoverable from the client, which is attributed to the financial risk for the contractor.

Client Scope Changes

Site instructions issued to Subcontractors for client scope changes, are for works relating to variations for the principal. The costs of these works are recoverable from the client.

The aim of analysing the subcontractor site instruction register, was to validate firstly whether there was a relationship between the use of the D&B method and increased financial risks as identified in the literature, and secondly to identify specific errors that occurred on the project that the use of BIM tools would help to alleviate.

Figure 5.1 on the following pages provides a summary of the number of subcontractor variations claimed on the project:

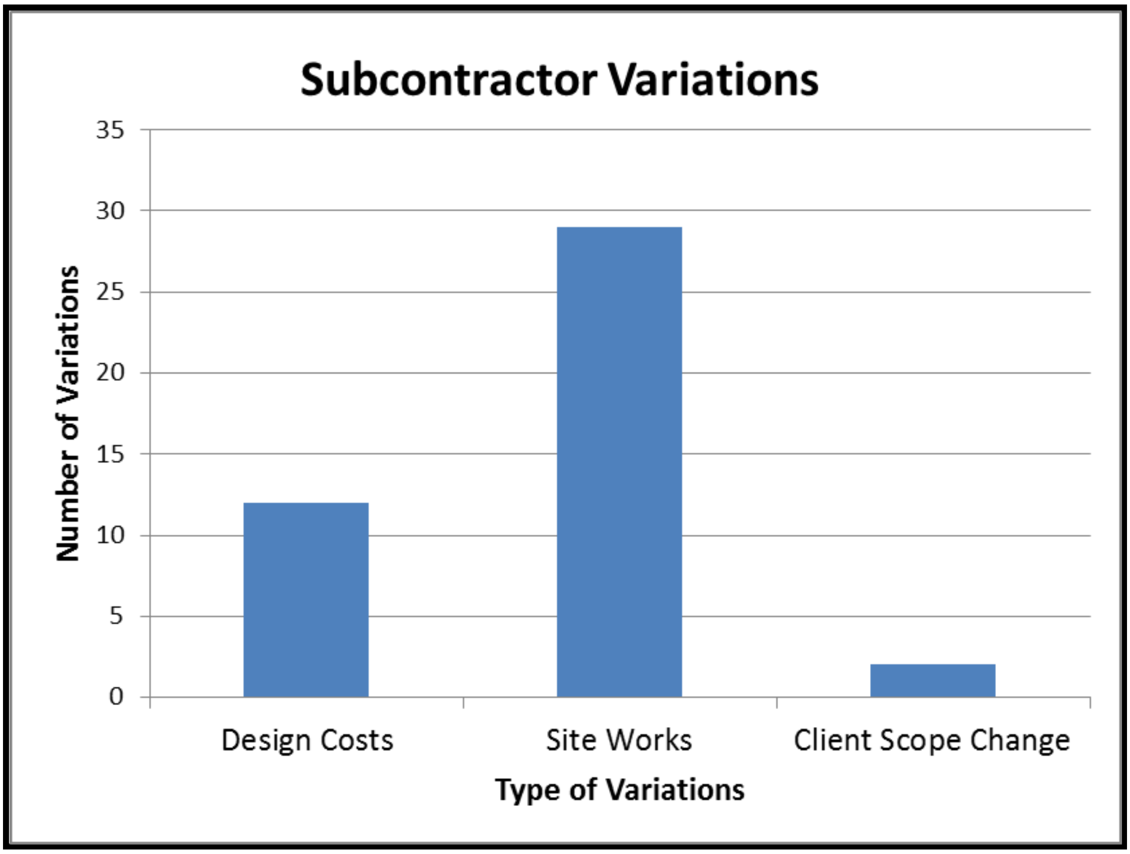


Figure 5.1 - Subcontractor Variation Summary

The results identified, show a significant number of the variations are related to site works variations, with a moderate number attributable to design variations and the least number of variations relating to client scope changes. These results have validated the findings of the literature review, that there is an increased financial risk for contractors in undertaking projects using the D&B method due to the number of variations that were claimed by subcontractors that were not able to be recovered from the client.

A summary of the subcontractor variations that relate to design costs are shown in the following Table 5.2:

Table 5.2 - Design Cost Subcontract Variations

Trade	Works	Design Costs
Foundations	Revised Pier Design	Yes
Hydraulics	Various Hydraulic Changes	Yes
Hydraulics	Stormwater Changes from Tender Drawings	Yes
Hydraulics	Stormwater Changes from Tender Drawings	Yes
Concrete Tilt Panels	Reduction in scope of works - Delete Panels	Yes
Blockwork	Increase in scope of works - Add Blockwork	Yes
Roofing	Supply and install additional cappings	Yes
Concrete Tilt Panels	Hebel infills	Yes
Hydraulics	Change to Stormwater Design	Yes
Blockwork	Increase in scope of works - Add Blockwork	Yes
Concrete	Reduction in scope of works - Reduced Footings	Yes
Formwork	Increase in scope of works - Add additional formwork due to wall design change	Yes

The design cost subcontractor variations have been further analysed utilising the projects design documentation with an aim to determine the causes of the design changes and the further impact on the project, if any:

Trade - Hydraulics

An analysis of the hydraulic trade subcontractor variations have identified that the costs were a result of works not included on the tender documentation. The works were therefore priced after the subcontractor had been awarded the Subcontract Agreement for the project.

Trade - Roofing

Costs associated with the supply and installation of additional cappings in the roofing package was associated with additional works not included in the tender documentation. The works were therefore priced after the subcontractor had been awarded the Subcontract Agreement for the project.

Trade – Foundations, Concrete, Concrete Tilt Panels, Formwork and Blockwork

The costs associated with these trades, each relate to the same design change.

Multiple revisions of the following drawings were used as the basis for the analysis of these design costs:

Table 5.3- Drawings used in Design Cost analysis

Drawing Number	Drawing Title
B300	Footings Plan
B302	Internal Concrete Plan – Basement
B303	Internal Concrete Plan – Level 1
B308	Details & Section Details
B400	Tilt Panel Elevations – Sheet 1
B401	Tilt Panel Elevations – Sheet 2
B402	Tilt Panel Elevations – Sheet 3

Based on an analysis of the documentation, the subcontractor tender documentation included the following works in the Building B Basement:

- strip footing to perimeter
- concrete tilt panel to from basement floor to level 1 floor
- concrete basement floor slab
- condek level 1 floor slab, including structural steel floor framing
- concrete tilt panels to southern side of level 1 from level 1 concrete floor slab to underside of roof structure
- feature cast in situ concrete blades to the external north eastern elevation.

Changes to the documentation between the documentation issued for tender, and the final issue of drawings resulted in the following design for Building B:

- strip footing to north, east and west sides of basement and partially to southern side
- soldier piles to southern side of basement from basement to level 1
- concrete tilt panels to north, east and west sides of basement
- concrete basement floor slab
- condek level 1 floor slab, including structural steel floor framing
- blockwork to southern side of level 1 from level 1 concrete floor slab to underside of roof structure.

The construction manager for the project was interviewed to ascertain the cause for the design change:

Question 1 – What was the cause for the design change in Building B Basement and Level 1 for the project?

'The design change was a result of constructability in the design. The previous design required the works to be constructed compartmentally with trades, which would require the works to stop and start in small areas. The original design would require significant props for the concrete tilt panels, which would have caused significant delays the works continuing due to access restrictions'

Question 2 – In your opinion, if the project construction was simulated, would this have been beneficial in resolving this issue prior to commencing construction works?

'Yes, had the project been simulated prior to commencing onsite the main constructability concerns in the original design would have been highlighted'

The findings from this analysis have identified the importance of the constructability in the design, for success on D&B projects. 3D BIM is used by The Organisation; however the use of 3D BIM alone in the review process was not able to identify these issues. In the event that the construction of the project was able to be simulated prior to commencing onsite, the issues could have been priced and resolved during the design phase, rather than the construction phase.

5.3.5 Request for Information

A key advantage of the use of the D&B method was the reduction in claims by the contractor against the client due to the delay in provision of information. The Request for Information (RFI) Register for the project is a method by which to track requests between parties of the project team, for additional or clarification of information.

The literature review identified that an advantage for the use of the D&B method was improved co-ordination between the design and construction teams on the project. In addition to this, the D&B method reduced the potential for claims associated with the delay in responding to information requests. The purpose of evaluating the RFI register for the project was to validate these findings.

The following Table 5.4 provides a summary of all RFI's submitted on the project, a total of 3:

Table 5.4 - Project RFI's

RFI	Description
200	RW 1 Footing Levels
201	Disabled Ramp Dimension
202	Driveway Discrepancies

The following chart provides an overview of the RFI's based on the parties that the requests were directed to:

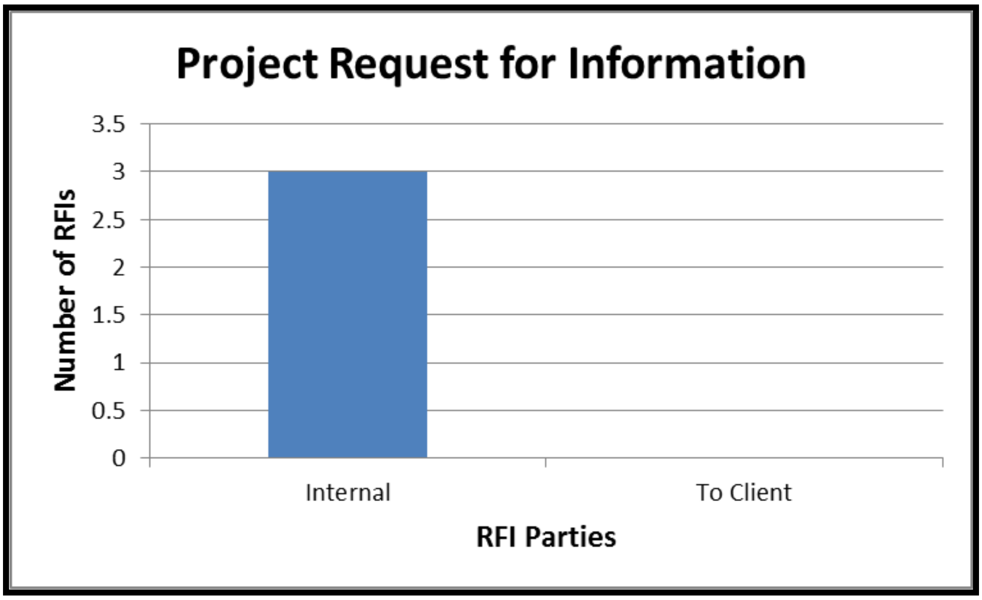


Figure 5.2 - Project RFI Summary

As identified in the analysis, each of the RFI's was sent internally within the organisation – between the site staff and the design office. No RFI's were submitted to the client for the project, which validates the findings of the literature review.

5.3.6 Project Schedule Performance

A finding from the literature review was the contractor utilising the D&B method is responsible for the completion of the project including the design, within the specified timeframe, therefore claims are unable to be made based on errors or co-ordination issues encountered with the design or onsite. The aim of the review of the historical projects performance with regards to time was to validate these findings.

As discussed in section 5.3.2 the contract completion time was 28 weeks from the receipt of all council approvals. The Extension of Time (EOT) register for the project was maintained as a method of tracking delay claims made to the principal, for delays experienced onsite. The review of the EOT register identified 12 claims submitted throughout the duration of the project. The delays totalled 28 days, and were submitted only for rain delays, with each EOT claim approved by the projects Superintendent. The following table 5.5 is a summary of the Extension of Time Claims made on the project:

Table 5.5 - Project Extension of Time Claims

EOT	Description	Days
1	Rain Delays	2
2	Rain Delays	5
3	Rain Delays	2
4	Rain Delays	1
5	Rain Delays	1
6	Rain Delays	3
7	Rain Delays	1
8	Rain Delays	3
9	Rain Delays	2
10	Rain Delays	1
11	Rain Delays	3
12	Rain Delays	4
		28

As discussed in section 5.3.3, a number of subcontractor variations were submitted on the project. These variations have been further analysed to determine potential time impacts on the project caused by the changes. The analysis has been limited to the design changes in Building B, not the changes associated with works not included in the tender documentation. The purpose of this analysis is to determine delays to the project that were not claimed to the principal.

The following Table 5.6 provides an analysis based on the Initial Construction Programme for the project dated 15th January 2013, and the dates that the design changes were made:

Table 5.6 - Construction Programme Analysis

Construction Programme - dated 15/01/13			Drawing Changes			
Works	Start	Finish	Works - Issued For Tender	Design Change - Basement	Design Change - Level 1	Time Impact
Foundations	12/03/2013	3/04/2013	11/02/2013	13/03/2013	-	YES
Building B - Concrete Tilt Panels	24/04/2013	7/05/2013	11/02/2013	13/03/2013	22/04/2013	YES
Building B - Level 1 Structural Steel Erection	8/05/2013	23/05/2013	11/02/2013	NIL	NIL	NO
Building B - Level 1 Floor Slab	24/05/2013	30/05/2013	11/02/2013	NIL	NIL	NO
Building B - Blockwork	Not Initially Programmed				22/04/2013	YES

The analysis has identified three areas that the design changes affected the project schedule - foundations, concrete tilt panels and blockwork.

Short term look-ahead plans were issued monthly for the project, which detailed the works to be undertaken in the following month. The three areas in which the design changes were identified as affecting the project schedule were further analysed against the projects short term look-ahead plans that were issued each month, the results are presented in Table 5.7:

Table 5.7 - Construction Programme Analysis

Construction Programme - dated 15/01/13			Short Term Programmes		
Works	Start	Finish	Start	Finish	Short Term Programme Date
Foundations	12/03/2013	3/04/2013	10/04/2013	17/04/2013	28/03/2013
Building B - Concrete Tilt Panels	24/04/2013	7/05/2013	3/06/2013	14/06/2013	24/05/2013
Building B - Blockwork	Not Initially Programmed		24/06/2013	28/06/2013	24/05/2013

The results of the analysis identify that the design changes, and timing of the changes had an effect on the overall schedule for the project. It should be noted however, that the results presented in Table 5.6 are also affected by the extension of time claims submitted for the project, as previously discussed.

The interview as discussed in Section 5.3.3 identified that these changes were made to improve the construction sequence onsite, and in the long run save the project time. However the changes that were made did have an impact on the co-ordination of construction works onsite. Identifying these changes prior to construction works commencing onsite, would have resulted in an opportunity to schedule trades for works onsite without the disruption of the design change.

The analysis on the schedule performance for the project has identified areas with which the project was affected; upon review of the project handover documentation, the project was completed within the contractual timeframe. The findings from the literature review therefore have been validated, as no claims were made for the design co-ordination issues that were encountered. In addition to this, the contractor was still able to maintain the contract completion date.

5.3.7 Summary of Results – Historical Project Case Study 1

The aim of Historical Project Case Study 1 was to augment the concerns identified in the literature review and the interview findings, as well as understand, first hand, concerns faced by medium scale D&B contractors. In addition to this, the case study was used as a means to identify whether there were specific areas with which the use of 4D and 5D BIM tools would provide value to the organisation.

Contract clauses included in the projects contract, including on the limitation of delay claims to inclement weather, a force majeure event or an act or omission by the superintendent or principal increases the contractor's responsibility for time performance. Furthermore, the project schedule performance as discussed in Section 5.3.5 also validates the finding from both the literature review and interview findings that claims are reduced when the D&B method is used.

The contract for the project was based on a lump sum contract sum for the works, which provides cost certainty for the client; however an increased responsibility of cost performance for the contractor is also imposed. The project was tendered when the design was incomplete, and a contingency sum was not included to allow for unknowns. This was a disadvantage of the D&B method that was reported in the literature, and the findings from this case study augment these concerns.

The project schedule was affected due to design constructability issues, however contractual conditions prevented claims for both cost and time to be made to the client. 3D BIM was utilised in the design review process, however this review did not identify the constructability concerns of the design. The importance of the constructability of designs was trend in the results of the interviews, where it was acknowledged to be integral to the success of D&B projects. Where there are constructability concerns on a project, both the project programme and project budget can be affected. The identification of the specific constructability concern and subsequent effect on both the project schedule and budget on the historical project has augmented the concerns of the literature review and interview results.

Results from the literature, previously summarised in Section 2.7, report on the advantage that the use of 4D BIM tools provide in the constructability review process on projects. The use of 5D BIM tools are also advantageous in pricing scope changes and variations, which are able to be undertaken in reduced timeframes using the revised 3D BIM model. Further research will therefore be undertaken on the project in Historical Project Case Study 2, with the implementation of 4D and 5D BIM tools, in order to determine the feasibility of using BIM tools in managing and resolving key issues faced by medium scale D&B contractors. This case study will be undertaken in accordance with the case study protocol as outlined in section 3.8.

5.4 Pilot Case Study

5.4.1 Introduction

A pilot case study is being undertaken in order to clarify the requirements for the final case study. The pilot study will be undertaken in accordance with the case study protocol, as outlined in Section 3.6. The test project utilises the selected BIM tools, Navisworks and CostX, selected in accordance with the requirements previously discussed in Section 3.3. The test project is being undertaken as a means to gain a better understanding of the methods to be implemented on the Second Historical Case Study, and also achieve Sub-Objective 5 of the Research Project Objectives.

5.4.2 Design

The test project design was undertaken utilising Autodesk REVIT, a 3D BIM tool. The timeframe for the design model to be created was approximately 10 hours and is shown in the following figure:

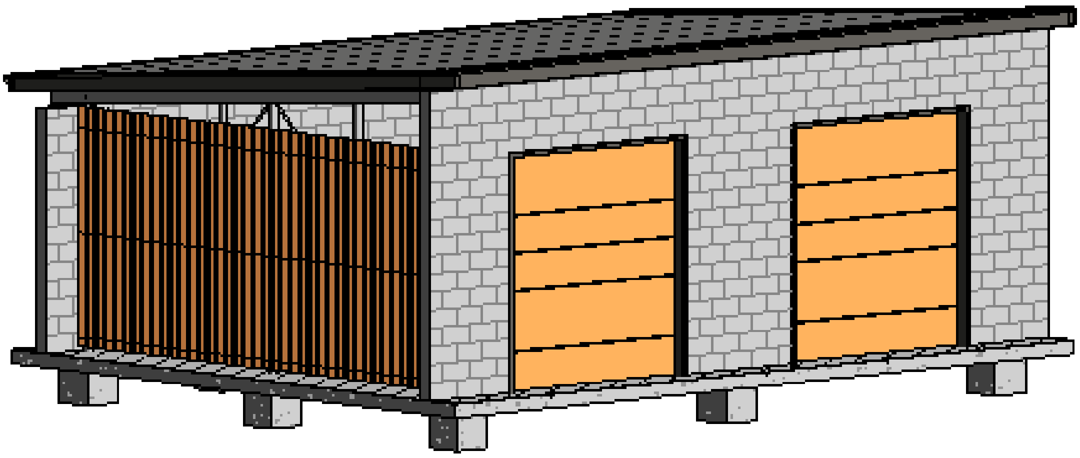


Figure 5.3 - Test Project Design

It should be noted that the design was not created with accuracy, however is an indicative model of a carport for the purposes of the research project.

5.4.3 Data Collection

Data collection for the test project will be undertaken in accordance with the method as outlined in Section 3.6.3. The data collection questions have been established in order to aid in the resolution of the usage of the BIM tools on the Second Historical Project Case Study. The results of the data collection will be analysed and used to finalise the 4D and 5D BIM implementation strategies for the Second Historical Project Case Study.

Question 1 - What Cost Information can be extracted from the Model

Utilising CostX, an overall cost estimate was able to be extracted from the BIM model as shown in Figure 5.4:

EDUCATIONAL VERSION — COLLECTION SUMMARY

COLLECTION	PAGE NO	
Doors	1/1	4,000
Fascias	2/1	1,488
Floors	3/1	4,891
Wall Screening	4/1	3,600
Gutters	5/1	330
Roofs	6/1	2,310
Structural Columns	7/1	1,922
Structural Foundations	8/1	1,100
Structural Framing	9/1	12,896
Walls	10/1	7,040
Total Amount:		39,577

Figure 5.4 - Budget Cost Estimate

The rates that have been utilised in the CostX model are indicative rates only, however used as a guide for the purposes of this research project. This data was able to be extracted from the BIM model, in approximately 2 minutes.

As a method to understand how design changes in the BIM model can be managed utilising CostX, a minor modification was made to the carport design to change the Pad Footings, to Bored Piers. This change was made to purely understand how the BIM model could be managed. The new design is shown in Figure 5.5:

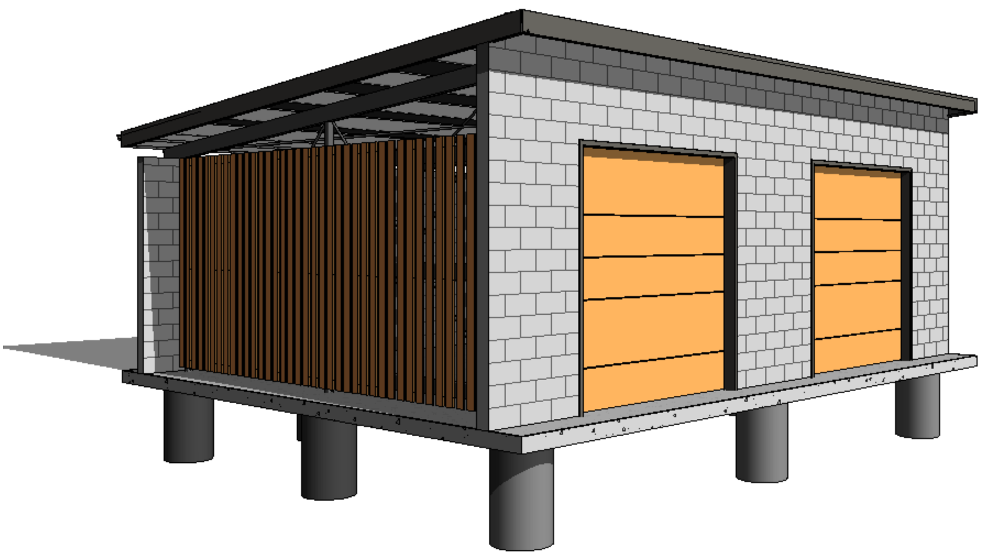


Figure 5.5 - Modified Test Project Design

The revised BIM model was loaded into CostX and a comparison was made between each of the models to identify the changes. Once completed the following comparison model identified what items had changed (yellow) and which items remained the same as the previous design (blue). An overall cost estimate was also able to be undertaken from the new design:

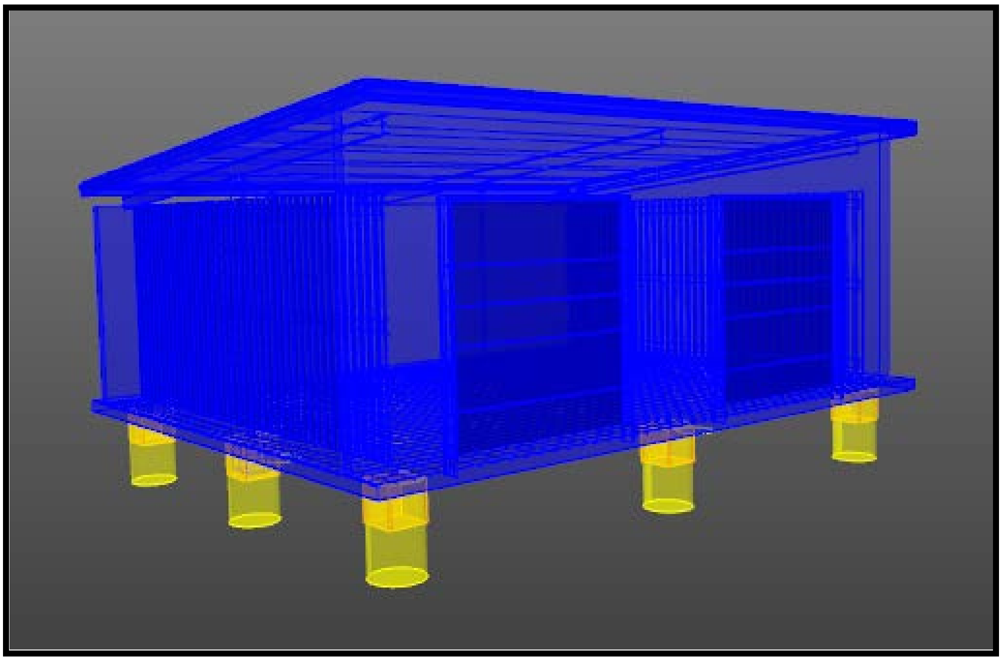


Figure 5.6 - CostX Comparison Model

This method will be advantageous in the review of revised designs and the pricing of variations. The specific changes in revised designs are able to be reviewed for cost, in a minimal amount of time.

Question 2 – Can the schedule information be manipulated to produce different results?

The test project was simulated in Navisworks utilising the sample project schedule that was completed in Microsoft Project. The project schedule was then revised in Navisworks Timeliner to identify Actual Start and Actual Completion dates as shown in Figure 5.7:

		Name	Status	Planned Start	Planned End	Actual Start	Actual End	Total Cost	Task Type
9.44%		**New Data Source (Root)**		29/06/2015	20/07/2015	30/06/2015	7/07/2015		Construct
Finished		Footings		29/06/2015	29/06/2015	30/06/2015	3/07/2015		Construct
74.09%		Install Columns		30/06/2015	1/07/2015	6/07/2015	7/07/2015		Construct

Figure 5.7 - Test Project Schedule Modifications

The project schedule was re-simulated, with settings that identify when tasks are behind schedule by highlighting them as Green, as shown in Figure 5.8:

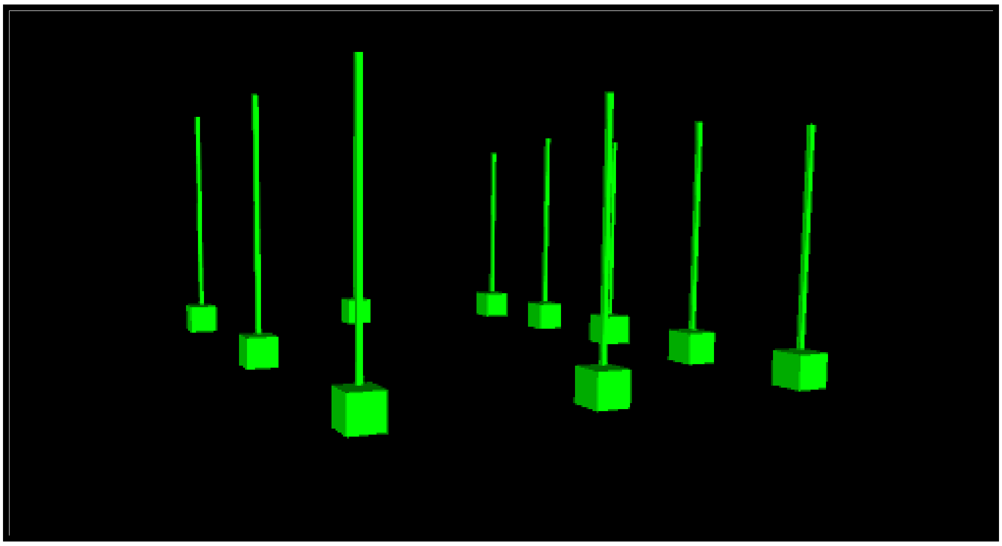


Figure 5.8 - Test Project Modified Schedule Simulation

The benefit of this tool is when project changes are made; actual dates are able to be modified within the 4D BIM model. The simulation is then able to identify the critical areas that are affected due to these changes.

Question 3 – Can the project schedule be reviewed at different stages of the project?

The project schedule is able to be reviewed at any selected date; a date within the Test Projects Schedule was selected from the calendar to determine the status of works completed. The 4D BIM model is then shown with works completed at that point in time, as shown in Figure 5.9 at the project schedule date of 14th July 2015:

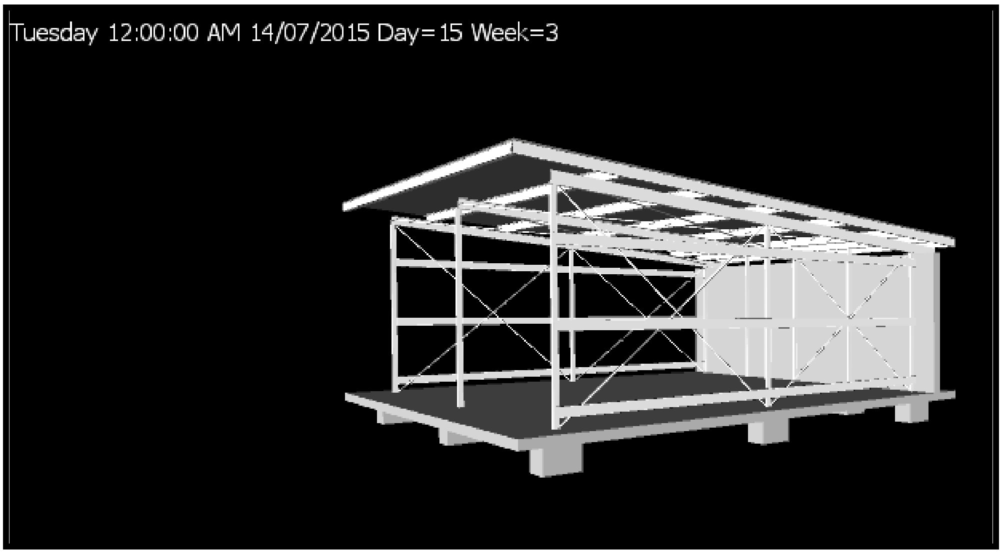


Figure 5.9 - Test Project Selected Schedule Date

This will enable analysis of the design and construction works at a specific time which will enable an analysis to be undertaken on the impact of changes to the design at a specific date.

Question 4 – Can the cost and time information be included in the BIM model to produce a cost loaded schedule?

The cost data that was produced using 5D BIM with CostX was then input into the Navisworks 4D Model to produce a cost loaded schedule. This enables tracking of project costs as works are completed, and can be shown on the projects simulation as shown in Figure 5.10:

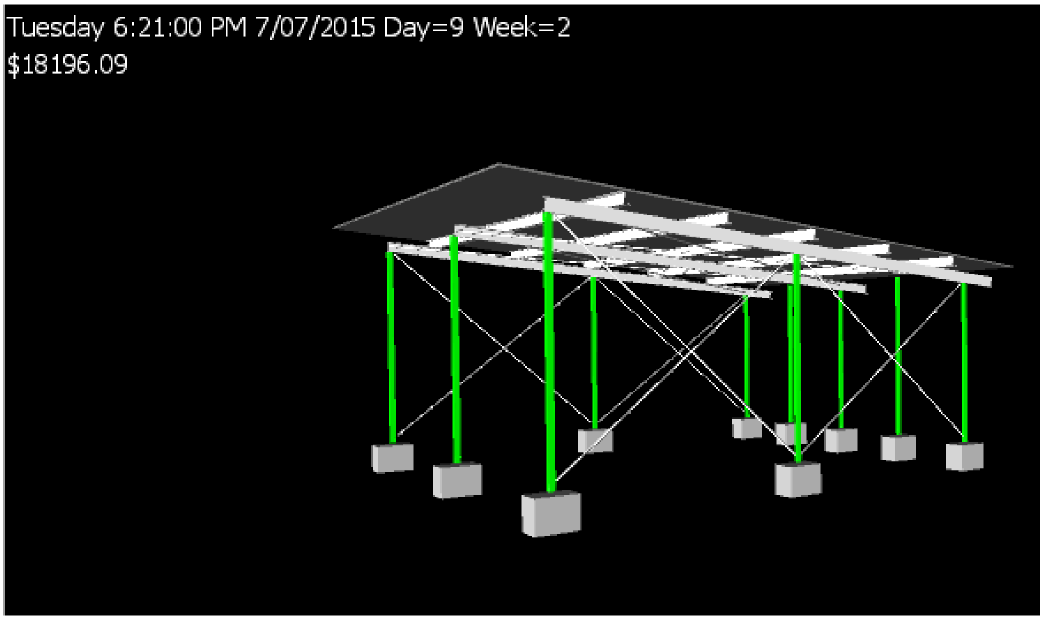


Figure 5.10 - Test Project Cost Loaded Schedule

The advantage of utilising this information is to track the costs of works completed onsite, prior to changes being made on the project. This was identified in the interviews with organisation members as a concern with D&B projects that the timing of scope changes, significantly affects the costs.

5.4.4 Summary of Results – Pilot Case Study

The Pilot Case Study was undertaken as a means to resolve and finalise the implementation strategies for the Second Historical Project Case Study. The use of CostX was successful in completing an overall cost estimate that was extracted from the 3D BIM model. CostX was also able to provide a comparison between the original 3D BIM model and a revised 3D BIM model with design changes included.

Navisworks enabled the 3D BIM model and the Microsoft Project Schedule, to be manipulated and the schedule re-simulated. The objective of testing this was to gain an understanding of how the schedule can be modified, when a design change or construction sequence change is made to the project.

Navisworks also enables the user to review the project schedule at different stages, and dates of a project. The BIM model then shows the project in its completed construction state at that point in time. Cost information is also able to be added to the schedule to provide a cost loaded schedule that can be used for the tracking of the projects costs as works are completed. The objective of analysing this was to understand the usage of Navisworks in reviewing the project schedule for specific areas of the project and the costs associated with these works.

Due to the simplicity of the design of the test project, the feasibility of using 4D and 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors cannot be resolved. The Pilot Case Study however was able to resolve the methods that will be adopted for the Second Historical Project Case Study, to determine the value of these BIM tools in resolving constructability concerns that were identified in the Historical Case Study, prior to project commencement.

The 4D BIM tool, Navisworks, will be used with the projects 3D BIM model to analyse the original Project Schedule and Design, reviewing the project schedule at different stages of the project in order to undertake a constructability review. The 5D BIM tool, Exactal CostX, will then be used to analyse the design change that occurred that was identified in the historical case study, after the constructability concerns were resolved. This will be completed as a means to understand the value of utilising 5D BIM tools to price the project changes for variations. The results of this further case study are included in Section 5.5.

5.5 Historical Project Case Study 2 – Commercial Development: BIM Tools Implemented

5.5.1 Introduction

Historical Project Case Study 1 identified design changes to Building B Basement that were as a result of constructability concerns identified in the building design, as discussed in Section 5.3. The design changes were made after the construction works had commenced, therefore resulting in delays onsite while the design was finalised and additional costs. The use of the D&B method for the project prevented claims for both time and costs being made to the client.

The aim of Historical Project Case Study 2 is to retrospectively adopt 4D and 5D BIM tools on the historical project as a means to determine the feasibility of using 4D and 5D BIM tools in managing and resolving these issues faced by medium-scale D&B contractors. The Historical Case Study 2 will be undertaken in accordance with the case study protocol, as outlined in Section 3.8. The case study utilises the selected BIM tools, Navisworks and CostX, which have been selected in accordance with the requirements previously discussed in Section 3.3. Furthermore, the case study is being undertaken as a means to achieve Sub-Objective 6 of the Research Project Objectives.

5.5.2 Design

The design for the historical project was undertaken utilising Autodesk REVIT, a 3D BIM tool. Revit models were created for Building A, Building B and also the project site. Based on the findings of the historical project case study, as discussed in Section 5.3, the key issues faced by The Organisation on the project were identified in Building B basement, therefore this is the design model that has been used for this case study.

Two 3D BIM design models were obtained for the project. The 3D BIM model completed at Building Approval stage, which was prior to the design change being made to Building B Basement and the Final 3D BIM design model for the project, which incorporated the design change and all other scope changes for the project undertaken as part of client variations. No other 3D BIM design models for Building B were available for use in the case study.

5.5.3 Project Schedule

The schedule for the project was completed using Microsoft Project, with a contract completion timeframe of 28 weeks from receipt of all council approvals as discussed in section 5.3.3. The project schedule completed included all works for Building A, Building B and the Site Works. For the purposes of this research project, only works on the schedule relating to Building B have been used in this case study.

As discussed in Section 5.3 and also 5.5.2, key issues were identified in Building B basement. As the key issues were identified in the Building B Basement works, the project schedule has been limited to those items modelled by the organisation in the BIM model. Works excluded from the schedule therefore are:

- finishes trades – paint, floor coverings, tiling
- line marking to basement carpark
- floor coverings installation
- fire sprinkler pipework
- electrical wiring and lighting

Fire sprinkler pipework and electrical wiring and lighting have been excluded from this case study as they are not included in the organisations BIM model as the fire and electrical services design are completed by D&B subcontractors, using non-BIM software. Finishes trades such as paint and floor coverings are also not detailed in the BIM model, therefore cannot be included in this analysis.

5.5.4 Data Collection – 4D BIM – Building Approval Design Model

The following Figure 5.11 and 5.12 shows the 3D BIM model and imported project schedule at the Building Approval stage, initially uploaded into Navisworks.

Figure 5.11 - 3D BIM Model (Building Approval Stage)

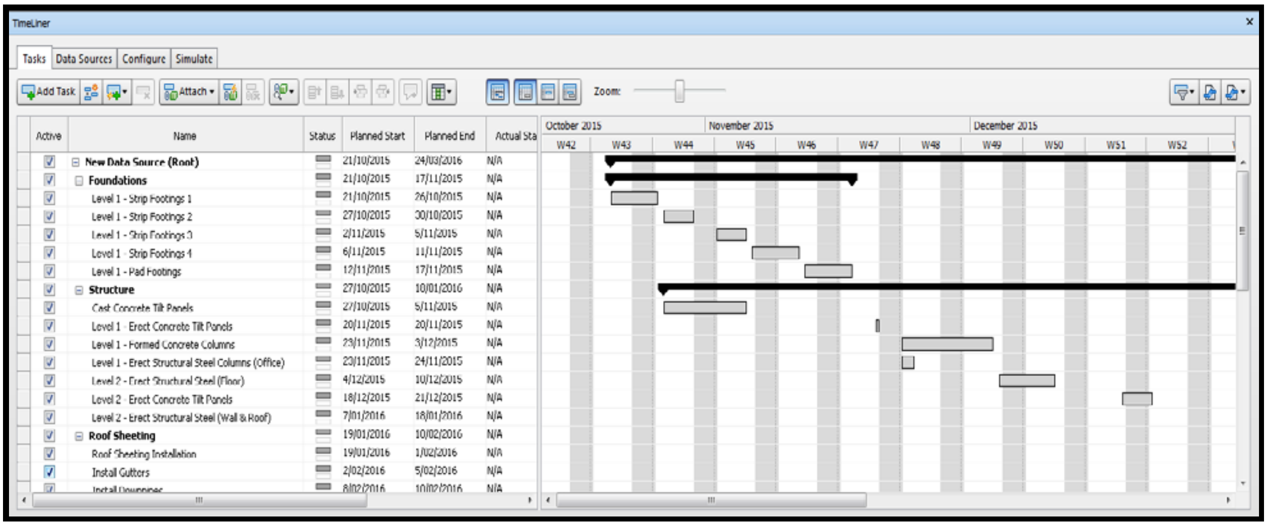


Figure 5.12 - Project Schedule (Building Approval Stage)

The model elements and project schedule were linked in Navisworks, in accordance with the steps outlined in the Software Guide included in Chapter 4. The timeframe to complete the Selection Set Links with the project schedule was 6 hours.

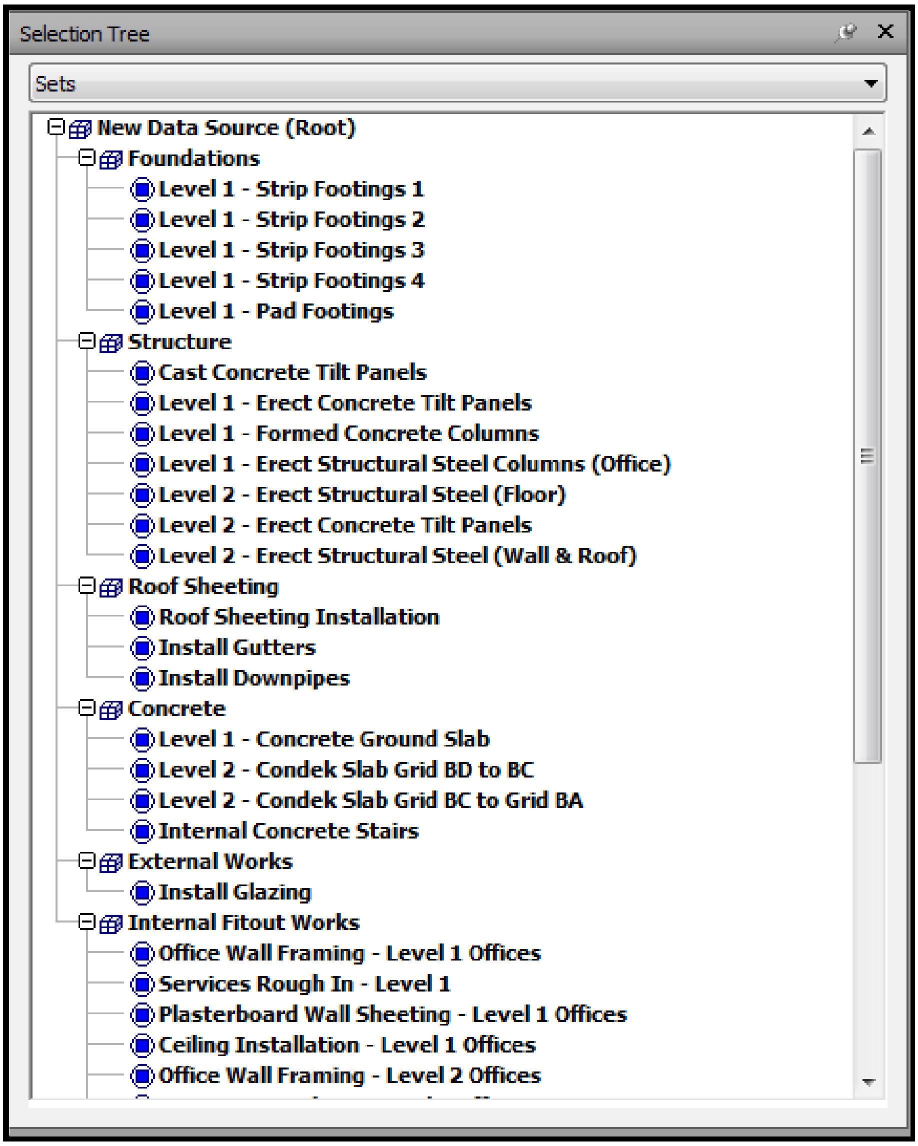


Figure 5.13 - Autodesk Navisworks Selection Sets

In order to undertake a review of the 3D BIM model in Navisworks, to ensure links were created with each model element, the Hide Element feature was used. Figure 5.14 on the following page, shows the advantage of hiding the roof and associated structural framing and the ceiling from the view to enable a review of the Level 2 Office Layout.

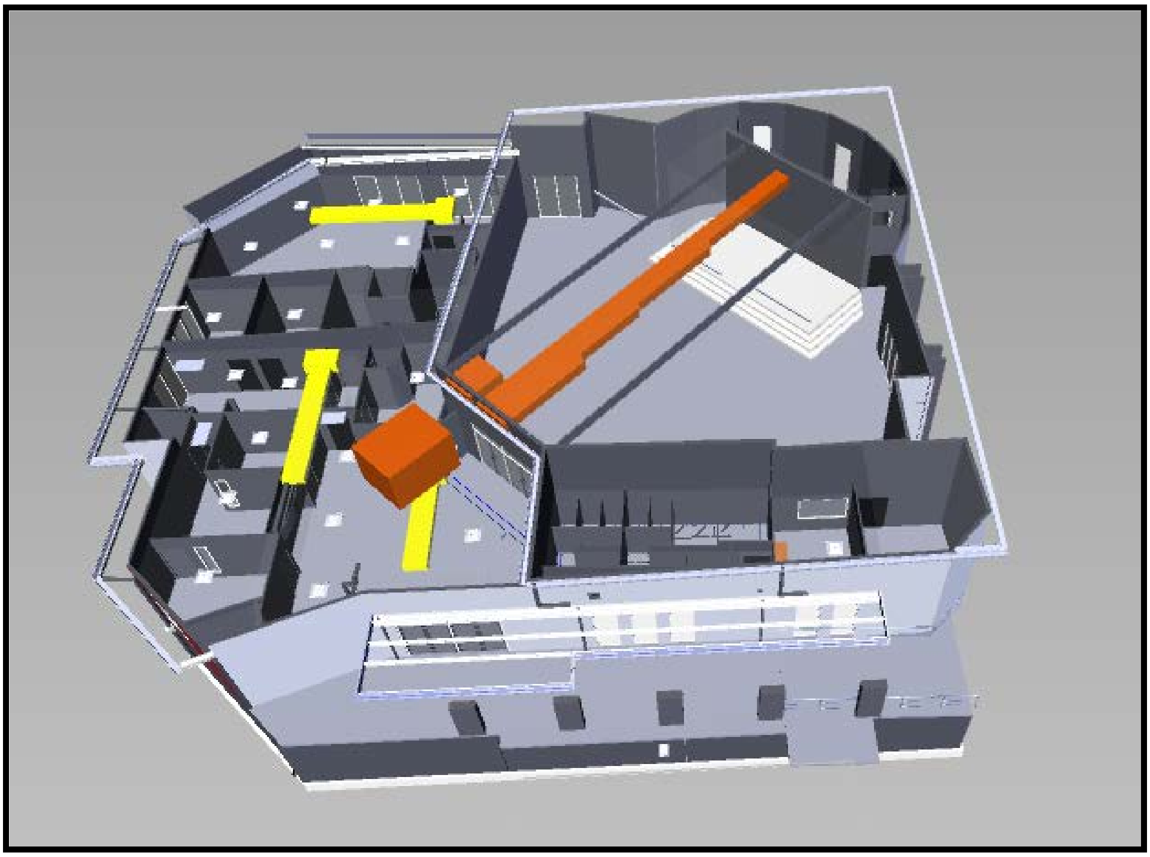


Figure 5.14 - Level 2 Office Layout using Autdesk Navisworks Hide Element

In accordance with the findings from the Pilot Case Study outlined in Section 5.4.2, the project schedule can be reviewed at various stages of the construction project. Two viewpoints were established on the project – Viewpoint 1 – South Eastern Corner, and Viewpoint 2 – South Western Corner. As a means to provide clarity to the simulation for the basement works, sections of walls have been hidden from view. The following figures show the simulation of the construction works viewed from Viewpoint 1 – South Eastern Corner.

The following Figure 5.15 shows works completed at Week 9. As can be seen from the simulation, the basement (Level 1) foundations, erection of concrete tilt panels and formed concrete columns were completed. The Floor Steel for Level 2 was underway, as shown in green.

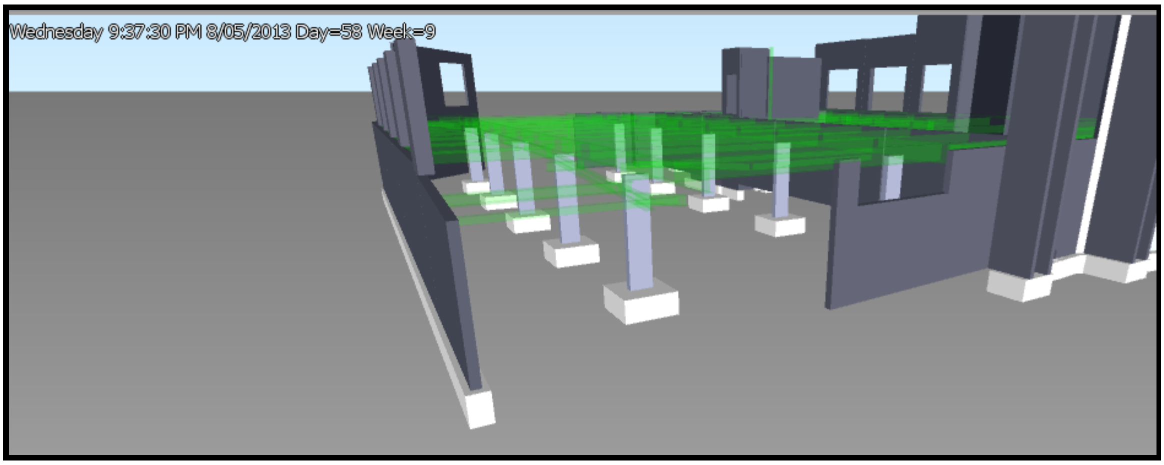


Figure 5.15 - Building Approval Stage (Viewpoint 1) - Works Complete Week 9

The following Figure 5.16 shows works completed at Week 11. As can be seen from the simulation, The Floor Steel for Level 2 is now complete, and the Level 2 Concrete Tilt Panels have been erected. The suspended concrete slab for Level 2 is under construction, as shown in green.

The simulation has identified a key issue in the project schedule:

The structural steel for the roof has not yet commenced, therefore the Concrete Tilt Panels for Level 2 will be braced by temporary props. These temporary props would therefore prevent the Level 2 suspended concrete floor slab from commencing. The concrete tilt panels must remain temporarily braced, until the final brace from the roof structural steel has been erected.

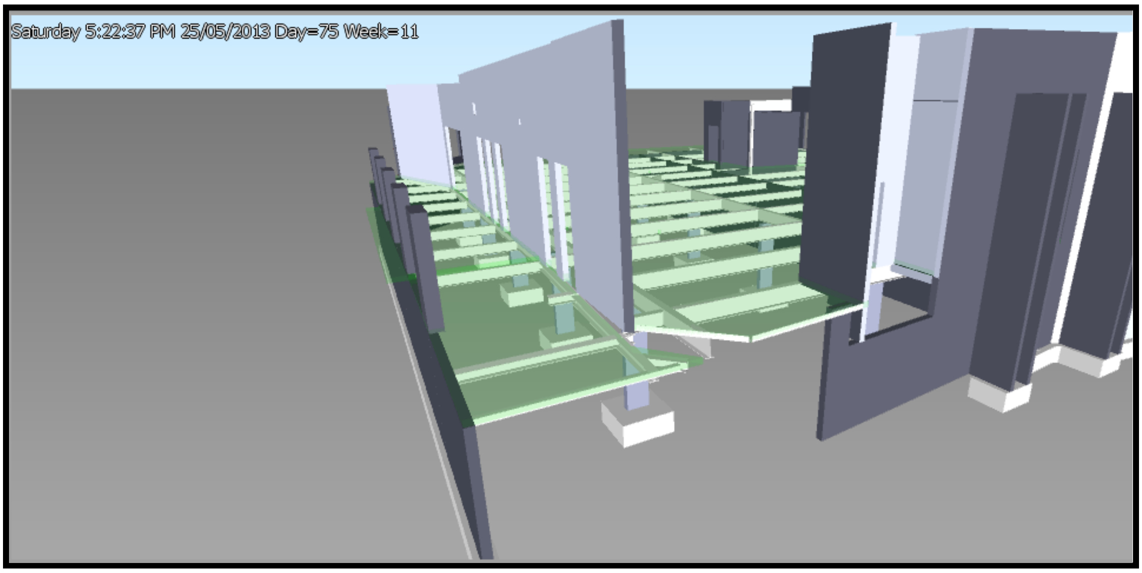


Figure 5.16- Building Approval Stage (Viewpoint 1) - Works Complete Week 11

The following Figure 5.17 shows works completed at Week 13. As can be seen from the simulation, The Level 2 Suspended Slabs are now complete, and the Level 2 Structural Roof and Wall Steel Erection has commenced, as shown in green.

This stage of the simulation provides an understanding of the key issue in the project schedule that has been identified:

The roof steel that is currently being erected, we need to be completed in order for the temporary props for the concrete tilt panels, to be removed.

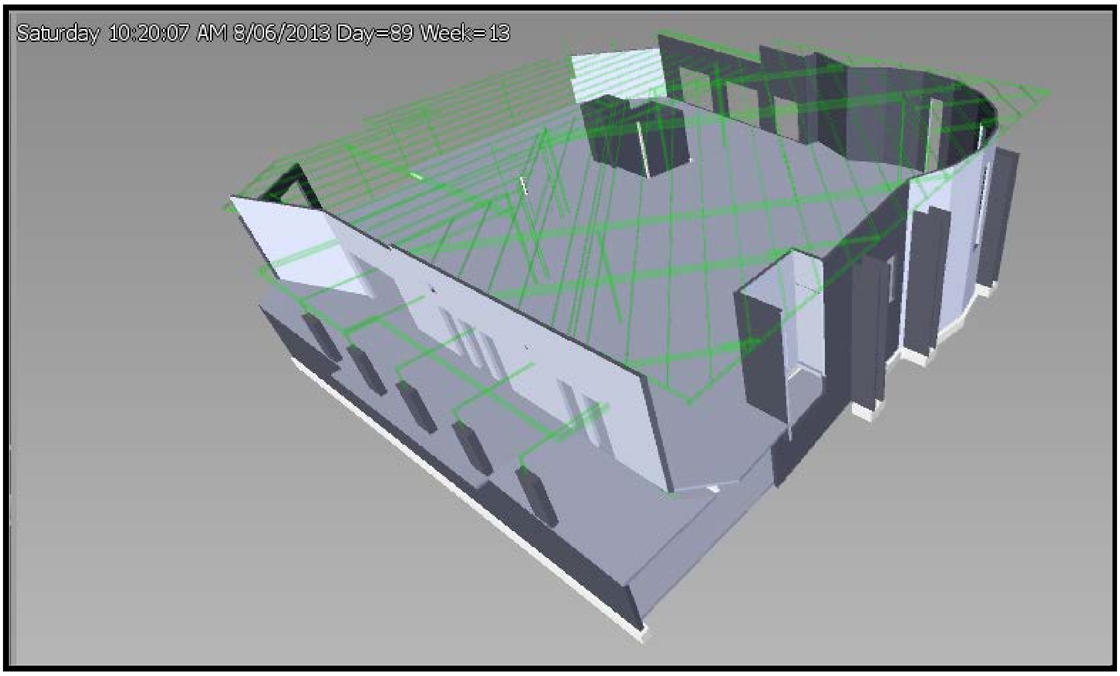


Figure 5.17- Building Approval Stage (Viewpoint 1) - Works Complete Week 13

The following Figure 5.18 shows works completed at Week 15. As can be seen from the simulation, the Level 2 Structural Roof and Wall Steel Erection has been completed and the roof cladding has commenced, as shown in green.

This point of the simulation has not identified any key issues in the project schedule.

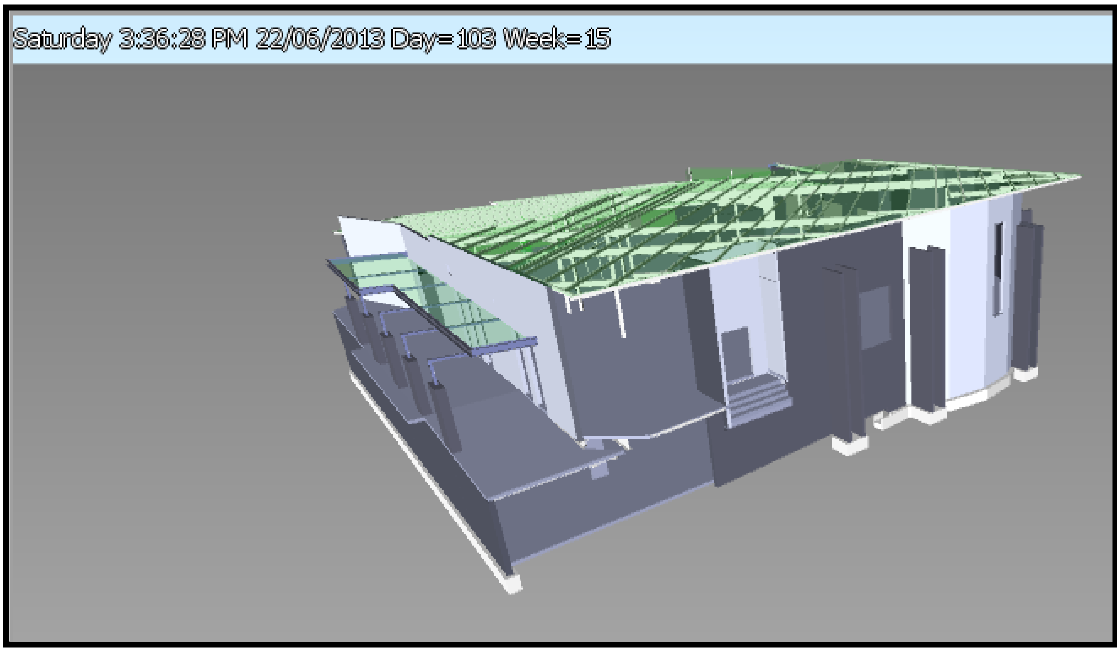


Figure 5.18- Building Approval Stage (Viewpoint 1) - Works Complete Week 15

The following Figure 5.19 shows works completed at Week 19. As can be seen from the simulation, roof sheeting installation is now completed with internal partition walls also complete. The door installation is currently underway, as shown in green.

This point of the simulation has not identified any key issues in the project schedule.

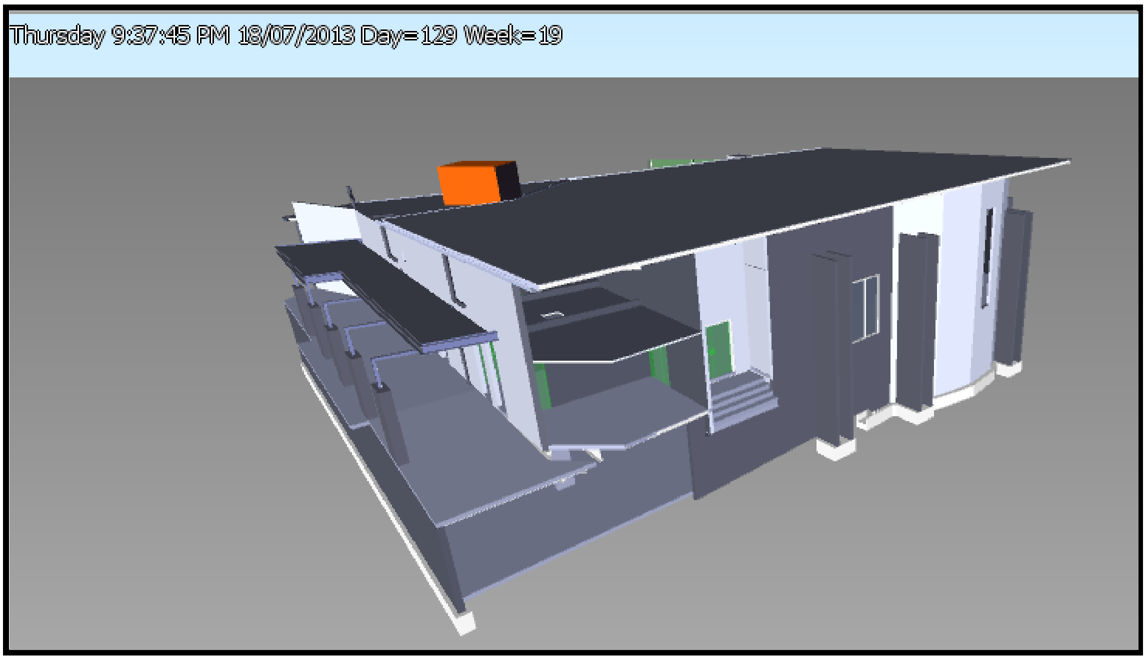


Figure 5.19- Building Approval Stage (Viewpoint 1) - Works Complete Week 19

A second view point, on the South Western corner of the building has been established to enable a secondary analysis of the project schedule simulation. The following Figure 5.20 shows works completed at Week 9. As can be seen from the simulation, the basement (Level 1) foundations, erection of concrete tilt panels and formed concrete columns were completed. The Floor Steel for Level 2 is underway, as shown in green.

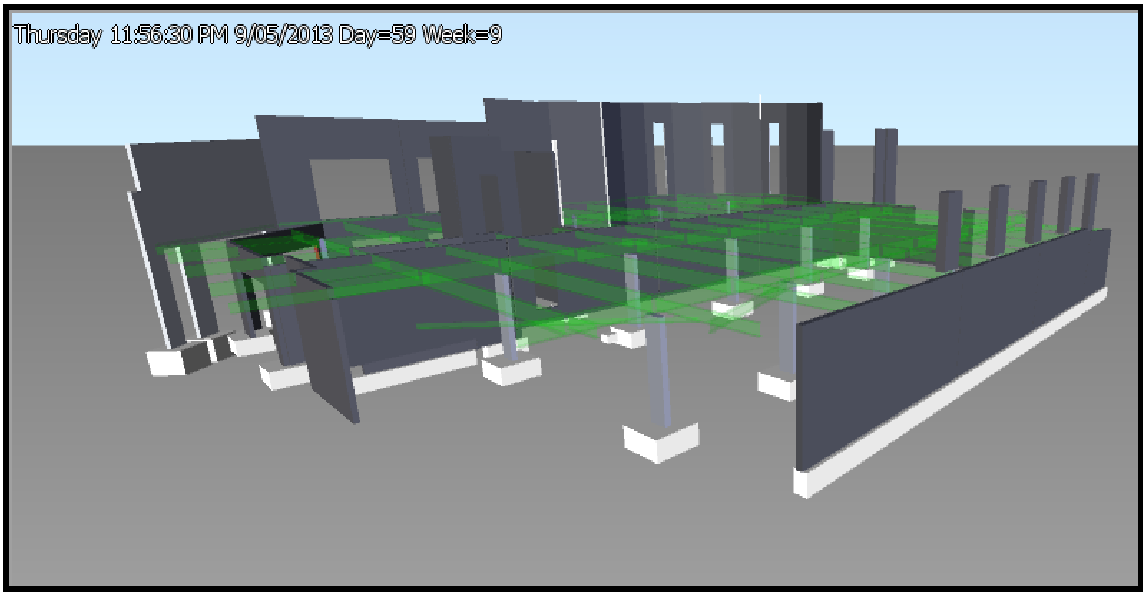


Figure 5.20 - Building Approval Stage (Viewpoint 2) - Works Complete Week 9

The following Figure 5.21 shows works completed at Week 11. As can be seen from the simulation, Level 2 Concrete Tilt panels have been erected and the Level 2 suspended concrete floor slab has commenced.

This viewpoint of the simulation has confirmed the findings from the previous simulation of the issue in the project schedule and constructability of the design:

The structural steel for the roof has not yet commenced, therefore the Concrete Tilt Panels for Level 2 will be braced by temporary props. The temporary props would therefore prevent the concrete floor slab from being completed in full. The floor slab would need to be completed in sections, enabling the temporary props to remain in place until the structural steel for the roof has been fully erected providing the final brace for the concrete tilt panels.

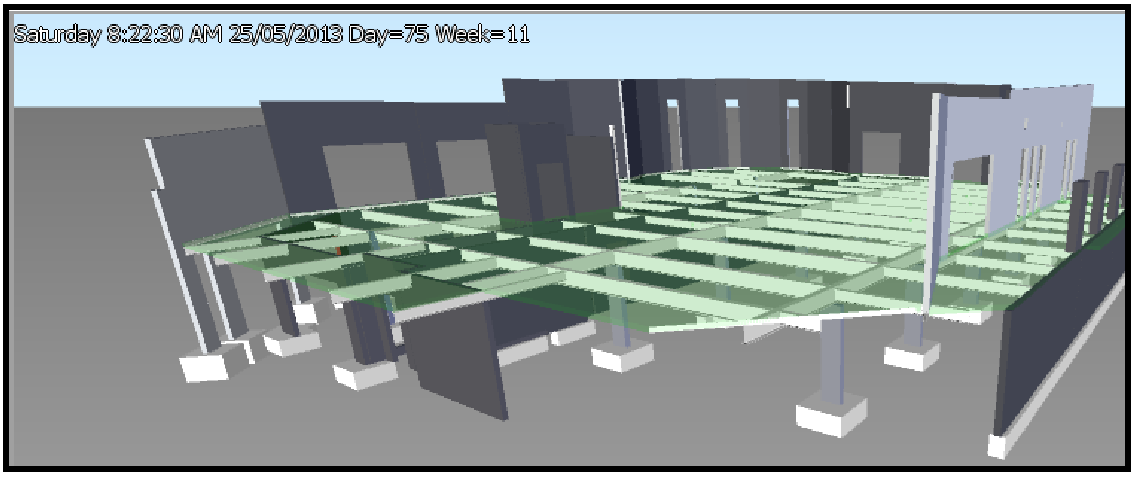


Figure 5.21- Building Approval Stage (Viewpoint 2) - Works Complete Week 11

Figure 5.22 following shows works completed at Week 13. As can be seen from the simulation, the basement (Level 1) concrete ground slab and the Level 2 Suspended Concrete Slab are complete. Structural Roof and Wall Steel has commenced.

This viewpoint of the simulation also provides an overview of the structural steel roof framing that must be completed, prior to the temporary props for the concrete tilt panels, being removed.

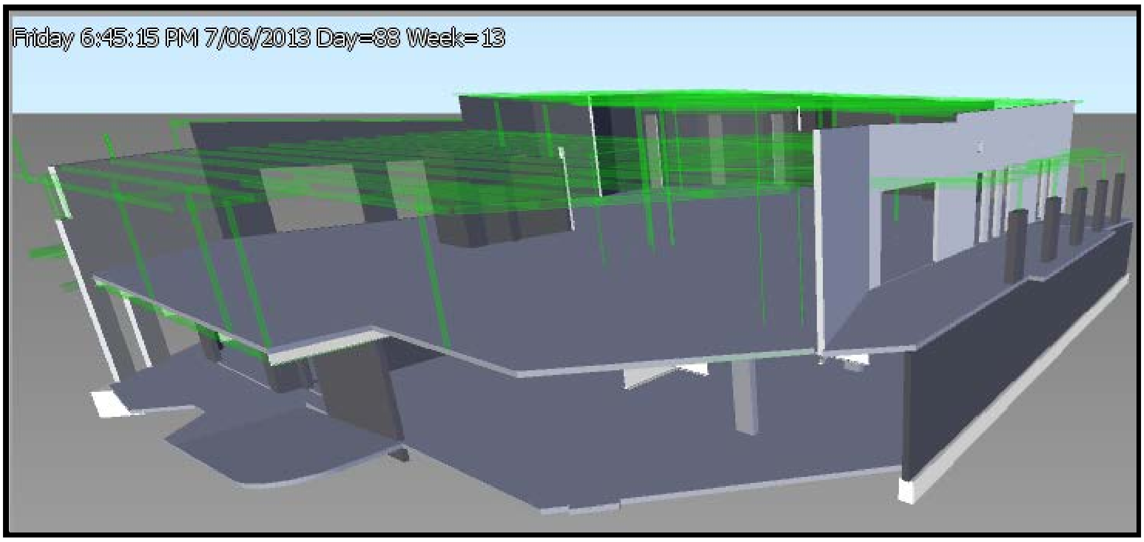


Figure 5.22- Building Approval Stage (Viewpoint 2) - Works Complete Week 13

Works completed at Week 15 are illustrated in Figure 5.23. Roof sheeting installation has commenced, as well as the external wall cladding.

No issues have been identified in the project schedule at this stage of the simulation.

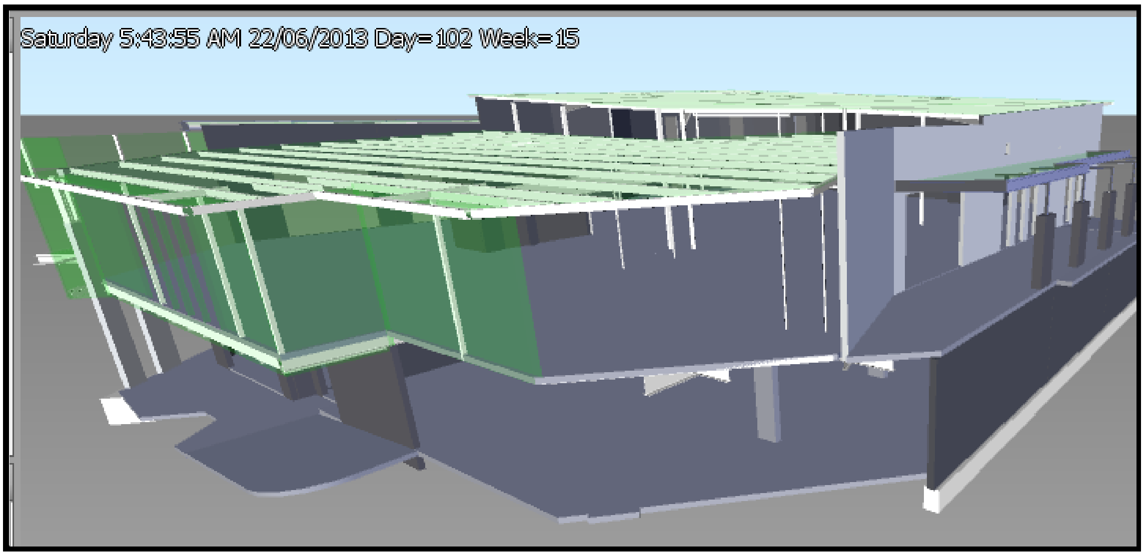


Figure 5.23- Building Approval Stage (Viewpoint 2) - Works Complete Week 15

The following Figure 5.24 shows works completed at Week 17. Internal partition framing and sheeting has commenced, as well as the external wall cladding continuing.

No issues have been identified in the project schedule at this stage of the simulation.

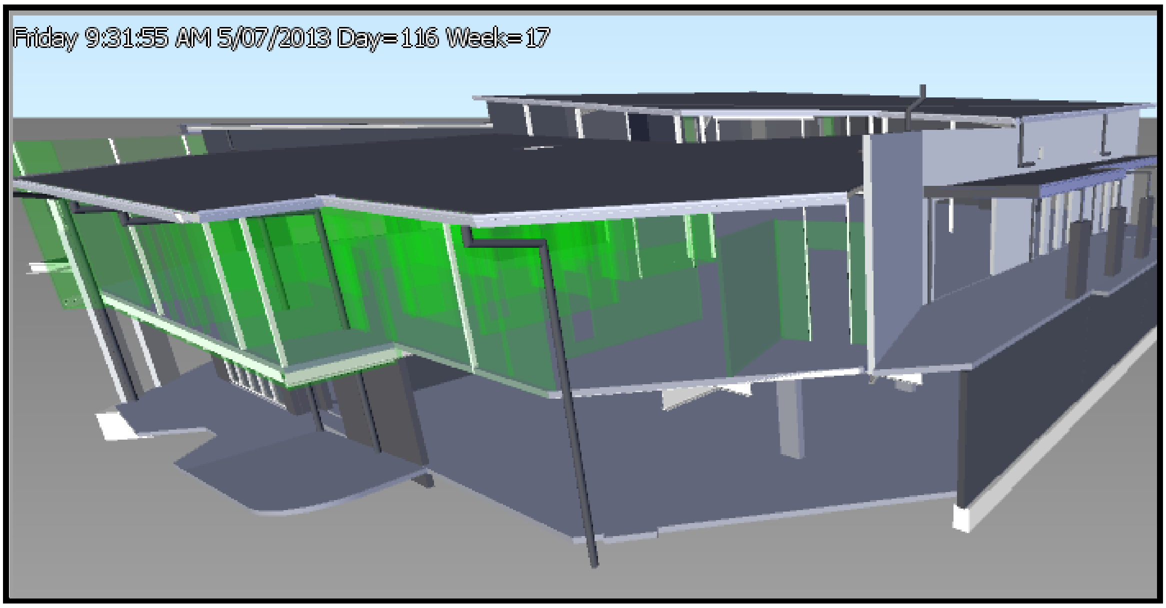


Figure 5.24- Building Approval Stage (Viewpoint 2) - Works Complete Week 17

At the completion of the simulation, no further issues were identified in the project schedule.

The results of Historical Case Study 1, as discussed in Section 5.3.7 identified that the project performance was affected due to changes made to the design after construction works had commenced onsite, due to constructability concerns. As a result of the timing of identifying the constructability concerns; the design changes impacted the co-ordination of trades' onsite, the project programme performance and the project budget performance. The findings also identified that a claim for these changes was unable to be made to the client, due to contractual conditions.

The use of Navisworks in this case study has enabled the simulation of the construction schedule using the 3D BIM design model. Simulating the construction schedule, identified constructability areas of concern, that aligned with the same concerns aforementioned in Historical Case Study 1.

The results of this case study have identified that the use of Navisworks in the design phase of the project has provided value in identifying the issues that were encountered onsite. A key advantage has been the ability to identify the issues prior to any works commencing onsite therefore enabling a change to the design to be made without impacting the construction works.

5.5.5 Data Collection – 4D BIM – Final 3D BIM Design Model

In order to provide an analysis of the potential improved timeframe performance of the project, had the changes been identified prior to commencing construction works onsite, the Final 3D BIM Design Model was analysed. As discussed in Section 5.5.2, this BIM Design Model incorporates the design changes identified in the Historical Case Study 1.

The predicted project schedule was created in Microsoft Project, utilising the construction timeframes included in the Monthly Project Programmes for the project. The project schedule however was created without incorporating the delays experienced due to the design changes. A copy of the project schedule used as a basis for this this analysis is included in Appendix D. The new project schedule was then simulated in Navisworks with the Final 3D BIM Design Model, as a means to identify any further areas of concern with the new model.

The following figures show the simulation of the construction works viewed from Viewpoint 1 – South Eastern Corner.

The following Figure 5.25 shows works completed at Week 5. As can be seen from the simulation, the basement (Level 1) foundations were completed, and the formed concrete columns had commenced.

No issues have been identified at this stage of the project schedule.

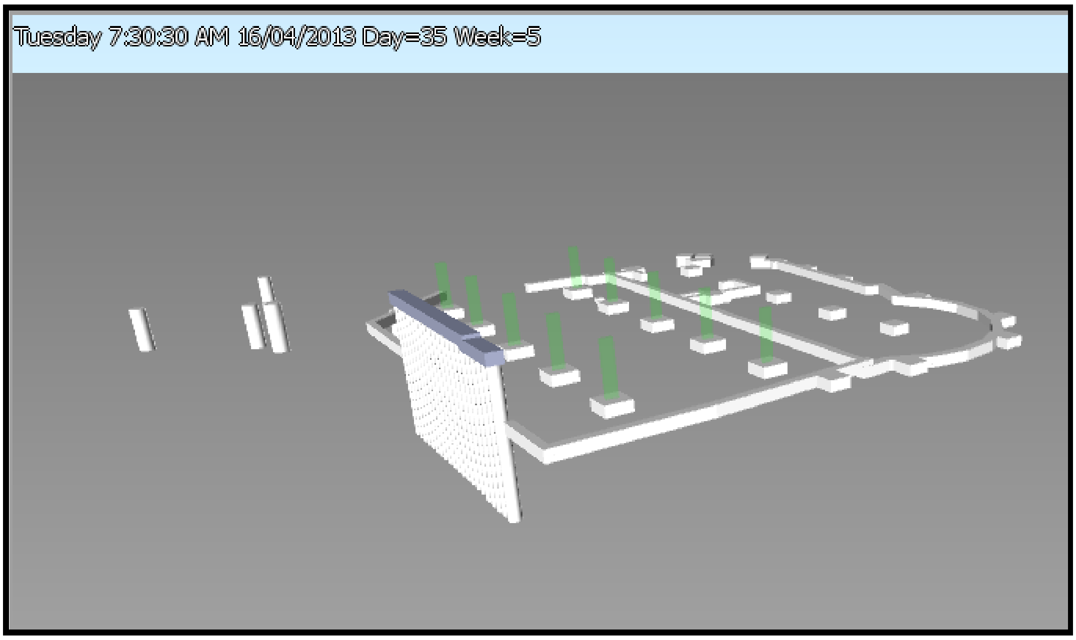


Figure 5.25 - Final BIM Model - Works Complete Week 5

At the completion of Week 9, Concrete Tilt Panels have been erected, and Level 2 Floor Structural Steel erection has commenced. Figure 5.26 shows the status of works at Week 9.

No issues have been identified at this stage of the project schedule.

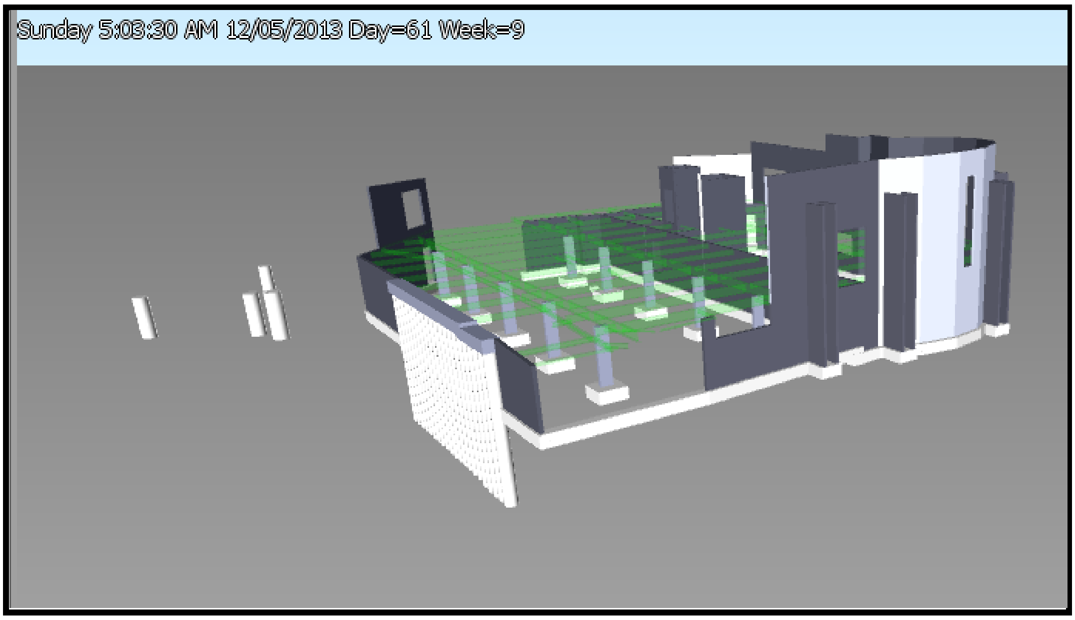


Figure 5.26 - Final BIM Model - Works Complete Week 9

The construction of the level 2 suspended concrete slab was completed in Week 11 and the basement concrete ground slab was underway. As discussed in Historical Project Case Study 1, the concrete tilt panels were changed to blockwork at Level 2 to remove the requirement for the temporary props. The level 2 concrete slab was therefore able to be constructed, which is shown in Figure 5.27. The blockwork is currently under construction in Week 11, as shown below on level 2. The basement concrete ground slab had also commenced construction. The following Figure 5.27 shows the works completed.

No issues have been identified at this stage of the project schedule.

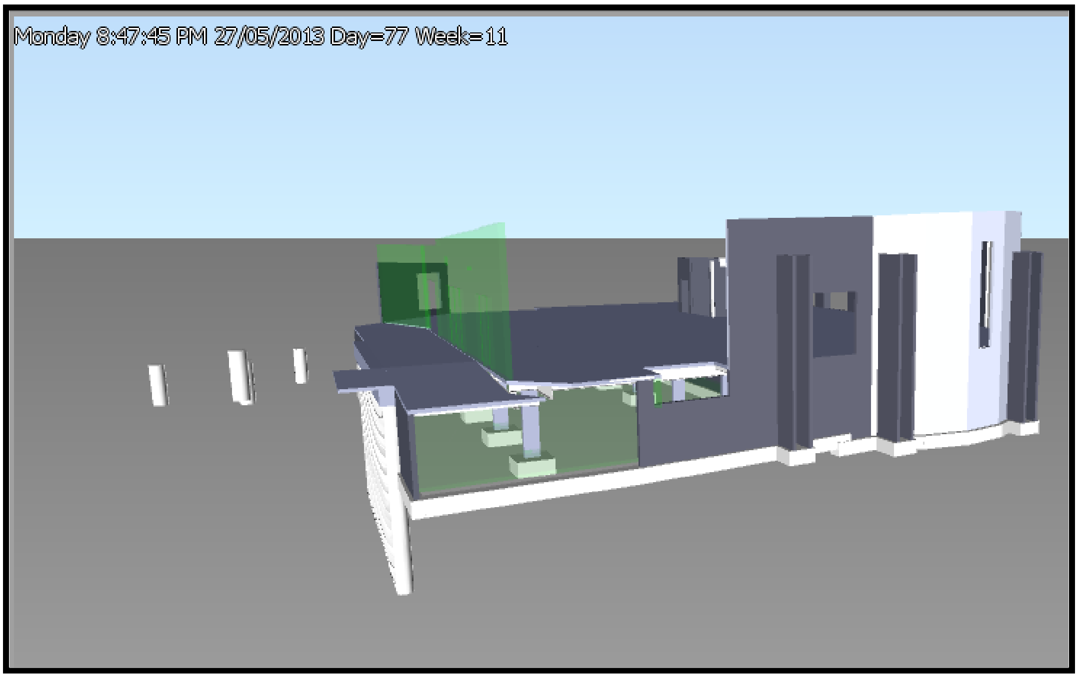


Figure 5.27 - Final BIM Model - Works Complete Week 11

The following Figure 5.27 shows works completed at Week 13. Blockwork to Level 2 been completed, and structural steel for both the roof and awning structures is complete. No issues have been identified at this stage of the project schedule.

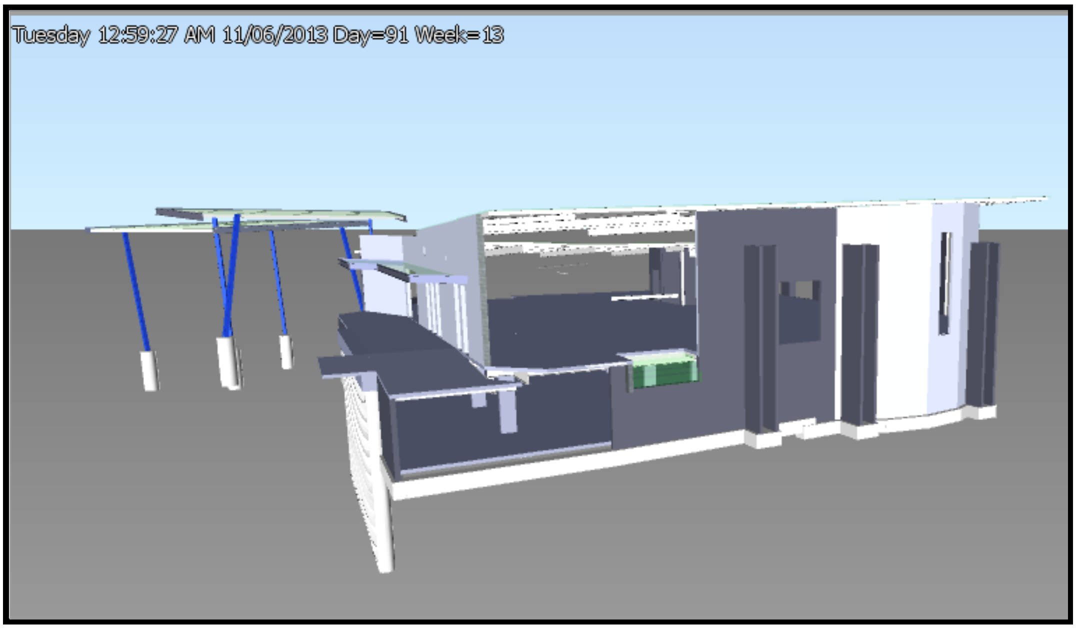


Figure 5.28 - Final BIM Model - Works Complete Week 13

Office fitout works had commenced construction in Week 15, as well as the roof soffit installation. The following Figure 5.29 shows the status of works at Week 15. No issues have been identified at this stage of the project schedule.

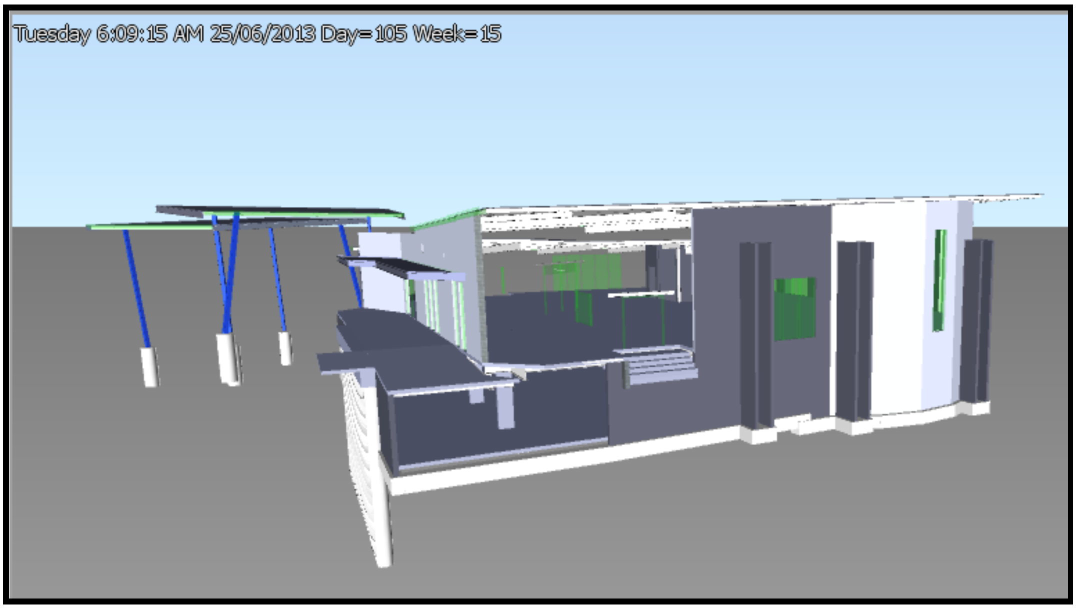


Figure 5.29 - Final BIM Model - Works Complete Week 15

The following Figure 5.30 shows works completed at Week 19. External windows have been installed, and office fitout works are continuing. No issues have been identified at this stage of the project schedule.

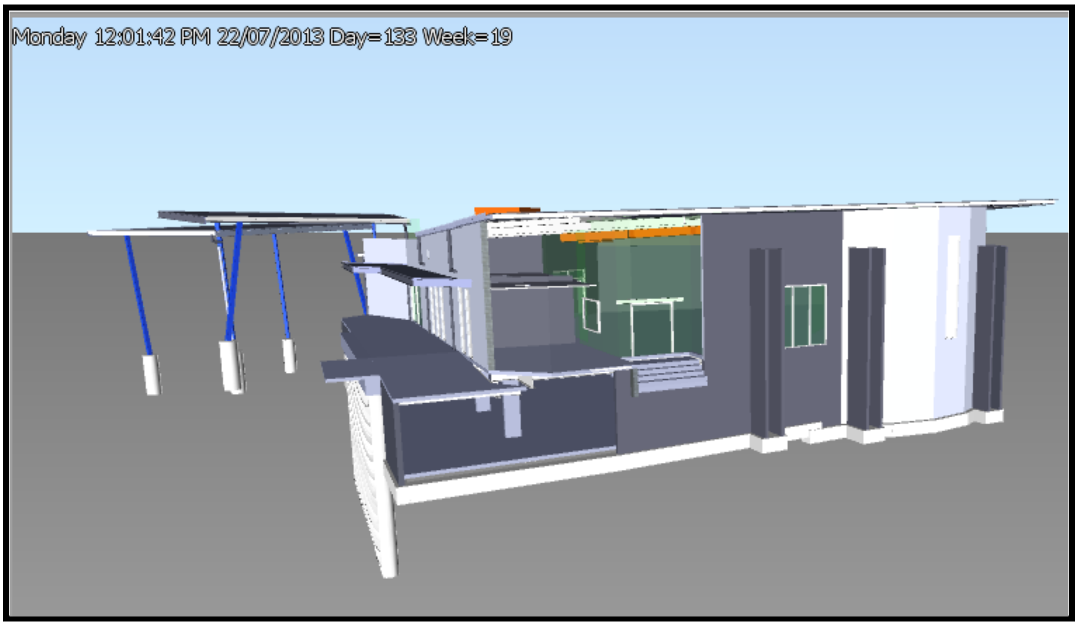


Figure 5.30 - Final BIM Model - Works Complete Week 19

The following Figure 5.31 shows the project at completion at Week 22. The simulation of the project schedule for the current design incorporating the design changes identified no issues.

Figure 5.31 - Final BIM Model - Works Complete Week 26

Using the construction timeframes included in the Monthly Project Programmes, the new construction schedule for Building B is 22 weeks. Therefore the construction of Building B would be completed within the Contract timeframe of 28 weeks from receipt of all council approvals. Identifying the constructability issues and resolving the design changes prior to the commencement on site, would therefore prevent any delays onsite.

The project schedule performance results of the Historical Project Case Study 1, previously discussed in Section 5.3.6, identified that the change to the design affected project schedule performance in comparison to the initial Construction Programme dated 15th January 2013. The use of 4D BIM tools on the project has enabled a key issue faced by The Organisation on the project to be managed and resolved prior to commencing construction works onsite.

The following Table provides a comparison between the projects Construction Programme dated 19th September 2013, after the design change had been made and subsequent delay incurred, and the current schedule completed for the project with the use of 4D BIM tools. An initial review of the results show the performance of the project schedule with regards to Building B works only, is much improved; however no Extension of Time Claims have been included for rain delays.

Table 8 - Project Schedule Performance - 4D BIM Tools

Construction Programme - dated 19/09/13		**Programme - 4D BIM Tools in Use**
Works	**Finish Date**	**Finish**
Building B Completion Date	19/09/2013	15/08/2013

As discussed in Section 5.3.6, a number of Extension of Time Claims were submitted on the project for rain delays. A review of the Extension of Time Claims Register dated 23rd July 2013, has been undertaken to determine the delays incurred, relating to Building B works. The following Table 18 identifies that 19 days related to delays on Building B.

Table 9 - Extension of Time Claim Register: Building B Delays

EOT	Description	Days	Bldg B Works	Bldg B Delay
1	Rain Delays	2	No	0
2	Rain Delays	5	Yes	5
3	Rain Delays	2	Yes	2
4	Rain Delays	1	Yes	1
5	Rain Delays	1	Yes	1
6	Rain Delays	3	Yes	3
7	Rain Delays	1	Yes	1
8	Rain Delays	3	Yes	3
9	Rain Delays	2	Yes	2
10	Rain Delays	1	Yes	1
11	Rain Delays	3	No	0
12	Rain Delays	4	No	0
		28		19

An adjustment to the results in Table 17 to incorporate the Extension of Time delays is included in Table 19. The project completion date with the use of 4 BIM tools is the 11th September 2013, which is a reduction of the construction schedule by 1 week and 1 day.

Table 10 - Project Schedule Performance - 4D BIM Tools: EOT Delays Included

Construction Programme - dated 19/09/13		Programme - 4D BIM Tools in Use	Add Extension of Time Claim Delays	Revised Completion Date - 4D BIM Tools in Use
Works	**Finish Date**	**Finish Date**		**Finish Date**
Building B Completion Date	19/09/2013	15/08/2013	19	11/09/2013

The use of 4D BIM tools, will not remove the requirement for the project management team producing project schedules for the project, however it was identified in this case study that project scheduling performance will be improved. The advantage of allowing the project management team to visualise the schedule prior to construction has enabled areas of concern to be identified, prior to commencing construction works.

The results of the use of 4D BIM tools, specifically Navisworks, on the historical project therefore indicate the implementation of 4D BIM tools would provide value to medium scale D&B organisations. It is also feasible to utilise 4D BIM tools in managing and resolving issues faced by medium scale D&B contractors.

5.5.6 Data Collection – 5D BIM – Comparison of Design Models

As discussed in Section 2.7 the use of the 5D BIM tool provides an advantage in pricing scope and variation changes in 3D BIM design revisions. The results included in Section 5.4.3 identified that the use of CostX is also able to provide a comparison between BIM model revisions for both quantities and costs, which aids in pricing scope changes in the design.

The following Figure 5.32 shows the 3D BIM model at the Building Approval stage, uploaded into CostX:

Figure 5.32 - 3D BIM Model (Building Approval Stage) - Uploaded to Exactal CostX

The second BIM model used was the Final 3D BIM design model produced for the project, which included both the Basement Design changes, and also all other scope changes on the project as a result of client variation requests.

The following Figure 5.33 shows the Final 3D BIM model, uploaded into CostX:

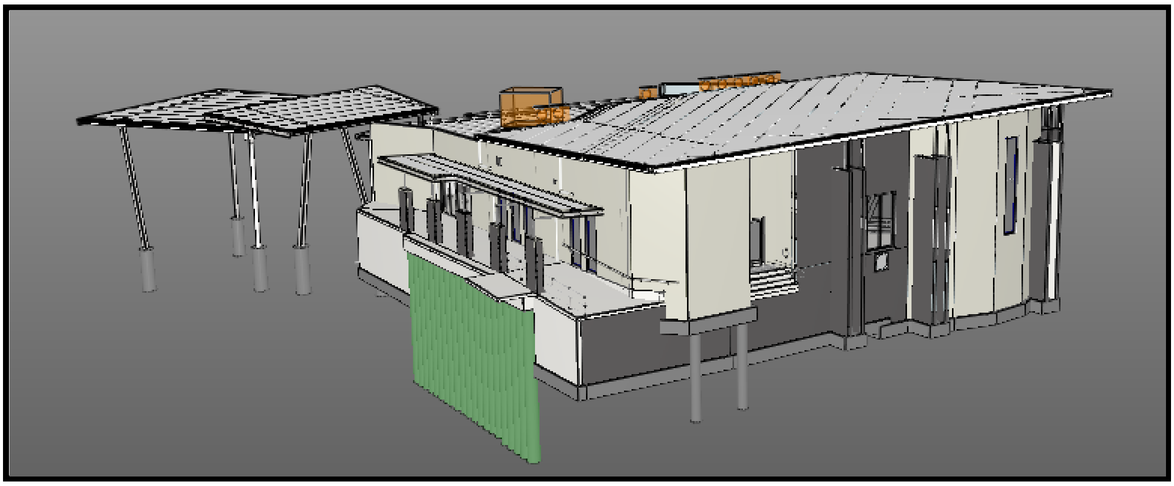


Figure 5.33 - Final 3D BIM Model - Uploaded to Exactal CostX

Quantities for each building element were extracted from the BIM model and an Elemental Report was produced for each BIM model. The reports are included in Appendix E of the Report. The reports were able to be completed within five minutes after uploading each of the BIM models into CostX.

The use of the layers function in CostX enables areas of the model to be hidden, which provides the user with the opportunity to review the internal areas of the model. The wall model elements have been hidden on the final BIM model, as shown in Figure 5.34:

Figure 5.34 - Exactal CostX Layers Function

A comparison was undertaken on the BIM models in CostX, to determine the design changes in the model revisions. As shown in Figure 5.35 the colours represent changes made in the models as follows:

- Blue – No Change
- Yellow – Revised
- Green – Addition
- Red – Deletion

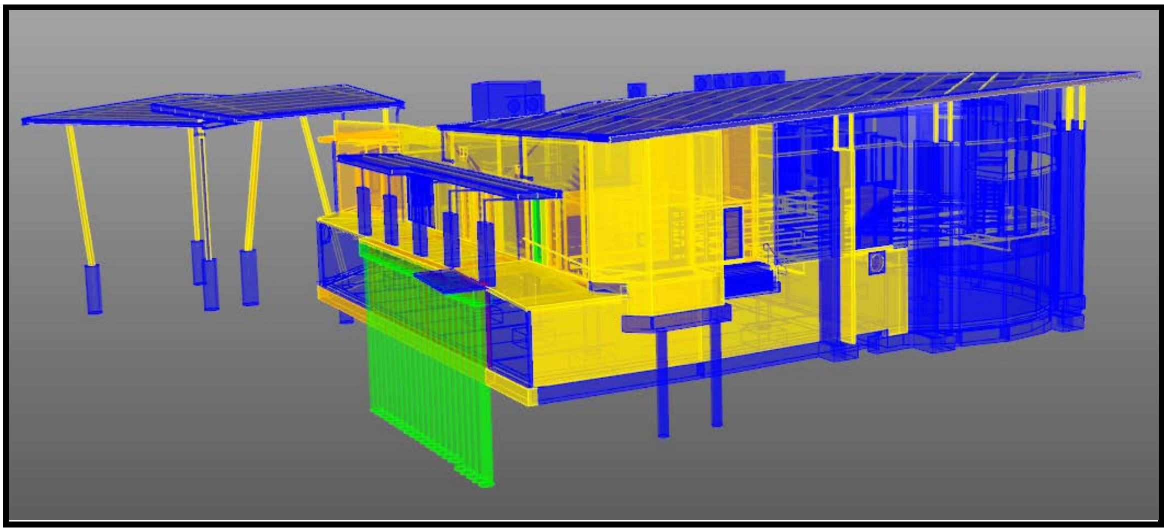


Figure 5.35 - 3D BIM Model Revision Comparison

In order to review the changes to the model, the areas that were unchanged were hidden, using the layers function. This resulted in only additions, deletions and revisions to the model being displayed, as shown in Figure 5.36 below:

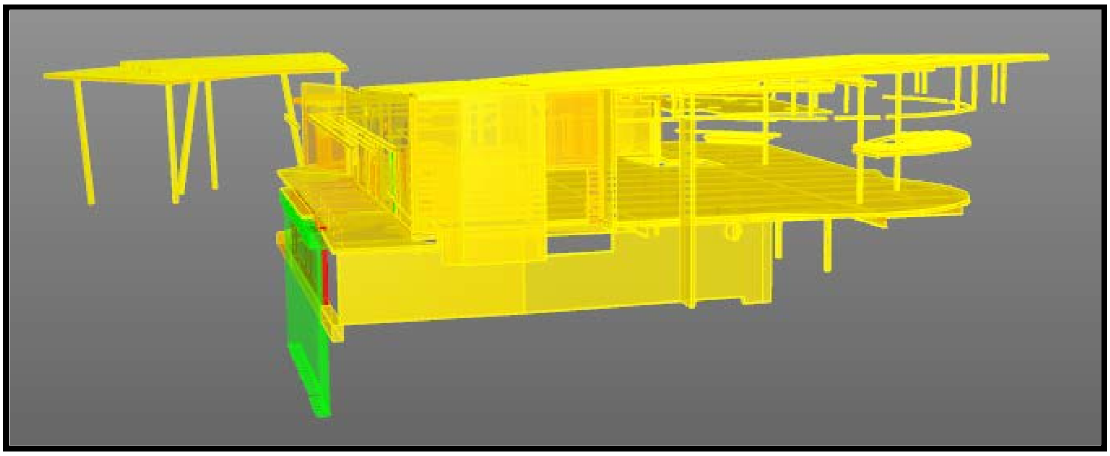
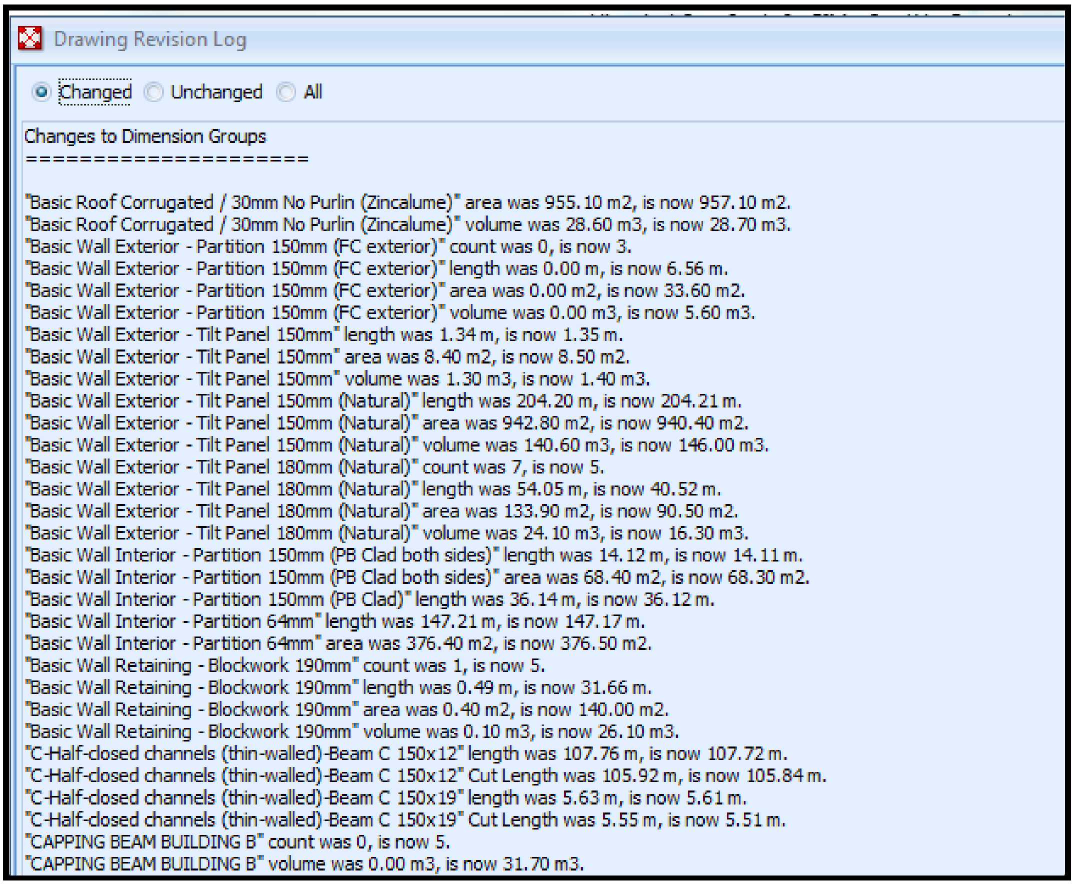


Figure 5.36 - 3D BIM Model Revision Comparison (Revisions, Additions and Deletions Only)

As discussed previously, the Final 3D BIM model available for use in the case study included all changes for the project. This identified a limitation in the case study into the use of CostX, as a comparison was unable to be undertaken on the scope change relating to the Building B basement works only.

A drawing revision log was produced identifying the changes in dimensions between the BIM models for the project. An extract of the Drawing Revision Log produced by CostX is shown in Figure 5.37 on the following page.



Drawing Revision Log

Changed Unchanged All

Changes to Dimension Groups
====================

"Basic Roof Corrugated / 30mm No Purlin (Zincalume)" area was 955.10 m2, is now 957.10 m2.
"Basic Roof Corrugated / 30mm No Purlin (Zincalume)" volume was 28.60 m3, is now 28.70 m3.
"Basic Wall Exterior - Partition 150mm (FC exterior)" count was 0, is now 3.
"Basic Wall Exterior - Partition 150mm (FC exterior)" length was 0.00 m, is now 6.56 m.
"Basic Wall Exterior - Partition 150mm (FC exterior)" area was 0.00 m2, is now 33.60 m2.
"Basic Wall Exterior - Partition 150mm (FC exterior)" volume was 0.00 m3, is now 5.60 m3.
"Basic Wall Exterior - Tilt Panel 150mm" length was 1.34 m, is now 1.35 m.
"Basic Wall Exterior - Tilt Panel 150mm" area was 8.40 m2, is now 8.50 m2.
"Basic Wall Exterior - Tilt Panel 150mm" volume was 1.30 m3, is now 1.40 m3.
"Basic Wall Exterior - Tilt Panel 150mm (Natural)" length was 204.20 m, is now 204.21 m.
"Basic Wall Exterior - Tilt Panel 150mm (Natural)" area was 942.80 m2, is now 940.40 m2.
"Basic Wall Exterior - Tilt Panel 150mm (Natural)" volume was 140.60 m3, is now 146.00 m3.
"Basic Wall Exterior - Tilt Panel 180mm (Natural)" count was 7, is now 5.
"Basic Wall Exterior - Tilt Panel 180mm (Natural)" length was 54.05 m, is now 40.52 m.
"Basic Wall Exterior - Tilt Panel 180mm (Natural)" area was 133.90 m2, is now 90.50 m2.
"Basic Wall Exterior - Tilt Panel 180mm (Natural)" volume was 24.10 m3, is now 16.30 m3.
"Basic Wall Interior - Partition 150mm (PB Clad both sides)" length was 14.12 m, is now 14.11 m.
"Basic Wall Interior - Partition 150mm (PB Clad both sides)" area was 68.40 m2, is now 68.30 m2.
"Basic Wall Interior - Partition 150mm (PB Clad)" length was 36.14 m, is now 36.12 m.
"Basic Wall Interior - Partition 64mm" length was 147.21 m, is now 147.17 m.
"Basic Wall Interior - Partition 64mm" area was 376.40 m2, is now 376.50 m2.
"Basic Wall Retaining - Blockwork 190mm" count was 1, is now 5.
"Basic Wall Retaining - Blockwork 190mm" length was 0.49 m, is now 31.66 m.
"Basic Wall Retaining - Blockwork 190mm" area was 0.40 m2, is now 140.00 m2.
"Basic Wall Retaining - Blockwork 190mm" volume was 0.10 m3, is now 26.10 m3.
"C-Half-closed channels (thin-walled)-Beam C 150x12" length was 107.76 m, is now 107.72 m.
"C-Half-closed channels (thin-walled)-Beam C 150x12" Cut Length was 105.92 m, is now 105.84 m.
"C-Half-closed channels (thin-walled)-Beam C 150x19" length was 5.63 m, is now 5.61 m.
"C-Half-closed channels (thin-walled)-Beam C 150x19" Cut Length was 5.55 m, is now 5.51 m.
"CAPPING BEAM BUILDING B" count was 0, is now 5.
"CAPPING BEAM BUILDING B" volume was 0.00 m3, is now 31.70 m3.

Figure 5.37 - Drawing Revision Log Extract

In order to provide a comparison of costs based on the revised BIM models, CostX provides a Comparison Report as part of the Workbooks Function. The Workbooks functionality in the Student Licensed Version of CostX however prevents the production of Comparison Reports. This has identified a limitation in the case study into the use of CostX, as the full functions of the BIM tool cannot be used in the analysis.

As previously discussed in Section 5.3, Historical Case Study 1 identified design changes to Building B Basement. This design change was as a result of constructability concerns identified in the original design. In order to provide an analysis of the cost impact of the design changes, workbooks were created in CostX for both BIM models. Rates were applied against the quantities for each revised building element from the BIM models. A Bill of Quantity (BOQ) was then produced for each BIM model. The following Figures 5.38 and 5.39 provide a summary of each of the BOQ's produced for the BIM models:

EDUCATIONAL VERSION **COLLECTION SUMMARY**

COLLECTION	PAGE NO	
Floors	1/1	140,320
Structural Foundations	2/1	3,355
Walls	3/1	165,580
Total Amount:		**309,255**

Figure 5.38 - BOQ Building Approval BIM Model

EDUCATIONAL VERSION **COLLECTION SUMMARY**

COLLECTION	PAGE NO	
Floors	1/1	140,640
Structural Foundations	2/1	47,430
Walls	3/1	183,170
Total Amount:		**371,240**

Figure 5.39 - BOQ Final Design BIM Model

As can be seen from the BOQ, the design change resulted in an increase in costs of $61, 985.00. The advantage however of identifying these changes prior to construction works commencing, is the reduction in cost of Project Overheads that are incurred while projects are delayed. The BOQ's are included in Appendix F.

The use of 5D BIM tools on the project enabled cost comparisons to be undertaken on the design changes, within approximately two hours. The reduced timeframe of pricing and resolving the costs of the scope change, provide the ability for further alternative designs to be reviewed, without a significant impact on the projects programme. The use of CostX however in this case study, firstly relied upon Navisworks identifying the area of concern to therefore drive the design change requiring a price comparison. This indicates that the use of CostX provides the most benefit to the project team during the design and construction phases when used in collaboration with a 4D BIM tool such as Navisworks.

As previously discussed in the Literature Review in Section 2.3.2 (e), the 3D BIM design model is considered the authoring tool for the project. The use of CostX in the case study has illustrated the significance of the 3D BIM design model as 5D BIM extracts all quantities and data from this model. If there is an omission from the model, or an error in the design, the use of 5D BIM cannot be used to resolve this.

The information provided by the CostX 5D BIM model was used in the Navisworks simulation, to provide an analysis of costs at a specific point in the project schedule. The combination of CostX and Navisworks therefore enables the identification of when the impact on the projects cash flow occurs for scope changes and variations. At Week 11 in the project schedule, subcontractor costs incurred on Building B was $268, 783.00, as shown in Figure 5.40:

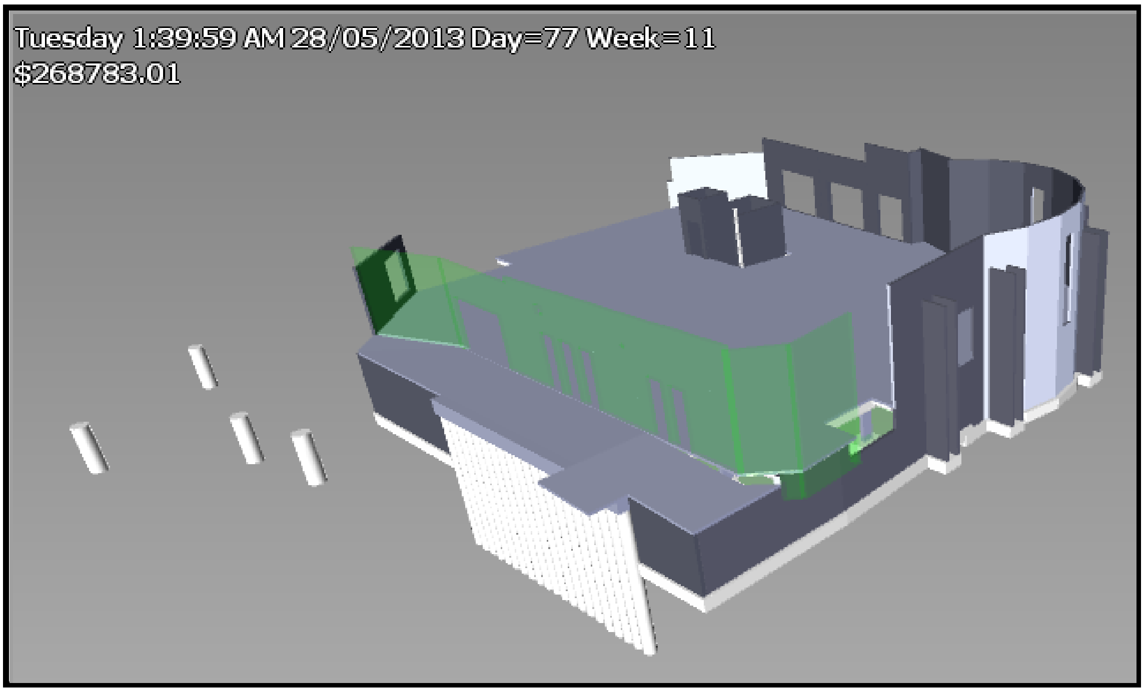


Figure 5.40 - Subcontractor Costs Week 11

5.5.7 Summary of Results – Historical Project Case Study 2

The aim of Historical Project Case Study 2 in meeting Sub-Objective 6 was to retrospectively adopt 4D and 5D BIM tools on the historical project as a means to determine the value of utilising 4D and 5D BIM tools in managing and resolving issues faced by medium-scale D&B contractors.

The adoption of 4D BIM tools in collaboration with the 3D BIM Design Model at the Building Approval milestone, identified the use of Navisworks was able to improve the constructability review process for the project. Sequencing the construction schedule, prior to construction commencing enabled the project to be further reviewed and analysed. The sequencing of the project schedule also enabled concerns to be identified, prior to commencing construction works onsite.

Project schedule performance for Building B was improved by one week and one day in comparison to the project schedule performance of the project without the use of BIM tools. As discussed in Section 2.7 of the Literature Review and also the findings of the Historical Project Case Study 1 included in Section 5.3.3, D&B contractors, due to an increased design responsibility, are unable to claim for delays incurred due to design changes or errors that are not requested as a change under the contract scope of works. Therefore, to ensure project schedule performance the constructability of designs is paramount as claims cannot be made for design changes that are made as a result of constructability concerns.

The results of Historical Project Case Study 2 has identified that Navisworks is still reliant upon the initial scheduling of the project team. The project schedules are written in external scheduling tools, in the case study Microsoft Project was used. Navisworks will therefore not replace the requirement of the project team to schedule the project, however the results of the case study have shown the scheduling of the project is improved, through the ability of the user to visualise the construction sequence of the project. Improved project schedule performance due to the use of 4D BIM tools will therefore aid in the alleviation of risks associated with the increased design responsibility, and is therefore considered a feasible tool to be used by medium scale D&B contractors in managing and resolving issues that are encountered.

The use of 5D BIM tools and specifically CostX has enabled cost reviews to be undertaken on the revised BIM models. The results identified that the use of CostX on the project enabled cost comparisons to be undertaken on the design changes, within approximately two hours. This provides an advantage to D&B contractors in reviewing cost implications of alternative design proposals for projects prior to commencing works onsite. The use of 5D BIM CostX in collaboration with 4D BIM Navisworks also provides an advantage in monitoring the cost of the project at specific periods of time in the project schedule.

The findings from the case study have illustrated the importance of the 3D BIM model, when utilising 5D BIM tools. All information in the case study for use in the 5D BIM tool was extracted from the 3D BIM design model, therefore the accuracy of this model is paramount to the success of the 5D BIM tool. The results of the previous Historical Project Case Study 1 identified that the use of the D&B method resulted in an increased design responsibility for the contractor. Therefore the responsibility for the accuracy of the 3D BIM design model lies with the contractor.

In contrast however to the use of 4D BIM Navisworks, the results of the case study have not resolved any quantifiable improvements on the project performance with the use of 5D BIM CostX. The foregoing discussion identified that the use of CostX was most beneficial for the use in managing and resolving key issues, when used in collaboration with Navisworks. Therefore, while the use of the 5D BIM was able to improve variation and scope change pricing, the use of the 5D BIM tool in managing and resolving issues faced by D&B contractors provides the most advantage when used in collaboration with a 4D BIM tool, such as Navisworks.

5.6 Results and Analysis Summary

The results of the research project have been successful in achieving the sub-objectives for the project. The project sub-objectives have been completed as a means to determine the feasibility of the utilisation of 4D and 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors.

Interviews conducted with key organisation members in Section 5.2 validated the findings of the literature review and achieved sub-objective 3. A trend in the interview responses was the importance of the constructability of the designs. The constructability of designs affects not only on the projects programme performance, but also the budget performance. Furthermore, when the designs have to be modified due to constructability concerns, additional costs are not recoverable from the client. The constructability of designs is therefore integral in the success of D&B Projects.

Historical Project Case Study 1 was completed as a means to augment the concerns identified in the literature review and the results of the interviews. The results of the case study identified constructability concerns on the project affected both the project schedule and also budget performance. Contractual conditions however prevented claims for both cost and time to be made to the client. BIM was utilised on the project however the use was limited to 3D in the design review process, this review did not identify the constructability concerns of the design. Identifying specific constructability concerns and the subsequent effect on both the project schedule and budget on the historical project has augmented the concerns of the literature review and interview results.

The results of the interviews and Historical Project Case Study 1, confirmed that there are areas of concerns in the use of the D&B method of contracting. This also identified the need to further understand the feasibility of using 4D and 5D BIM tools to manage these concerns, further research was therefore undertaken.

The use of the Pilot Case Study was advantageous in resolving the usage of 4D and 5D BIM tools; however the simplicity of the project in the Case Study therefore meant a definitive answer was unable to be determined on the feasibility of 4D and 5D BIM tools in managing and resolving key issues faced by medium scale D&B contractors. The use of the specific BIM tools, Autodesk Navisworks and Exactal CostX was however resolved for use on the second case study.

Previous research in the literature has discussed the advantage that the use of 4D BIM tools provide in the constructability review process on projects, however the results have been limited to use on large scale projects. The use of 5D BIM tools are also advantageous in pricing scope changes and variations, which are able to be undertaken in reduced timeframes using the revised 3D BIM model. The use of the second case study therefore enabled 4D and 5D BIM tools to be implemented on the same historical project, in order to undertake a comparative analysis of the projects performance with the use of BIM tools.

Retrospectively adopting 4D and 5D BIM tools on the Historical Project Case Study 2 proved beneficial in improving the projects performance. The use of 4D BIM tools, Autodesk Navisworks, to visualise the projects construction schedule prior to commencing construction works onsite enabled the constructability concern to be identified, prior to commencing works onsite. In doing so, the projects schedule was improved by one week and one day.

The results of the case study adopting 5D BIM tools indicate that there is an improvement in pricing variations and scope changes, as the 3D BIM design models are able to be priced as the design changes are made. The use of CostX in the case study however relied upon Navisworks to firstly identify the concern on the project. Once the constructability concern was identified by Navisworks, the costs associated with the revised 3D BIM design model was able to be compared with the original 3D BIM design model, using CostX.

The findings from the case study illustrate that the use of Autodesk Navisworks still require project schedules to be written in external scheduling tools, in the case study Microsoft Project was used. Autodesk Navisworks therefore will not replace the requirement of the project team to schedule the project. The case studies have also highlighted the importance of the 3D BIM model for use with the third party BIM tools. The third party BIM tools are reliant upon the 3D BIM design model, specifically CostX. In order for the BIM tool to be used effectively on projects, the 3D BIM design model must be accurate, as 5D BIM does not account for missing information or errors in the design model.

The results of the case study indicate that Autodesk Navisworks is a feasible BIM tool to be adopted by medium scale D&B contractors, for managing and resolving key issues. Based on the results of this study however, the feasibility of 5D BIM tools such as CostX is reliant upon its adoption in collaboration with a 4D BIM tool.

CHAPTER 6 - CONCLUSIONS

6.1 Introduction

The aim of the research project was to examine the feasibility of utilising 4D and 5D Building Information Modelling (BIM) tools for managing and resolving key issues faced by contemporary medium-scale Design and Build contractors. The research project was driven by a desire to understand the use of 4D and 5D BIM tools in medium scale Design and Build organisations in Australia.

The analysis of previous research completed as part of the literature review, identified previous research had been undertaken on the benefits provided to organisations that have adopted BIM tools for use on projects. Both project schedule and budget performance had improved when 4D and 5D BIM tools had been implemented. The focus of previous research however has been on the use in large scale organisations, therefore the research failed to provide an understanding of the feasibility of medium scale D&B contractors utilising the BIM tools. There was a need for further research into the use of 4D and 5D BIM tools by medium scale D&B contractors.

The outcome of the literature review into the use of the D&B method of contracting identified a number of key issues. The use of the D&B method improves the budget and schedule performance on projects however the constructability of designs is key to achieving this. The D&B method results in a reduction of claims, as specific contract clauses are included in Standard Form Contracts that provide limitations on the claims contractors are able to make. The contractor also has an increased design responsibility when using the D&B method; this therefore increases the importance of ensuring that there are no errors of constructability concerns with the design. Claims cannot be made for either time or costs to modify or rectify the designs.

6.2 Conclusions

Historical Project Case Study 1 achieved sub-objective 4 for the research project. The use of the historical project, Project A, enabled a case study to be undertaken on a specific D&B project completed by a medium scale D&B contractor. The findings of the case study augmented the concerns previously identified in the literature review. Key issues were identified that are as a result of the contractual conditions that are specific to D&B projects. Contractors have an increased design responsibility, therefore claims for both time and cost relating to design co-ordination or errors are unable to be made on D&B projects. The results identified that the increased design responsibility can provide advantages to contractors due to the ability to control the design, it was also concluded in the results that the constructability of the designs was paramount to project success.

The results of Historical Project Case Study 1 demonstrated a specific constructability concern in Building B of the project, which affected both the project schedule and budget. Concerns were identified in the constructability of the design for Building B basement; these concerns however were identified after the commencement of construction works onsite. Designs for the basement area were therefore revised, affecting both the project schedule and budget performance. The use of the D&B

method on the project however prevented claims for both time and costs being made to the client for the change. The identification of this key issue faced by D&B contractors provided a focus for the second case study, Historical Project Case Study 2.

Historical Project Case Study 2 achieved sub-objective 6 which was to examine value of utilising 4D and 5D BIM tools in managing and resolving issues on projects undertaken by medium-scale D&B contractors. Project A was again used for this case study, with 4D and 5D BIM tools adopted retrospectively. The introduction of specific BIM tools onto the same historical project enabled a comparative case study to be undertaken between the performance of the project without BIM tools and the predicted performance with BIM tools.

As predicted, the project with the use of 4D BIM tools outperformed the project without the use of BIM tools. The projects schedule performance was improved, by shortening the predicted construction timeframe by one week and one day. Autodesk Navisworks was able to be used to manage and resolve the constructability concerns identified on the project, that the previous case study had indicated was a key issue faced by medium scale D&B contractors. This improved performance resolved that the utilisation of 4D is feasible for managing and resolving key issues faced by medium scale D&B contractors.

The performance of 5D BIM tools however did not result in a significant improvement on the projects performance when adopted. The results of the case study indicated that there is an advantage to the use of Exactal CostX and 5D BIM on projects, whereby variations and scope changes are able to be priced in a reduced timeframe. This provides advantages when designs are changed, as the project team is able to undertake cost comparisons between multiple designs. Whilst the results demonstrated the advantages of the use of 5D BIM, it was resolved that the use of 5D BIM tools in managing and resolving issues faced by medium scale D&B contractors is feasible when used in collaboration with 4D BIM tools.

The research project has been successful in providing an understanding of the use of 4D and 5D BIM tools in medium scale D&B contractors. The adoption of specific BIM tools in the case study enabled a review of the specific attributes of each of the BIM tools. The aim of the research was to examine the feasibility of the use of both 4D and 5D BIM tools by medium scale D&B contractors, and the research project has been successful in achieving this aim. The use of 4D BIM tools, specifically Autodesk Navisworks is feasible however the use of 5D BIM tools, specifically Exactal CostX is reliant upon its use in collaboration with 4D BIM tools.

6.3 Further Research and Recommendations

The aforementioned results resolve that the use of BIM tools is not limited to large scale contractors and is feasible for use in medium scale D&B contractors. It is recommended therefore, that the use of 4D BIM, and specifically Autodesk Navisworks, should be implemented in The Organisation as a means to manage and resolve issues that are encountered on projects. Prior to the implementation of Navisworks however it is recommended that further research should be undertaken as a means to strengthen these findings. Furthermore, further research should be undertaken on the use of 5D BIM tools, and specifically Exactal CostX to determine whether performance is improved and therefore can be considered a feasible BIM tool.

As previously discussed, the utilisation of the historical project in the Historical Project Case Study 1 and 2 provided value in undertaking a comparative analysis of the performance of the project without BIM tools, and the potential performance of the project with the use of 4D and 5D BIM tools. It is recommended however that further case studies be undertaken on current projects of medium scale D&B contractors. The use of current projects will enable a real time analysis of the feasibility of utilising 4D and 5D BIM tools in managing and resolving key issues, rather than the controlled historical projects.

A single project was utilised for Historical Project Case Study 1 and 2, which was a combined church assembly hall and offices. The use of one project type in the case study therefore has not enabled a comparison to be undertaken on projects with differing scopes that are also completed by medium scale D&B contractors. It is recommended future research should be undertaken on multiple projects as a means to provide a consensus in the results. The multiple projects should also vary in project type, such as Industrial Warehouses, Offices and Retail Centres, all of which are projects undertaken by medium scale D&B contractors. The use of differing project types will demonstrate whether the performance of the BIM tool is affected by the project type it has been used on.

6.4 Limitations

The research project was successful in achieving the aim, however there were limitations encountered in the completion of the research work. The case studies performed in the research project identified a number of limitations that should be considered for further research prior to a final recommendation being handed down on the feasibility of utilising 4D and 5D BIM tools in managing and resolving key issues faced by D&B contractors.

The results of the use of Exactal CostX on Historical Project Case Study 2, included in Section 5.5.6 identified a limitation of the case study undertaken. The available License for the Software for use on the case study was a Student Version. The use of the Student Version of Exactal CostX limited the functions of the software. Comparison Reports comparing revised BIM models were therefore unable to be produced. These limitations restricted the research that was undertaken as a complete analysis of the performance of the BIM tool was unable to be completed. It is therefore recommended that the use of Full Licenses is used in any future research.

The 3D BIM Design Files available for use in the case study, for the historical project were Building Approval stage, prior to the design changes being made, and the Final 3D BIM Design Files that incorporated all changes for the project, not specifically the design change that the case study was analysing. The restriction in the availability of the 3D BIM design file for the design change provided limitations in the Historical Project Case Study 2, as the specific design changes in the 3D BIM model were unable to be analysed. 4D and 5D BIM tools are unable to differentiate between specific design changes, as the 3D BIM model is reviewed as a whole file. The use of current projects in future research will provide access to the current 3D BIM files as the designs are changed, this will alleviate some of these limitations in the research.

APPENDICES

APPENDIX A – Project Specification

University of Southern Queensland

FACULTY OF HEALTH, ENGINEERING & SCIENCES

ENG 4111 / 4112 RESEARCH PROJECT

PROJECT SPECIFICATION

FOR: MELANIE PATTERSON

TOPIC: BUILDING INFORMATION MODELLING: AN EXPLORATIVE STUDY

SUPERVISOR: DR VASANTHA ABEYSEKERA

ENROLMENT: ENG4111 – S1 2015 & ENG4112 – S2 2015

PROJECT AIM: The project seeks to examine the feasibility of utilising 4D and 5D BIM tools for managing and resolving key issues faced by contemporary medium-scale Design and Build contractors.

PROGRAMME: Issue E – 15th September 2015

1. Establish risks faced by design and build contractors through an extensive literature review.
2. Undertake extensive literature review to research and evaluate currently available Building Information Modelling software and the developments in the software since its inception, focussing on the integration between 3D and the elements of 4D (Time) & 5D (Cost).
3. Undertake interviews with key organisation members in order to validate the findings from the literature review.
4. Undertake a historical case study on one of our Organisations completed projects in order augment these concerns (Historical Case Study 1).
5. Undertake Pilot Case Study using a small scale test project created in Autodesk REVIT and selected 4D and 5D BIM tools, as a means to provide an understanding of the tools and resolve the usage of the tools for the remainder of the research project.
6. Apply selected 4D and 5D BIM tools to the historical project and then undertake a case study (Historical Case Study 2) to resolve the value of using these tools in managing and resolving the issues that are encountered.

APPENDIX B – Project Timeline

MELANIE PATTERSON
PROJECT TIMELINE

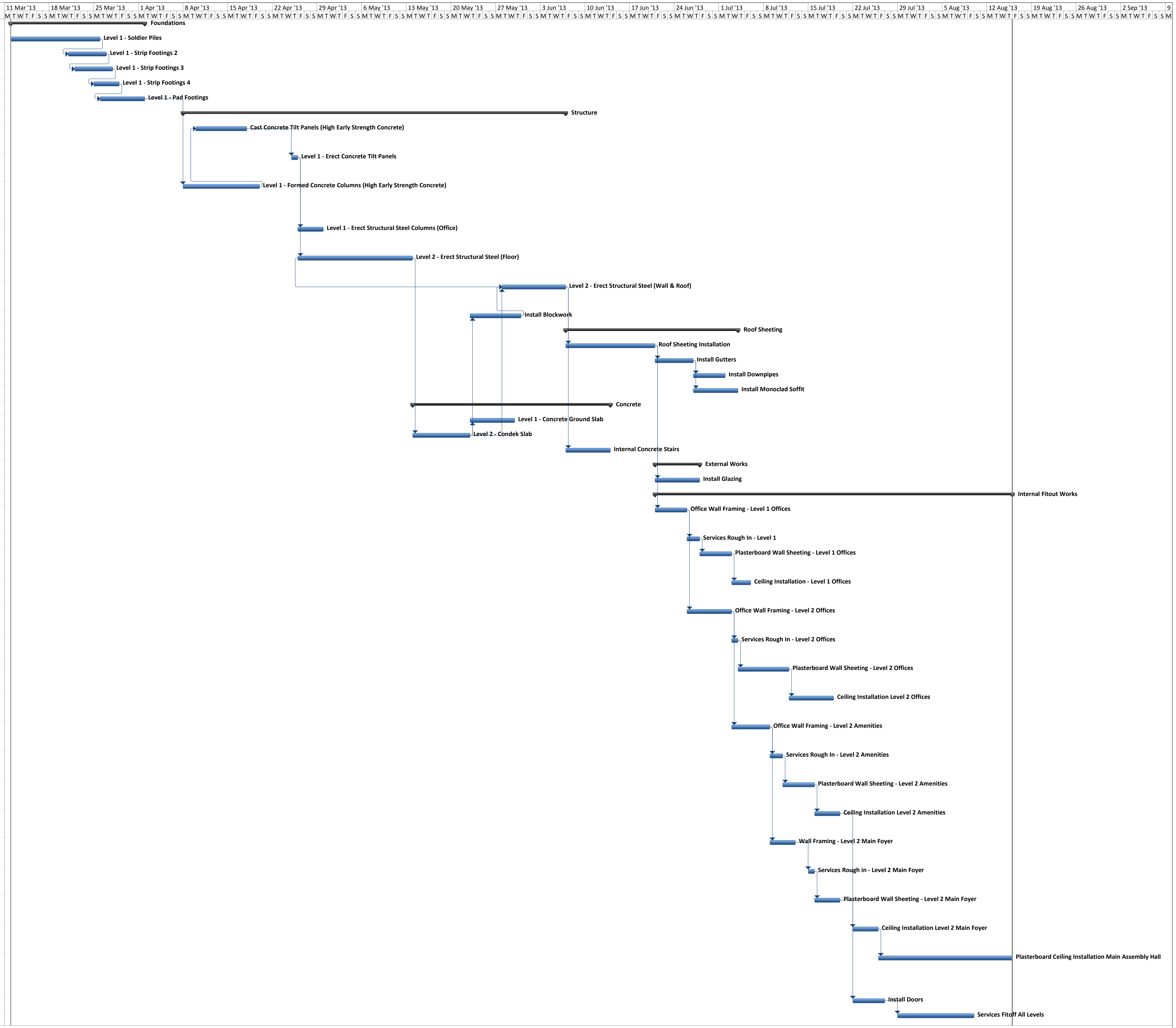
	SEMESTER 1							SEMESTER 2														
	WEEKS																					
			EXAMS		RECESS																	
TASKS	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**
Establish Case Study Protocols		12-Jun																				
Complete Design of Pilot Case Study Carport					3-Jul																	
Undertake Pilot Case Study							17-Jul															
Undertake historical Case Study augmenting concerns of organisation											14-Aug											
Implement BIM Techniques to new project and undertake case study															11-Sep							
ASSESSMENT PROGRAMME																						
Preliminary Report Project Progress Assessment from Supervisor			17/06																			
Write Draft Disseration																						
Partial Draft Dissertation Submission																16-Sep						
Assessment Concference Seminar																						
Complete Presentation of Conference Seminar																18-Sep						
Attend Conference Seminar																						
Finalise Dissertation																					26-Oct	
Dissertation Submission																						29/10

APPENDIX C – Historical Project Case Study 1 - Subcontractor Variations

Trade	Works	Design Costs	Site Works	Client Scope Change	Vari. Claimed to Client
Concrete	Additional Concrete Footpath		Yes		
Foundations	Revised Pier Design	Yes			
Earthworks	Import additional fill		Yes		
Electrical	Temporary Power		Yes		
Roofing	Demolition Works		Yes		
Hydraulics	Various Hydraulic Changes	Yes			
Concrete	Kerb and Channel Changes		Yes		
Hydraulics	Stormwater Changes from Tender Drawings	Yes			
Electrical	Additional Electrical Scope of Works		Yes		
Electrical	Temporary Power		Yes		
Hydraulics	Temp Sewer Connection		Yes		
Internal Fitout	Temporary Lunchroom Construction		Yes		
Hydraulics	Stormwater Changes from Tender Drawings	Yes			
Earthworks	Import additional fill		Yes		
Steel Erection	Rigger and Dogman for additional misc works		Yes		
Internal Fitout	Construction Temporary Stairs for access		Yes		
Earthworks	Supply Drainage Gravel		Yes		
Internal Fitout	Alter internal wall linings			Yes	Yes
Concrete Tilt Panels	Reduction in scope of works - Delete Panels	Yes			
Blockwork	Increase in scope of works - Add Blockwork	Yes			
Roofing	Supply and install additional cappings	Yes			
Concrete Tilt Panels	Hebel infills	Yes			
Hydraulics	Change to Stormwater Design	Yes			
Internal Fitout	Door Hardware Changes		Yes		
Concrete	Demolition Works & Construction of Telstra Pit		Yes		
Metalwork	Change Handrail Design		Yes		
Blockwork	Increase in scope of works - Add Blockwork	Yes			
Concrete	Reduction in scope of works - Reduced Footings	Yes			
Formwork	Increase in scope of works - Add additional formwork due to wall design change	Yes			
Paint	Additional Painting		Yes		
Metalwork	Height Bar to basement		Yes		
Paint	Additional Painting		Yes		
Floor Coverings	Change in nosing to stairs		Yes		
Paint	Touchup Steel Work		Yes		
Paint	Additional Painting		Yes		
Roofing	Birdspikes to top of pillars			Yes	Yes
Hydraulics	Change to temp services connections		Yes		
Roofing	Additional Flashings		Yes		
Metalwork	Handrail Extensions		Yes		
Electrical	Additional Power Outlets		Yes		
Plumber	Rectify existing sewer connection		Yes		
Concrete	Rectify existing footpaths		Yes		
Roller Doors	Additional Card Readers		Yes		

APPENDIX D – Historical Project Case Study 2 - Predicted Project Schedule

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1			**Foundations**	**15 days**	**Tue 12/03/13**	**Mon 1/04/13**		
2			Level 1 - Soldier Piles	10 days	Tue 12/03/13	Mon 25/03/13		
3			Level 1 - Strip Footings 2	4 days	Thu 21/03/13	Tue 26/03/13	2FS-3 days	
4			Level 1 - Strip Footings 3	4 days	Fri 22/03/13	Wed 27/03/13	3FS-3 days	
5			Level 1 - Strip Footings 4	4 days	Mon 25/03/13	Thu 28/03/13	4FS-3 days	
6			Level 1 - Pad Footings	5 days	Tue 26/03/13	Mon 1/04/13	5FS-3 days	
7			**Structure**	**44 days**	**Mon 8/04/13**	**Thu 6/06/13**		
8			Cast Concrete Tilt Panels (High Early Strength Concrete)	6 days	Wed 10/04/13	Wed 17/04/13	10FS-8 days	
9			Level 1 - Erect Concrete Tilt Panels	1 day	Thu 25/04/13	Thu 25/04/13	8FS+5 days	
10			Level 1 - Formed Concrete Columns (High Early Strength Concrete)	10 days	Mon 8/04/13	Fri 19/04/13	6FS+4 days	
11			Level 1 - Erect Structural Steel Columns (Office)	2 days	Fri 26/04/13	Mon 29/04/13	9	
12			Level 2 - Erect Structural Steel (Floor)	12 days	Fri 26/04/13	Mon 13/05/13	9	
13			Level 2 - Erect Structural Steel (Wall & Roof)	8 days	Tue 28/05/13	Thu 6/06/13	12SS,22,14FS-3 days	
14			Install Blockwork	6 days	Thu 23/05/13	Thu 30/05/13	22	
15			**Roof Sheeting**	**19 days**	**Fri 7/06/13**	**Wed 3/07/13**		
16			Roof Sheeting Installation	10 days	Fri 7/06/13	Thu 20/06/13	13	
17			Install Gutters	4 days	Fri 21/06/13	Wed 26/06/13	16	
18			Install Downpipes	3 days	Thu 27/06/13	Mon 1/07/13	17	
19			Install Monoclad Soffit	5 days	Thu 27/06/13	Wed 3/07/13	17	
20			**Concrete**	**23 days**	**Tue 14/05/13**	**Thu 13/06/13**		
21			Level 1 - Concrete Ground Slab	5 days	Thu 23/05/13	Wed 29/05/13	22	
22			Level 2 - Condek Slab	7 days	Tue 14/05/13	Wed 22/05/13	12	
23			Internal Concrete Stairs	5 days	Fri 7/06/13	Thu 13/06/13	13	
24			**External Works**	**5 days**	**Fri 21/06/13**	**Thu 27/06/13**		
25			Install Glazing	5 days	Fri 21/06/13	Thu 27/06/13	16	
26			**Internal Fitout Works**	**40 days**	**Fri 21/06/13**	**Thu 15/08/13**		
27			Office Wall Framing - Level 1 Offices	3 days	Fri 21/06/13	Tue 25/06/13	16	
28			Services Rough In - Level 1	2 days	Wed 26/06/13	Thu 27/06/13	27	
29			Plasterboard Wall Sheeting - Level 1 Offices	3 days	Fri 28/06/13	Tue 2/07/13	28	
30			Ceiling Installation - Level 1 Offices	3 days	Wed 3/07/13	Fri 5/07/13	29	
31			Office Wall Framing - Level 2 Offices	5 days	Wed 26/06/13	Tue 2/07/13	27	
32			Services Rough In - Level 2 Offices	1 day	Wed 3/07/13	Wed 3/07/13	31	
33			Plasterboard Wall Sheeting - Level 2 Offices	6 days	Thu 4/07/13	Thu 11/07/13	32	
34			Ceiling Installation Level 2 Offices	5 days	Fri 12/07/13	Thu 18/07/13	33	
35			Office Wall Framing - Level 2 Amenities	4 days	Wed 3/07/13	Mon 8/07/13	31	
36			Services Rough In - Level 2 Amenities	2 days	Tue 9/07/13	Wed 10/07/13	35	
37			Plasterboard Wall Sheeting - Level 2 Amenities	3 days	Thu 11/07/13	Mon 15/07/13	36	
38			Ceiling Installation Level 2 Amenities	4 days	Tue 16/07/13	Fri 19/07/13	37	
39			Wall Framing - Level 2 Main Foyer	4 days	Tue 9/07/13	Fri 12/07/13	35	
40			Services Rough in - Level 2 Main Foyer	1 day	Mon 15/07/13	Mon 15/07/13	39	
41			Plasterboard Wall Sheeting - Level 2 Main Foyer	4 days	Tue 16/07/13	Fri 19/07/13	40	
42			Ceiling Installation Level 2 Main Foyer	4 days	Mon 22/07/13	Thu 25/07/13	41	
43			Plasterboard Ceiling Installation Main Assembly Hall	15 days	Fri 26/07/13	Thu 15/08/13	42	
44			Install Doors	5 days	Mon 22/07/13	Fri 26/07/13	38	
45			Services Fitoff All Levels	10 days	Mon 29/07/13	Fri 9/08/13	44	



Task	Milestone	Project Summary	External Milestone	Inactive Milestone	Manual Task	Manual Summary Rollup	Start-only	Deadline
Split	Summary	External Tasks	Inactive Task	Inactive Summary	Duration-only	Manual Summary	Finish-only	Progress

APPENDIX E – Historical Project Case Study 2 – Exactal CostX Elemental Report

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Model Lines	0.00		92	no	0.00	0		0
	M_Counter Top w Sink Hole 600mm Depth	0.00		5	m	0.00	0		0
	Compound Ceiling Flush Plasterboard on Battens	0.00		436	m2	0.00	0		0
	Compound Ceiling Suspended - Rondo, Classic 600 x 1200mm Mineral	0.00		574	m2	0.00	0		0
	Compound Ceiling Suspended - Rondo, Classic 600 x 1200mm Vinyl	0.00		54	m2	0.00	0		0
	Concrete Cast-in Situ	0.00		1	no	0.00	0		0
	Concrete Cast-in Situ1	0.00		1	no	0.00	0		0
	System Panel Glass	0.00		72	m2	0.00	0		0
	Rectangular Mullion1 70 x 100mm	0.00		225	m	0.00	0		0
	Curtain Wall - Door - Double	0.00		4	no	0.00	0		0
	Curtain Wall - Door - Double Curtain Wall - Door - 2400	0.00		1	no	0.00	0		0
	Curtain Wall - Door - Double solid	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 1200 X 2100	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 1600 X 3150	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 2100 X 900	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 2500 x 5300	0.00		1	no	0.00	0		0
	Swing - Double 2040 x 870/420	0.00		1	no	0.00	0		0
	Swing-Single-Standard 2040 x 820-Hollow Core	0.00		1	no	0.00	0		0
	Swing-Single-Standard 2040 x 920-Hollow Core	0.00		12	no	0.00	0		0
	Swing-Single-Standard 2040 x 920-Solid Core	0.00		10	no	0.00	0		0
	Toilet Partition Door	0.00		5	no	0.00	0		0
	pocket_door_658 920w	0.00		6	no	0.00	0		0
	Main DB	0.00		1	no	0.00	0		0
	Fascia Box Gutter (150x50) 150x150 Box Gutter	0.00		18	m	0.00	0		0
	Fascia Eaves Gutter (150sqm) 150sqm 5 deg (Tilt)	0.00		15	m	0.00	0		0
	Fascia Eaves Gutter (300sqm) 300sqm 3 deg (Sheet)	0.00		81	m	0.00	0		0
	Fascia Flashing-Barg 210 x 210, 80	0.00		2	m	0.00	0		0
	Fascia Flashing-Barg with return 200x250 200 x 250, 90	0.00		48	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Fascia Flashing-Barg with return 200x280 200 x 280, 90 (Continued)	0.00		3	m	0.00	0		0
	Fascia Flashing-Junction Under Over	0.00		34	m	0.00	0		0
	DB FLOOR	0.00		1	m2	0.00	0		0
	DOWNSTAND BEAM RAMP 2	0.00		2	m2	0.00	0		0
	DOWNSTAND SLOPED BEAM	0.00		2	m2	0.00	0		0
	Floor Slab 100mm On Ground Broom Finish	0.00		50	m2	0.00	0		0
	Floor Slab 140mm On Ground	0.00		832	m2	0.00	0		0
	Floor Slab 140mm On Ground (Floors)	0.00		197	m	0.00	0		0
	Floor Suspended 140mm	0.00		790	m2	0.00	0		0
	Floor Suspended 140mm (Floors)	0.00		958	m	0.00	0		0
	Floor Suspended 140mm Broom Finish	0.00		87	m2	0.00	0		0
	Floor Timber	0.00		24	m2	0.00	0		0
	Stair Exit	0.00		1	m2	0.00	0		0
	Bollard Footing	0.00		1	no	0.00	0		0
	Cleat plate 10	0.00		1	no	0.00	0		0
	Cleat plate 19	0.00		1	no	0.00	0		0
	Cleat plate 8 Cleat plate 1	0.00		1	no	0.00	0		0
	Cleat plate 9 Cleat plate 1	0.00		1	no	0.00	0		0
	Downpipe with Spreader 150	0.00		5	m	0.00	0		0
	ENTRY FEATURE CLEAT1	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT10	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT11	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT14	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT15	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT16	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT17	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT18	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT19	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT2	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT20	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT21	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT22	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT23	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT24	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT25	0.00		1	no	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	ENTRY FEATURE CLEAT29 (Continued)	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT4	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT5	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT6	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT7	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT9	0.00		1	no	0.00	0		0
	Leaf Guard Type 1	0.00		3	no	0.00	0		0
	Model Text Signage 1	0.00		1	no	0.00	0		0
	Roof_Access_Hatch	0.00		1	m3	0.00	0		0
	SIGNAGE	0.00		1	m3	0.00	0		0
	Stage	0.00		26	m3	0.00	0		0
	Tactile Indicator	0.00		19	no	0.00	0		0
	150x150 Box Gutter	0.00		5	m	0.00	0		0
	200 x150 Box Gutter 150x150 Box Gutter	0.00		19	m	0.00	0		0
	Gutter 300sqm 3 deg (Sheet) 300sqm 3 deg (Tilt)	0.00		13	m	0.00	0		0
	Gutter 300sqm 5 deg (Sheet)	0.00		10	m	0.00	0		0
	Lighting BAr	0.00		1	no	0.00	0		0
	Lighting BAr1	0.00		1	no	0.00	0		0
	Lighting BAr2	0.00		1	no	0.00	0		0
	Model Lines (Lines)	0.00		362	no	0.00	0		0
	Air Conditioning System Combination FCU and Duct	0.00		6	no	0.00	0		0
	Mech Round Duct 600D	0.00		1	no	0.00	0		0
	OPA800 AC unit	0.00		1	no	0.00	0		0
	Return Air Grille DDL-20	0.00		7	no	0.00	0		0
	Split Outdoor Unit	0.00		8	no	0.00	0		0
	Supply Air Register 600x600	0.00		42	no	0.00	0		0
	Wall Mech Vent Outlet 950x950	0.00		2	m	0.00	0		0
	Wall Mech Vent Outlet Type 1	0.00		4	m	0.00	0		0
	Brisbane 5.4 x 2.5	0.00		3	no	0.00	0		0
	Brisbane 5.4 x 2.7	0.00		14	no	0.00	0		0
	Gold Coast 5.4 x 2.5 PWD	0.00		1	no	0.00	0		0
	Downpipe	0.00		1	no	0.00	0		0
	Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 10	0.00		1	no	0.00	0		0
	Downpipe 11	0.00		1	no	0.00	0		0
	Downpipe 12	0.00		1	no	0.00	0		0
	Downpipe 13	0.00		1	no	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Downpipe 15 (Continued)	0.00		1	no	0.00	0		0
	Downpipe 16	0.00		1	no	0.00	0		0
	Downpipe 2 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 4 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 5 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 6 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 7 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 8 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 9 Downpipe 1	0.00		1	no	0.00	0		0
	FHR 540mm	0.00		4	no	0.00	0		0
	Rheem HWU - 125L	0.00		1	no	0.00	0		0
	Rheem HWU - 50L	0.00		1	no	0.00	0		0
	Sink DP1	0.00		1	no	0.00	0		0
	Sink DP2	0.00		1	no	0.00	0		0
	Water Cooler - Free Standing (AUS) 140 glass capacity	0.00		1	no	0.00	0		0
	Zip Autoboil Type 1	0.00		1	no	0.00	0		0
	Railing 40mm DIA. CIRCULAR HANDRAIL	0.00		27	m	0.00	0		0
	Railing Mounted Pipe Handrail 900mmV	0.00		9	m	0.00	0		0
	Railing Type 2	0.00		5	m	0.00	0		0
	Railing Type 3 FOR CONCRETE	0.00		13	m	0.00	0		0
	Railing Type 3 FOR CONCRETE with ext	0.00		2	m	0.00	0		0
	Ramp 1/14	0.00		1	no	0.00	0		0
	Roof Soffit Metal Sheeting	0.00		10	no	0.00	0		0
	Basic Roof Catwalk	0.00		18	m2	0.00	0		0
	Basic Roof Corrugated / 203mm Purlin (Zincalume)	0.00		196	m2	0.00	0		0
	Basic Roof Corrugated / 30mm No Purlin (Zincalume)	0.00		956	m2	0.00	0		0
	Bicycle Rail	0.00		3	no	0.00	0		0
	Kerb Ramp AS1438 Kerb Ramp -AS1438	0.00		1	no	0.00	0		0
	Slab Edge 100 x 200mm	0.00		6	m	0.00	0		0
	Stair CONCRETE	0.00		1	no	0.00	0		0
	Stair Type 1	0.00		1	no	0.00	0		0
	CHS-Round tubes-Column CHS 165.1x3.5	0.00		3	m	0.00	0		0
	CHS-Round tubes-Column CHS 88.9x2.6	0.00		3	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
Generated 25/10/2015 10:58:10 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Concrete Columns (Continued)	0.00		3	m3	0.00	0		0
	PFC-Channels (with constant flange thickness)-Column PFC 150	0.00		3	m	0.00	0		0
	RHS-Rectangular tube - rounded-Column RHS 100x50x3	0.00		6	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 100x100x2	0.00		52	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 150x150x5	0.00		56	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 200x200x5	0.00		53	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 50x50x3	0.00		14	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 89x89x5	0.00		19	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 90x90x2.5	0.00		1	m	0.00	0		0
	SHS-column + rafter SHS 100x100x2	0.00		3	m	0.00	0		0
	Pad PF1 450 x 450 x 300	0.00		1	m3	0.00	0		0
	Pad PF2 1200 x 1200 x 600	0.00		5	m3	0.00	0		0
	Pad PF3 1200 x 1200 x 900	0.00		4	m3	0.00	0		0
	Pad PF4 1400 x 1400 x 600	0.00		12	m3	0.00	0		0
	Pier BP1 450 x 4000	0.00		2	m3	0.00	0		0
	Pier BP2 750 x 2400	0.00		6	m3	0.00	0		0
	Strip SF1 400 x 600	0.00		7	m3	0.00	0		0
	Strip SF2 500 x 600	0.00		26	m3	0.00	0		0
	Strip SF3 600 x 600	0.00		19	m3	0.00	0		0
	Strip SF4 1200 x 600	0.00		4	m3	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 150x12	0.00		108	m	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 150x19	0.00		6	m	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 150x24	0.00		90	m	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 200x15	0.00		162	m	0.00	0		0
	CHS-Round tubes-Beam CHS 165.1x3.5	0.00		8	m	0.00	0		0
	EA-Equal angles-Beam EA 100x100x10	0.00		73	m	0.00	0		0
	EA-Equal angles-Beam EA 125x125x10	0.00		67	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
Generated 25/10/2015 10:58:10 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	EA-Equal angles-Beam EA 90x90x8 (Continued)	0.00		1	m	0.00	0		0
	FB-Rectangular solid-Beam FB 50x5	0.00		46	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 125	0.00		28	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 150	0.00		58	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 150.	0.00		25	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 200	0.00		84	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 200.	0.00		15	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 250	0.00		25	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 250.	0.00		14	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 380	0.00		7	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC150.	0.00		3	m	0.00	0		0
	Roof 3 PFC Fascia	0.00		1	m3	0.00	0		0
	Roof 4 PFC Fascia	0.00		1	m3	0.00	0		0
	Roof 5 Structure Roof 5 PFC Fascia	0.00		1	no	0.00	0		0
	Roof 6 PFC Fascia	0.00		1	m3	0.00	0		0
	Roof 7 Fascia Roof 7 PFC Fascia	0.00		1	m3	0.00	0		0
	SHS-Rectangular tube - rounded-Beam SHS 50x50x3	0.00		7	m	0.00	0		0
	SHS-Rectangular tube - rounded-Beam SHS 89x89x5	0.00		10	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 180x16.1	0.00		3	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 200x25.4	0.00		38	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 250x25.7	0.00		11	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
Generated 25/10/2015 10:58:10 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	UB-I-sections (with constant flange thickness)-Beam UB 250x25.7. (Continued)	0.00		7	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 250x31.4	0.00		16	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 250x37	0.00		10	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x32	0.00		51	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x40.4	0.00		42	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x40.4.	0.00		4	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x46.2	0.00		73	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 360x44.7	0.00		64	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 410x53.7	0.00		16	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 410x53.7.	0.00		65	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x67.1.	0.00		30	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x74.6	0.00		38	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x74.6.	0.00		118	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x82.1.	0.00		27	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 530x92.4	0.00		4	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 150x23.4	0.00		13	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 150x23.4.	0.00		25	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 200x52.2	0.00		8	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 200x59.5	0.00		7	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Project - Building Approval Model
Generated 25/10/2015 10:58:10 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Z-Stiffened Z-sections (thin-walled)-Beam Z 150x12 (Continued)	0.00		98	m	0.00	0		0
	Z-Stiffened Z-sections (thin-walled)-Beam Z 150x19	0.00		710	m	0.00	0		0
	Z-Stiffened Z-sections (thin-walled)-Beam Z 200x15	0.00		165	m	0.00	0		0
	Basic Wall Exterior - Exotec Cladding	0.00		39	m2	0.00	0		0
	Basic Wall Exterior - Partition 150mm overall (offset studs)	0.00		2	m2	0.00	0		0
	Basic Wall Exterior - Partition 92mm (FC Clad)	0.00		77	m2	0.00	0		0
	Basic Wall Exterior - Tilt Panel 150mm	0.00		9	m2	0.00	0		0
	Basic Wall Exterior - Tilt Panel 150mm (Natural)	0.00		943	m2	0.00	0		0
	Basic Wall Exterior - Tilt Panel 180mm (Natural)	0.00		134	m2	0.00	0		0
	Basic Wall Interior - Furring Channel 50mm (FC)	0.00		9	m2	0.00	0		0
	Basic Wall Interior - Furring Channel 50mm (Plasterboard)	0.00		19	m2	0.00	0		0
	Basic Wall Interior - Fyrchek	0.00		19	m2	0.00	0		0
	Basic Wall Interior - Partition 150mm (PB Clad both sides)	0.00		69	m2	0.00	0		0
	Basic Wall Interior - Partition 150mm (PB Clad)	0.00		157	m2	0.00	0		0
	Basic Wall Interior - Partition 19mm (Single Skin)	0.00		241	m2	0.00	0		0
	Basic Wall Interior - Partition 38mm (Single Skin)	0.00		12	m2	0.00	0		0
	Basic Wall Interior - Partition 64mm	0.00		377	m2	0.00	0		0
	Basic Wall Interior - Partition 64mm (Double Skin)	0.00		11	m2	0.00	0		0
	Basic Wall Interior - Partition Toilet 20mm	0.00		13	m2	0.00	0		0
	Basic Wall Retaining - Blockwork 190mm	0.00		1	m2	0.00	0		0
	Tilt Panel 1	0.00		1	m2	0.00	0		0
	Window (1,1) 900 x 2700	0.00		4	no	0.00	0		0
	Window (1,1) 900 x 4750	0.00		3	no	0.00	0		0
	GFA: 0.00 m2	**100.00**	**0.00**						**0**

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
Generated 25/10/2015 11:32:15 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Model Lines	0.00		92	no	0.00	0		0
	M_Counter Top w Sink Hole 600mm Depth	0.00		5	m	0.00	0		0
	Compound Ceiling Flush Plasterboard on Battens	0.00		436	m2	0.00	0		0
	Compound Ceiling Suspended - Rondo, Classic 600 x 1200mm Mineral	0.00		574	m2	0.00	0		0
	Compound Ceiling Suspended - Rondo, Classic 600 x 1200mm Vinyl	0.00		54	m2	0.00	0		0
	Concrete Cast-in Situ	0.00		1	no	0.00	0		0
	Concrete Cast-in Situ1	0.00		1	no	0.00	0		0
	System Panel Glass	0.00		72	m2	0.00	0		0
	Rectangular Mullion1 70 x 100mm	0.00		225	m	0.00	0		0
	Curtain Wall - Door - Double	0.00		4	no	0.00	0		0
	Curtain Wall - Door - Double Curtain Wall - Door - 2400	0.00		1	no	0.00	0		0
	Curtain Wall - Door - Double solid	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 1200 X 2100	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 1600 X 3150	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 2100 X 900	0.00		1	no	0.00	0		0
	Roller Shutter-Standard 2500 x 5300	0.00		1	no	0.00	0		0
	Swing - Double 2040 x 870/420	0.00		1	no	0.00	0		0
	Swing-Single-Standard 2040 x 820-Hollow Core	0.00		1	no	0.00	0		0
	Swing-Single-Standard 2040 x 920-Hollow Core	0.00		12	no	0.00	0		0
	Swing-Single-Standard 2040 x 920-Solid Core	0.00		10	no	0.00	0		0
	Toilet Partition Door	0.00		5	no	0.00	0		0
	pocket_door_658 920w	0.00		6	no	0.00	0		0
	Main DB	0.00		1	no	0.00	0		0
	Fascia Box Gutter (150x50) 150x150 Box Gutter	0.00		18	m	0.00	0		0
	Fascia Eaves Gutter (150sqm) 150sqm 5 deg (Tilt)	0.00		15	m	0.00	0		0
	Fascia Eaves Gutter (300sqm) 300sqm 3 deg (Sheet)	0.00		81	m	0.00	0		0
	Fascia Flashing-Barg 210 x 210, 80	0.00		2	m	0.00	0		0
	Fascia Flashing-Barg with return 200x250 200 x 250, 90	0.00		48	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
Generated 25/10/2015 11:32:15 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Fascia Flashing-Barg with return 200x280 200 x 280, 90 (Continued)	0.00		3	m	0.00	0		0
	Fascia Flashing-Junction Under Over	0.00		34	m	0.00	0		0
	DB FLOOR	0.00		1	m2	0.00	0		0
	DOWNSTAND BEAM RAMP 2	0.00		2	m2	0.00	0		0
	DOWNSTAND SLOPED BEAM	0.00		2	m2	0.00	0		0
	Floor Slab 100mm On Ground Broom Finish	0.00		50	m2	0.00	0		0
	Floor Slab 140mm On Ground	0.00		832	m2	0.00	0		0
	Floor Slab 140mm On Ground (Floors)	0.00		197	m	0.00	0		0
	Floor Suspended 140mm	0.00		792	m2	0.00	0		0
	Floor Suspended 140mm (Floors)	0.00		947	m	0.00	0		0
	Floor Suspended 140mm Broom Finish	0.00		87	m2	0.00	0		0
	Floor Timber	0.00		24	m2	0.00	0		0
	Stair Exit	0.00		1	m2	0.00	0		0
	Bollard Footing	0.00		1	no	0.00	0		0
	Cleat plate 10	0.00		1	no	0.00	0		0
	Cleat plate 19	0.00		1	no	0.00	0		0
	Cleat plate 8 Cleat plate 1	0.00		1	no	0.00	0		0
	Cleat plate 9 Cleat plate 1	0.00		1	no	0.00	0		0
	Downpipe with Spreader 150	0.00		5	m	0.00	0		0
	ENTRY FEATURE CLEAT1	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT10	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT11	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT14	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT15	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT16	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT17	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT18	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT19	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT2	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT20	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT21	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT22	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT23	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT24	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT25	0.00		1	no	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
Generated 25/10/2015 11:32:15 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	ENTRY FEATURE CLEAT29 (Continued)	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT4	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT5	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT6	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT7	0.00		1	no	0.00	0		0
	ENTRY FEATURE CLEAT9	0.00		1	no	0.00	0		0
	Leaf Guard Type 1	0.00		3	no	0.00	0		0
	Model Text Signage 1	0.00		1	no	0.00	0		0
	Roof_Access_Hatch	0.00		1	m3	0.00	0		0
	SIGNAGE	0.00		1	m3	0.00	0		0
	Stage	0.00		26	m3	0.00	0		0
	Tactile Indicator	0.00		19	no	0.00	0		0
	150x150 Box Gutter	0.00		5	m	0.00	0		0
	200 x150 Box Gutter 150x150 Box Gutter	0.00		19	m	0.00	0		0
	Gutter 300sqm 3 deg (Sheet) 300sqm 3 deg (Tilt)	0.00		13	m	0.00	0		0
	Gutter 300sqm 5 deg (Sheet)	0.00		10	m	0.00	0		0
	Lighting BAr	0.00		1	no	0.00	0		0
	Lighting BAr1	0.00		1	no	0.00	0		0
	Lighting BAr2	0.00		1	no	0.00	0		0
	Model Lines (Lines)	0.00		362	no	0.00	0		0
	Air Conditioning System Combination FCU and Duct	0.00		6	no	0.00	0		0
	Mech Round Duct 600D	0.00		1	no	0.00	0		0
	OPA800 AC unit	0.00		1	no	0.00	0		0
	Return Air Grille DDL-20	0.00		7	no	0.00	0		0
	Split Outdoor Unit	0.00		8	no	0.00	0		0
	Supply Air Register 600x600	0.00		42	no	0.00	0		0
	Wall Mech Vent Outlet 950x950	0.00		2	m	0.00	0		0
	Wall Mech Vent Outlet Type 1	0.00		4	m	0.00	0		0
	Brisbane 5.4 x 2.5	0.00		3	no	0.00	0		0
	Brisbane 5.4 x 2.7	0.00		14	no	0.00	0		0
	Gold Coast 5.4 x 2.5 PWD	0.00		1	no	0.00	0		0
	Downpipe	0.00		1	no	0.00	0		0
	Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 10	0.00		1	no	0.00	0		0
	Downpipe 11	0.00		1	no	0.00	0		0
	Downpipe 12	0.00		1	no	0.00	0		0
	Downpipe 13	0.00		1	no	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
Generated 25/10/2015 11:32:15 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Downpipe 15 (Continued)	0.00		1	no	0.00	0		0
	Downpipe 16	0.00		1	no	0.00	0		0
	Downpipe 2 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 4 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 5 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 6 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 7 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 8 Downpipe 1	0.00		1	no	0.00	0		0
	Downpipe 9 Downpipe 1	0.00		1	no	0.00	0		0
	FHR 540mm	0.00		4	no	0.00	0		0
	Rheem HWU - 125L	0.00		0	no	0.00	0		0
	Rheem HWU - 50L	0.00		0	no	0.00	0		0
	Sink DP1	0.00		1	no	0.00	0		0
	Sink DP2	0.00		1	no	0.00	0		0
	Water Cooler - Free Standing (AUS) 140 glass capacity	0.00		1	no	0.00	0		0
	Zip Autoboil Type 1	0.00		1	no	0.00	0		0
	Railing 40mm DIA. CIRCULAR HANDRAIL	0.00		27	m	0.00	0		0
	Railing Mounted Pipe Handrail 900mmV	0.00		9	m	0.00	0		0
	Railing Type 2	0.00		5	m	0.00	0		0
	Railing Type 3 FOR CONCRETE	0.00		13	m	0.00	0		0
	Railing Type 3 FOR CONCRETE with ext	0.00		2	m	0.00	0		0
	Ramp 1/14	0.00		1	no	0.00	0		0
	Roof Soffit Metal Sheeting	0.00		10	no	0.00	0		0
	Basic Roof Catwalk	0.00		18	m2	0.00	0		0
	Basic Roof Corrugated / 203mm Purlin (Zincalume)	0.00		196	m2	0.00	0		0
	Basic Roof Corrugated / 30mm No Purlin (Zincalume)	0.00		958	m2	0.00	0		0
	Bicycle Rail	0.00		3	no	0.00	0		0
	Kerb Ramp AS1438 Kerb Ramp -AS1438	0.00		1	no	0.00	0		0
	Slab Edge 100 x 200mm	0.00		6	m	0.00	0		0
	Stair CONCRETE	0.00		1	no	0.00	0		0
	Stair Type 1	0.00		1	no	0.00	0		0
	CHS-Round tubes-Column CHS 165.1x3.5	0.00		3	m	0.00	0		0
	CHS-Round tubes-Column CHS 88.9x2.6	0.00		3	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
Generated 25/10/2015 11:32:15 AM

Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	Concrete Columns (Continued)	0.00		3	m3	0.00	0		0
	PFC-Channels (with constant flange thickness)-Column PFC 150	0.00		3	m	0.00	0		0
	RHS-Rectangular tube - rounded-Column RHS 100x50x3	0.00		6	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 100x100x2	0.00		52	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 150x150x5	0.00		56	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 200x200x5	0.00		53	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 50x50x3	0.00		14	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 89x89x5	0.00		19	m	0.00	0		0
	SHS-Rectangular tube - rounded-Column SHS 90x90x2.5	0.00		1	m	0.00	0		0
	SHS-column + rafter SHS 100x100x2	0.00		3	m	0.00	0		0
	CAPPING BEAM BUILDING B	0.00		8	m3	0.00	0		0
	Pad PF1 450 x 450 x 300	0.00		1	m3	0.00	0		0
	Pad PF2 1200 x 1200 x 600	0.00		5	m3	0.00	0		0
	Pad PF3 1200 x 1200 x 900	0.00		4	m3	0.00	0		0
	Pad PF4 1400 x 1400 x 600	0.00		12	m3	0.00	0		0
	Pier BP1 450 x 4000	0.00		2	m3	0.00	0		0
	Pier BP2 750 x 2400	0.00		6	m3	0.00	0		0
	Pier BP3 600 x 7000	0.00		42	m3	0.00	0		0
	Strip SF1 400 x 600	0.00		3	m3	0.00	0		0
	Strip SF2 500 x 600	0.00		26	m3	0.00	0		0
	Strip SF3 600 x 600	0.00		19	m3	0.00	0		0
	Strip SF4 1200 x 600	0.00		4	m3	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 150x12	0.00		108	m	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 150x19	0.00		6	m	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 150x24	0.00		90	m	0.00	0		0
	C-Half-closed channels (thin-walled)-Beam C 200x15	0.00		162	m	0.00	0		0
	CHS-Round tubes-Beam CHS 165.1x3.5	0.00		8	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	EA-Equal angles-Beam EA 100x100x10 (Continued)	0.00		73	m	0.00	0		0
	EA-Equal angles-Beam EA 125x125x10	0.00		66	m	0.00	0		0
	EA-Equal angles-Beam EA 90x90x8	0.00		1	m	0.00	0		0
	FB-Rectangular solid-Beam FB 50x5	0.00		46	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 125	0.00		28	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 150	0.00		58	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 150.	0.00		25	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 200	0.00		84	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 200.	0.00		15	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 250	0.00		25	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 250.	0.00		14	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC 380	0.00		7	m	0.00	0		0
	PFC-Channels (with constant flange thickness)-Beam PFC150.	0.00		3	m	0.00	0		0
	Roof 3 PFC Fascia	0.00		1	m3	0.00	0		0
	Roof 4 PFC Fascia	0.00		1	m3	0.00	0		0
	Roof 5 Structure Roof 5 PFC Fascia	0.00		1	no	0.00	0		0
	Roof 6 PFC Fascia	0.00		1	m3	0.00	0		0
	Roof 7 Fascia Roof 7 PFC Fascia	0.00		1	m3	0.00	0		0
	SHS-Rectangular tube - rounded-Beam SHS 50x50x3	0.00		7	m	0.00	0		0
	SHS-Rectangular tube - rounded-Beam SHS 89x89x5	0.00		10	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 180x16.1	0.00		3	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 200x25.4	0.00		38	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	UB-I-sections (with constant flange thickness)-Beam UB 250x25.7 (Continued)	0.00		11	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 250x25.7.	0.00		7	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 250x31.4	0.00		16	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 250x37	0.00		10	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x32	0.00		51	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x40.4	0.00		42	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x40.4.	0.00		4	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 310x46.2	0.00		73	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 360x44.7	0.00		64	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 410x53.7	0.00		16	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 410x53.7.	0.00		65	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x67.1.	0.00		30	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x74.6	0.00		38	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x74.6.	0.00		118	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 460x82.1.	0.00		27	m	0.00	0		0
	UB-I-sections (with constant flange thickness)-Beam UB 530x92.4	0.00		4	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 150x23.4	0.00		13	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 150x23.4.	0.00		25	m	0.00	0		0
	UC-I-sections with wide flanges-Beam UC 200x52.2	0.00		8	m	0.00	0		0

Elemental Summary

Project: <Templates>
Building: Historical Case Study 2 - BIM

Details: Revised
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Code	Description	% BC	Cost/m2	Quantity	Unit	Rate	SubTotal	Factor	Total
	UC-I-sections with wide flanges-Beam UC 200x59.5 (Continued)	0.00		7	m	0.00	0		0
	Z-Stiffened Z-sections (thin-walled)-Beam Z 150x12	0.00		98	m	0.00	0		0
	Z-Stiffened Z-sections (thin-walled)-Beam Z 150x19	0.00		710	m	0.00	0		0
	Z-Stiffened Z-sections (thin-walled)-Beam Z 200x15	0.00		165	m	0.00	0		0
	Basic Wall Exterior - Exotec Cladding	0.00		39	m2	0.00	0		0
	Basic Wall Exterior - Partition 150mm (FC exterior)	0.00		34	m2	0.00	0		0
	Basic Wall Exterior - Partition 150mm overall (offset studs)	0.00		2	m2	0.00	0		0
	Basic Wall Exterior - Partition 92mm (FC Clad)	0.00		77	m2	0.00	0		0
	Basic Wall Exterior - Tilt Panel 150mm	0.00		9	m2	0.00	0		0
	Basic Wall Exterior - Tilt Panel 150mm (Natural)	0.00		941	m2	0.00	0		0
	Basic Wall Exterior - Tilt Panel 180mm (Natural)	0.00		91	m2	0.00	0		0
	Basic Wall Interior - Furring Channel 50mm (FC)	0.00		9	m2	0.00	0		0
	Basic Wall Interior - Furring Channel 50mm (Plasterboard)	0.00		19	m2	0.00	0		0
	Basic Wall Interior - Fyrchek	0.00		19	m2	0.00	0		0
	Basic Wall Interior - Partition 150mm (PB Clad both sides)	0.00		69	m2	0.00	0		0
	Basic Wall Interior - Partition 150mm (PB Clad)	0.00		157	m2	0.00	0		0
	Basic Wall Interior - Partition 19mm (Single Skin)	0.00		241	m2	0.00	0		0
	Basic Wall Interior - Partition 38mm (Single Skin)	0.00		12	m2	0.00	0		0
	Basic Wall Interior - Partition 64mm	0.00		377	m2	0.00	0		0
	Basic Wall Interior - Partition 64mm (Double Skin)	0.00		11	m2	0.00	0		0
	Basic Wall Interior - Partition Toilet 20mm	0.00		13	m2	0.00	0		0
	Basic Wall Retaining - Blockwork 190mm	0.00		140	m2	0.00	0		0
	Tilt Panel 1	0.00		1	m2	0.00	0		0
	Window (1,1) 900 x 2700	0.00		5	no	0.00	0		0
	Window (1,1) 900 x 4750	0.00		3	no	0.00	0		0
	GFA: 0.00 m2	**100.00**	**0.00**						**0**

APPENDIX F – Historical Project Case Study 2 – Design Change BOQ's

	Floors				
A	Floor Suspended 140mm	m2	790	160.00	126,400
B	Floor Suspended 140mm Broom Finish	m2	87	160.00	13,920

To Collection: 140,320

Floors (Continued)				
COLLECTION				
Page 1/1:				140,320
Floors				
Carried to Summary:				**140,320**

	Structural Foundations				
A	Strip SF1 400 x 600	m3	6	550.00	3,355

To Collection: 3,355

Structural Foundations (Continued)				
COLLECTION				
Page 2/1:				3,355
Structural Foundations				
Carried to Summary:				**3,355**

	Walls				
A	Basic Wall Exterior - Tilt Panel 150mm	m2	9	150.00	1,350
B	Basic Wall Exterior - Tilt Panel 150mm (Natural)	m2	943	150.00	141,450
C	Basic Wall Exterior - Tilt Panel 180mm (Natural)	m2	134	170.00	22,780

To Collection: 165,580

Walls (Continued)

COLLECTION				
Page 3/1:				165,580
Walls				
Carried to Summary:				**165,580**

COLLECTION	PAGE NO	
Floors	1/1	140,320
Structural Foundations	2/1	3,355
Walls	3/1	165,580
Total Amount:		**309,255**

	Floors				
A	Floor Suspended 140mm	m2	792	160.00	126,720
B	Floor Suspended 140mm Broom Finish	m2	87	160.00	13,920

To Collection: 140,640

Floors (Continued)				
COLLECTION				
Page 1/1:				140,640
Floors				
Carried to Summary:				**140,640**

	Structural Foundations				
A	CAPPING BEAM BUILDING B	m3	7	600.00	4,200
B	Strip SF1 400 x 600	m3	3	550.00	1,650
C	Pier BP3 600 x 7000	m3	42	990.00	41,580

To Collection: 47,430

Structural Foundations (Continued)				
COLLECTION				
Page 2/1:				47,430
Structural Foundations				
Carried to Summary:				**47,430**

	Walls				
A	Basic Wall Exterior - Tilt Panel 150mm	m2	9	150.00	1,350
B	Basic Wall Exterior - Tilt Panel 150mm (Natural)	m2	941	150.00	141,150
C	Basic Wall Exterior - Tilt Panel 180mm (Natural)	m2	91	170.00	15,470
D	Basic Wall Retaining - Blockwork 190mm	m2	140	180.00	25,200

To Collection: 183,170

Walls (Continued)				
COLLECTION				
Page 3/1:				183,170
Walls				
Carried to Summary:				**183,170**

COLLECTION	**PAGE NO**	
Floors	1/1	140,640
Structural Foundations	2/1	47,430
Walls	3/1	183,170
Total Amount:		**371,240**

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