**Construction Management**

**School of Built Environment**

# Adoption of Building Information Modelling in Construction: The Case of a Small - to Medium-sized Enterprise

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## Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

**Human Ethics** The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014 . The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number # RDHU-33-15.

Signature:

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| | |
|---|---|
| 3D: | Three Dimensional |
| 4D: | Four Dimensional |
| 4D BIM: | The 3D BIM model extended with one extra variable - Time |
| BIM: | Building Information Modelling which is a process and technology for delivering construction projects. |
| CM: | Construction Management |
| CPM: | Critical Path Method |
| DB: | Design-Build |
| DBB: | Design-Bid-Build |
| IFC: | Industry Foundation Classes |
| IPD: | Integrated Project Delivery |
| LCA: | Life-Cycle Activities |
| MEP: | Mechanical, Engineering and Piping |
| Model: | The BIM Model |
| PERT: | Project Evaluation Review Technique |
| SME: | Small to Medium Enterprise |
| WBS: | Work Breakdown Structure |

# ABSTRACT

Design-build delivery methods are being increasingly used by small to medium enterprise (SME) construction companies to build assets due to changing client demands and their quests for innovation. Disruptive technologies offer SMEs the ability to improve their workflows, drive productivity increases and increase their competitiveness. Within the Australian construction industry, Building Information Modelling (BIM) has been identified as an innovative solution that can engender productivity and performance improvements throughout an asset's life-cycle. While BIM is beginning to be embraced within the Australian construction industry, particularly by the public sector for large-scale projects, and standards for its implementation are emerging, limited attention has been paid to how SMEs can effectively utilise this technological solution.

This research aims to understand why and how SMEs can effectively utilise BIM by focusing on organisations that use design-build delivery methods within the residential sector. In addressing this aim, a case study has been adopted to acquire a balanced understanding of the issues hindering the implementation of BIM and to demonstrate how it can be effectively utilised in the everyday practices of residential construction. The research commenced by undertaking a series of semi-structured interviews with individuals within the case study organisation to obtain their views, experiences and ideas about BIM implementation issues. A key objective of the interviews was to identify issues surrounding existing workflows so that new ones could be enabled by BIM. The main barriers hindering BIM adoption within the SME sector were identified. Through analysis of the adopted project documentation, and preparation of a construction simulation model, potential mechanisms for addressing the perceived barriers are proposed.

The findings of this study provide strong recommendations for BIM adoption by SMEs. It has been shown that, despite lagging behind with its adoption, many of the enabling foundations are already in place within this sector (including design-build, existing technology, willingness to change). The move towards a collaborative BIM environment can be enabled through a shift towards a construction-oriented modelling approach at the early stages of design, without the need for disruptive changes.

# CHAPTER 1: INTRODUCTION

## 1.1 Background

> "There is a BIM revolution happening across our industry – those organizing themselves now, will be best placed to do business in the future"
>
> Peter Bowtell - Buildings Practice Leader Australasia – Arup.

Design-build delivery methods increasingly are being used by small to medium enterprise (SME) construction enterprises to build assets, due to changing client demands and their quests for innovation. Disruptive technologies offer SMEs the ability to improve their workflows, drive productivity increases and increase their competitiveness. Within the Australian construction industry, Building Information Modelling (BIM) has been identified as a disruptive solution that can engender productivity and performance improvements throughout an asset's life-cycle. While BIM is beginning to be embraced within the Australian construction industry, particularly by the public sector for large scale projects, and standards for its implementation are emerging, limited attention has been paid to how SMEs can effectively utilise this technological solution.

The concept of BIM first emerged in Eastman's 1975 paper, "The Use of Computers Instead of Drawings In Building Design" (Eastman 1975), which highlighted the limitations of traditional paper-based workflows. Laiserin (2010, 4) further popularised the term and broadened its scope to encompass a "total design approach". He referred to Eastman as the "true father of BIM" while identifying himself as a "true believer".

It was not until the mid-2000s that BIM was first adopted by the construction industry (Azhar et al. 2012) when software to support the concept started to appear on the market. Since this time, BIM adoption has steadily increased and is now common practice in many countries such as the Finland, United Kingdom (UK), United States (US) and Australia, albeit with a focus on large-scale projects.

Although there is no agreement on a unique definition for BIM, there appears to be some agreement that the BIM concept refers to process, approach, integration, collaboration, management, knowledge-sharing and technology. Building Information Modelling, as a shared knowledge resource of project information, can be used in projects with different scales as an approach, processor or technology.

Modelling in the early stages of the design phase tends to focus on the artistic concepts or the "marketing model" rather than a construction model. Many of the firms preparing projects using three dimension (3D) models alongside time planning still experience delays and conflict during the construction phase. In contrast, BIM implementation offers firms the opportunity to review the project delivery process, to increase collaboration across the whole project team and to reduce the risk of delays and conflict during the construction phase. Those benefits are best realised when BIM is adopted across all project teams and project phases. As BIM adoption has increased among different project teams its value, particularly to owners and clients, has become evident and governments have started to mandate its use and to provide supporting guidance, standards and so forth. However, the focus has always been on large-scale projects with little attention paid to other sectors. According to the Small Business Development Corporation WA, (2016) business sizes have been defined as: "*micro-businesses, small businesses and medium sized firms. A small business has less than 20 employees; a medium business has between 20 and 199 employees and SMEs have less than 200 employees*". The SME sector accounts for a large proportion of construction companies and has been reluctant to adopt BIM. This highlights the need to consider why SMEs are not adopting BIM and examine how they can be supported to adopt executable BIM.

## 1.2 Research Aims

In this context, this research aims to understand why and how SMEs can effectively utilise BIM, by focusing on organisations that use design-build delivery methods within the residential sector. In addressing this aim, a case study of an actual construction project of an SME residential contractor will be undertaken for an extended period of time to acquire a fair understanding of the issues hindering the implementation of BIM and to demonstrate how it can be effectively utilised in the everyday practices of residential construction.

Specific objectives of the research are to:

- Identify current/traditional workflows and processes for collaboration within project teams;
- Examine existing potential for improvement through BIM adoption;
- Analyse existing barriers and opportunities for BIM adoption for SME's; and
- Propose fit-for-purpose guidelines for BIM adoption in the SME residential construction sector through collaboration between design and scheduling.

## 1.3 Research Significance

The adoption of BIM is on the increase and is set to make a significant impact on the workflows and processes within the construction sector. SMEs form a considerable portion of this sector and their involvement is essential if the full benefits of existing government technology investment plans are to be realised (NBS 2016). In addition, if the SME is to remain competitive within the business market they will be required to use BIM as a project delivery tool.

While BIM has the potential to provide an integrated model with all the required information from different project parties, it has been demonstrated that BIM implementation is currently being used by less than half of firms surveyed. This is highlighted in the McGraw Hill Construction 2014 survey that focused on BIM implementation within Australia and New Zealand. It cites that only 29% of firms were implementing BIM for more than 60% of their projects (where 60% is classified as “very heavy usage”). Design professionals are the ones currently reporting the deepest implementation of BIM, with 61% reporting very heavy usage, compared with only 33% of contractors at that usage level. It can be concluded that designers are often modelling projects in isolation from other parties. This operation in “silos” often results in “branching” models, duplication of effort and double-handling of data through inefficient processes (McGraw Hill Construction 2012).

This study explores 4D BIM implementation as a potential mechanism to engage contractors within a collaborative environment to extend the usage beyond design and into construction. A fully-formed 4D model linked to supporting building data offers the capability for downstream use of building information for users beyond the initial construction industry participants (Smith 2007).

In addition, for successful project delivery, time management is a key factor and effective integration of the schedule within the model could be one step forward to implementation of BIM. Therefore, implementation of a 4D BIM on an SME sample project could clarify the situation in relation to BIM adoption. 4D BIM is simply formed by the linkage between a project's 3D model and a project's schedule. The 4D model could be used for visualisation of the project's progress and consequences, time-based clash checks and identification of space conflict problems and effective site utilisation.

Although, the focus of this study examines existing potential for future improvement through collaboration between design and scheduling that can be enhanced in order to streamline BIM adoption by SMEs, it is envisaged that the final result could be extended, in the future, to support the integration of other processes such as those associated with costs.

## 1.4 Research Methodology

The research methodology for this study was designed to utilise qualitative data and analysis because it covers an area of research about which little is currently known (Yin 2003). In investigating complex situations, such as construction projects, a case study approach has been proven to be reliable in capturing the rich information required for the purpose of the study (Flyvbjerg 2006).

Following an in-depth analysis of the extant literature, a single case study of an SME residential contractor was adopted (Flyvbjerg 2006). The case study is categorised as a qualitative method of research with a focus on developing in-depth analysis of a single case, or multiple cases, within the social/urban/political sciences (Robson 2002). A single-case approach is particularly valuable when the aim is to provide a rich record and to get as close as possible to the phenomenon exemplified (Yin 2003). A single case study can be studied in terms of numbers of researches. As Yin (2003, 36-47) stated regarding the single case study: "*the single case can then be used to determine whether a theory's propositions are correct or whether some* *alternative set of explanations might be more relevant. In this manner, the single case can represent a significant contribution to knowledge and theory-building. Such a study can even help to refocus future investigations in an entire field*".

The research commenced by undertaking a series of semi-structured interviews with industry practitioners from the case study enterprise in order to obtain their views, experiences and ideas about BIM implementation issues. A key objective of the interviews was to identify issues surrounding existing workflows so that new ones could be enabled by BIM. A detailed analysis of existing documents, including design models and the specific construction program, was undertaken in order to identify problem areas as well as opportunities for collaborative BIM implementation. The case study was observed from initiation to completion on site and any problems encountered were retrospectively analysed, with potential solutions being proposed to mitigate future repetition.

The results of the literature review, interviews, data-analysis and observation were triangulated to propose guidelines for BIM adoption that would be suited to the SME residential construction sector.

## 1.5 Limitations

The efforts made by government to encourage larger construction projects to implement BIM are quite comprehensive, but less has been done to cover the smaller sectors or to keep the industry cohesive (Loveday and Scott 2016). Therefore, the research presented in this thesis is specific to SMEs that are adopting BIM, especially for residential projects, and this study is not necessarily suitable to extend to all SME projects. Moreover, the cost and financial details have not been considered because it was beyond the scope of this research, which has concentrated on how SMEs could adopt BIM and why they are not currently adopting BIM. Hence, simulation and adoption at early stages were considered rather than cost and operation. However, the extension of BIM implementation to later phases of projects, to also cover cost and quality, is recommended for future research.

## 1.6 Chapter Summary

The Design-Build (DB) project delivery method is widely adopted amongst private sector SMEs in Australia. However, the BIM adoption rate among SME firms is slow-growing. This case study of an SME residential contractor will help to acquire a balanced understanding of the issues hindering their implementation of BIM and will demonstrate how it can be effectively utilised in the everyday practices of residential construction. Time management, through the implementation of a 4D BIM on an SME sample project if examined in detail may help to clarify the sectors readiness in relation to BIM adoption.

This chapter has provided an overview of this research. There are six further chapters embedded in this thesis, including a literature review focusing on BIM use within the SME sector, the adopted research methodology, a qualitative exploratory study based on interviews, document analysis of the case study including simulation and modelling and finally, a review and discussion of the findings in the concluding chapters.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Chapter Introduction

The adoption of BIM for the management of building projects and communication of information between project stakeholders is transforming processes within the construction industry, enabling a more collaborative and potentially more efficient ways of working (Underwood and Isikdag 2013). The recently released Australian-National BIM initiative report (buildingSMART 2014) emphasises the need for collaboration between industry and government to maximise the economic returns when adopting BIM within Australia in order to remain competitive with the growing global market. Governments across the globe recognise the importance of effective collaboration using BIM (buildingSMART 2012), and see its potential to streamline processes throughout a building's life-cycle through the integration of project parties. If BIM is to be implemented in the construction phase, it is expected to be able to support the main aspects of construction.

## 2.2 Definition of Building Information Model

A single, concise definition of BIM, in its ever-evolving applications, is difficult because BIM has been constantly expanding to service more areas in the construction industry and has gained a variety of definitions, some of which are considered as: The American Institute of Architects (AIA) has defined BIM as *"a model-based technology linked with a database of project information",* and this reflects the general reliance on database technology as its foundation (NATSPEC 2013).

BIM is defined as a "*collaborative way of working, underpinned by the digital technologies, which unlock more efficient methods of designing, creating and maintaining our assets. BIM embeds key product and asset data and a computer* *model that can be used for effective management of information throughout a project lifecycle – from earliest concept through to operation*" (HM Government 2012, 3).

BIM has been defined by the National BIM Standard – NBIMS (2018) as "*a digital representation of physical and functional characteristics of a facility. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions-making during its life-cycle; defined as existing from earliest conception to demolition*".

A further definition has been given by Eastman (2011, 2): "*BIM is an information model of a building (or building project) that comprises complete and sufficient information to support all life-cycle processes, and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life-cycle*."

It is necessary to clarify that the BIM acronym has been used for both "Building Information Management" and "Building Information Modelling". Both "Modelling" and "Management" are needed to cover all aspects of building projects but "M" represents "Modelling" in the vast majority of definitions. However, Race (2012), in the book "BIM Demystified", compared the "M" interpretations of management and modelling, concluding that the manager's role in complex projects is to organise all project information into one resource and to keep it updated for the project team. He indicated that:

> "Interpreting 'M' as management gives a far more potent and all-encompassing notion of what the acronym is really intended to portray. Management, among other things, implies planning, organising, resourcing

and controlling not simply the information that is required on a project, but the people who create and combine it to produce the finished built environment artefact" (Race 2012).

It is Azhar's opinion that "*the foundation of BIM is based on two pillars, communication and collaboration*" (Azhar et al. 2012, 17). With so much information being produced and so many disciplines involved in the construction industry, "silos" need to become more goal-aligned. BIM has the potential to enable collaboration and to break down traditional silo barriers (Race 2012). BIM allows all parties and stakeholders to contribute right from the inception of the project - (Communication) - and connects them into a virtual model to review projects, share information and raise issues - (Collaboration).

Notwithstanding the foregoing studies show (Dakhil, 2016) BIM maturity-benefits awareness level among users plays a pivotal role to improve BIM collaboration level. "*The clients' degree of understanding of BIM maturity- benefits widening the knowledge base of the client regarding how to successfully implement BIM in current busines."(Dakhil, 2016, 12).*

Despite that fact that differences of opinion still exist, there appears to be some agreement that the concept of BIM refers to life-cycle processes, approach, integration, collaboration, management, knowledge sharing and technology. In summary, Building Information Modelling can be used in projects with different scales as an approach, processor and technology. Therefore, BIM offers a variety of potential advantages to its users and encourages them to implement its processes and technology for the benefit of their project's stakeholders.

## 2.3 BIM Benefits

The concept of BIM was initially embraced during the design stage of projects, with slower adoption during later phases. Therefore, in comparison to other project disciplines, BIM for designers is at a more mature stage. Hence, many examples of research have naturally considered BIM benefits from the perspectives of other project team members, including project management, planning, procurement and contract work.

### 2.3.1 BIM Benefits for Contractors

The McGraw-Hill (2014) report "The business value of BIM" considered the benefits of BIM from contractors' points of view. In the report, contractors were asked to select their three top BIM benefits among the 15 given choices. Overall, the top three benefits chosen were: (1) Reduced errors and omissions (42%), (2) Collaboration with owners and design firms (35%) and (3) Enhanced organisational image (32%). Rework reduction (31%) was placed fourth and the list continued in descending order with: Reduction of construction cost (23%), Better cost control/predictability (21%), Reduction of overall project duration (19%), Marketing of new business (19%), Offering of new services (14%), Increased profits (14%), Maintenance of repeat business (13%), Reduced cycle time of workflows (10%), Faster client approval cycle (9%), Improved safety (7%) and Faster regulatory approval cycles (6%). McGraw Hill has summarised the top five business benefits of BIM as "*(1) reducing errors, (2) promoting an industry leader image, (3) reducing rework, (4) improving collaborations and (5) offering new services*" (McGraw Hill 2014, 4).

### 2.3.2 BIM Benefits for Cost and Process

In an earlier study, and looking across a project rather than specifically from a contractors' perspective, Azhar et al. (2011) identified eight benefits of BIM implementation, namely: (1) more accurate geometrical representation, (2) faster and more efficient processes, (3) improved design, (4) controlled whole-life costs and environmental data, (5) better production quality, (6) automated assembly, (7) better customer service and (8) life-cycle data.

Various studies (Gilligan and Kunz 2007; Azhar et al. 2008, 2011; German 2012) have presented a variety of BIM benefits, irrespective of sequence are as follows: (1) reducing costs and improving the accuracy and speed of cost estimates, (2) avoiding clashes (up to 10% of the contract value is saved by detecting clashes), (3) shortening time (up to 7% reduction in project time), (4) ensuring lower whole-life costs for the asset through sustainable design, (5) facilitating construction coordination, (6) reducing requests for information and changes to orders (up to 40% elimination of unbudgeted changes), (7) facilitating generation of construction documents and (8) facilitating the simulation and visualisation of the construction project.

By the same token, (Love et al. 2013) reviewed BIM implementation benefits and summarised them as: (1) reduction in construction costs, (2) improved quality of design information, (3) integration of project systems, (4) data and teams improvement, (5) reduced propensity for changes to orders, (6) improved interoperability and (7) whole life-cycle asset management.

In summary, all these studies suggest that BIM adoption could help to reduce project cost and enhance project delivery throughout the project lifecycle.

### 2.3.3. BIM Benefits for Design and Construction

The benefits of implementing BIM during both the design and construction stages have also been observed in practice. Ghaffarianhoseini et al. (2017) enumerated the "*clear current benefits of BIM*" as: (1) Technical, (2) Knowledge management, (3) Standardisation, (4) Diversity management, (5) Integration, (6) Economic, (7) Planning/scheduling, (8) Building LCA and (9) Decision support.

The recurrence and variability of BIM definitions demonstrate the difficulty in defining and quantifying BIM and placing it in terms of its potential benefits. As the reviewed research findings have illustrated, this deficiency has resulted in the attempts to measure BIM's effectiveness being very general and subjective.

It is believed that implementing BIM offers solutions for many of shortcomings affecting the construction industry (Manderson, Jefferies and Brewer 2015). A review of BIM benefits from different research perspectives shows that the definitions depend upon the stage of project life-cycle that is studied for BIM adoption. By the same token, Barlish and Sullivan (2012, 150) gave an example that "*…architects are more likely to see the benefits of BIM as enhancing coordination, productivity, and business operations; whereas contractors see improvements in scheduling, estimating, and drawing processing*".

Similarly, considering the small size of projects handled by SMEs could explain the BIM benefits defined from SMEs viewpoints. Based on the research regarding BIM adoption by SMEs in Australia "*the common belief among SMEs in Australia (denotes) that BIM is not beneficial enough for their projects*" (Hosseini et al. 2016, 81), while other research reports show that implementation of BIM in SMEs could provide many advantages, resulting in visible productivity increases (Poirier, Staub-French and Forgues 2015a, 2015b) because the smaller number of project participants coupled with shorter project durations offer a wide range of opportunities for obtaining BIM benefits (Engineers Australia 2014) and the possibility to prompt organisational change (Arayici et al. 2011).

Therefore, based on the project capacity, there are advantages that BIM can present to any project life-cycle. Table 2.1 summarises the key benefits of BIM to a project, according to the reviewed research, along with the area of effect throughout a project's life-cycle. Nonetheless, despite all the benefits that BIM can provide to any project, the BIM adoption rate is only growing slowly, meaning that there are some barriers and limitations for its implementation and it isn't a fast or easy process.

Table 2.1 Summary of BIM implementation benefits

| KEY BENEFITS | Benefit stage during project life-cycle | Reference |
|---|---|---|
| Reducing rework and errors | Pre-Const/ Const | McGraw-Hill (2014) |
| Promoting an industry leader image | Whole Life-Cycle | |
| Improving collaborations | Whole Life-Cycle | |
| Offering new services | Whole Life-Cycle | |
| More accurate geometrical representation | Pre-Const/ Const | Azhar et al. (2011) |
| Faster and more efficient processes | Pre-Const/ Const | |
| Improved design | Pre-Const | |
| Controlled whole-life costs and environmental data | Whole Life-Cycle | |
| Better production quality | Pre-Const | |
| Automated assembly | Const | |
| Better customer service | Post-Const | |
| Life-cycle data | Whole Life-Cycle | |
| Reducing costs and improving the accuracy and speed of cost estimates | Pre-Const | Gilligan, Kunz 2007; Azhar et al.(2008) |
| Avoiding clashes (up to 10% of the contract value is saved by detecting clashes) | Pre-Const | |
| Shortening time (up to 7% reduction in project time) | Pre-Const/ Const | |
| Ensuring lower whole-life costs for the asset through sustainable design | Pre-Const/ Const | |
| Facilitating Const coordination | Const | |
| Reducing requests for information and change orders (up to 40% elimination of unbudgeted change) | Pre-Const/ Const | |
| Facilitating generation of Const documents | Const/ Post-Const | |
| Facilitating the simulation and visualisation of the Const project | Whole Life-Cycle | |
| Reduction in Const costs | Const | Love et al. (2013) |
| Improved quality of design information | Pre-Const | |
| Integration of project systems | Whole Life-Cycle | |
| Data and teams | Whole Life-Cycle | |
| Reduced propensity for change orders | Pre-Const/ Const | |
| Improved interoperability | Whole Life-Cycle | |
| Whole life-cycle asset management | Whole Life-Cycle | |
| Technical benefits | Whole Life-Cycle | Ghaffarianhoseini et al. (2017) |
| Knowledge management benefits | Whole Life-Cycle | |
| Standardisation benefits | Whole Life-Cycle | |
| Diversity management benefits | Whole Life-Cycle | |
| Integration benefits | Whole Life-Cycle | |
| Economic benefits | Whole Life-Cycle | |
| Planning/scheduling benefits | Const | |
| Building LCA benefits | Whole Life-Cycle | |
| Decision support benefits | Whole Life-Cycle | |

Const: Construction Phase    Pre-Const: Pre-construction Phase    Post-Const: Post-construction Phase

## 2.4 BIM Barriers

A number of research studies have been undertaken on factors that are limiting the adoption of BIM. For example, Tse et al. (2005) identified barriers occurring more at the early stage of a project, including:

- the split between architectural design and technology/detailing;
- poor object libraries with limited object customisation capability;
- a complex and laborious modelling processes;
- inadequate training and support;
- inability of clients to clearly articulate requirements; and
- additional costs coupled with a lack of free trial software.

Manning and Messner (2008) conducted a case study that identified the following items that are barriers to collaboration among project teams: (1) information exchange bottlenecks, (2) shortage of parametric objects for manufacturers' products, (3) unfamiliarity with BIM's abilities particularly experience with its application in programming, and (4) inadequate understanding of interoperability limitations and capabilities. The successful adoption of BIM usually requires organisational changes, which presents a large hurdle to the successful utilisation of BIM (Ashcraft 2006).

Howard and Björk (2008) interviewed a number of international experts and concluded that there are some negative issues associated with the implementation of BIM, namely that it: (1) is too complex, so it may need to be used firstly in specific areas, (2) has too many standards relevant to BIM, (3) takes a long time to gain benefit from its adoption, (4) depends on the chosen procurement approach in the distribution of its benefits, (5) needs a special information manager role requiring special education, (6) is mostly applied by large property owners in the public sector and (7) can lead to some clients with successful experiences of its use not wishing to share their knowledge.

Through a survey of 31 contracting firms in the United States, Ku and Taiebat (2011) identified BIM implementation barriers as:

- steep learning curve and lack of skilled personnel;
- high cost of implementation;
- reluctance of other stakeholders (e.g. architect, engineer, contractor);
- lack of collaborative work processes and modelling standards;
- interoperability; and
- lack of legal/contractual agreements.

Their findings also suggested that these barriers could be overcome by inevitable improvements in BIM technology, the adoption of collaborative procurement methods such as Integrated Project Delivery (IPD), the desire for BIM enabled projects by clients, and the recruitment of recent graduates with BIM knowledge into the project teams.

Table 2.2 Summary of barriers to implementation of BIM

| Key Barriers | Barrier stage during life-cycle | Common Barriers | Research |
|---|---|---|---|
| Split between architecture, design and drafting | Pre-Const | Collaboration and process | Tse et al. (2005) |
| Inadequate objects and object customisation capability | Pre-Const | Tech support and training | |
| Complicated and time-consuming modelling process | Pre-Const | Tech support and training | |
| Lack of training and technical support | Pre-Const | Tech support and training | |
| Lack of clear requirements from clients | Pre-Const | Collaboration and process | |
| Extra file acquisition costs and the unavailability of free trial software | Pre-Const | Cost | |
| Information transfer bottlenecks | Pre-Const/Const | Tech support and training | Manning & Messner (2008) |
| Current lack of parametric content for significant project vendor products | Pre-Const | Tech support and training | |
| Unfamiliarity with BIM's breadth of ability and associated experience in application of programming | Pre-Const | Tech support and training | |
| Lack of understanding of interoperability limitations and abilities | Pre-Const | Tech support and training | |
| Too complex so may need to be used first in specific areas | Pre-Const | Tech support and training | Howard & Björk (2008) |
| Too many standards relevant to BIM | Pre-Const | Tech support and training | |
| A long timeline required to gain benefit from the adoption of BIM | Pre-Const/Const | Collaboration and process/Cost | |
| The distribution of benefits depends on the chosen procurement approach | Pre-Const | Collaboration and process | |
| Needs a special role of information manager and special education | Pre-Const | Tech support and training | |
| Most applications of BIM are by large property owners in the public sector | Pre-Const/Const | Scale | |
| Some clients with successful experiences of using BIM may not wish to share their knowledge | Pre-Const/Const | Training | |
| Steep learning curve and lack of skilled personnel | Pre-Const/Const | Tech support and training | Ku and Taiebat (2011) |
| High cost of implementation | Pre-Const/Const | Cost | |
| Reluctance of other stakeholders (e.g. architect, engineer, contractor) | Pre-Const/Const | Tech support and training | |
| Lack of collaborative work processes and modelling standards | Pre-Const | Collaboration and process | |
| Interoperability | Const | Collaboration/Training | |
| Lack of legal/contractual agreements | Pre-Const | Collaboration and process | |

Table 2.2 summarises the BIM barriers identified by different researchers and defines the project stage at which the barriers occur. Table 2.2 shows that many barriers are within the Pre-construction stage, specifically modelling and collaboration issues. Therefore, it can be concluded that BIM adoption needs more work at the earlier stage of a project, with improved collaboration before the construction's inception. A recent study (Hosseini et al. 2016) regarding BIM adoption barriers for SMEs in Australia also supports this matter that the main barriers are at the earlier stages of projects. According to that research, the most

influential barrier was the decision-makers' opinions that there was no, or low, benefit in adopting BIM, followed by the sub-contractors' unwillingness to adopt BIM (a collaboration issue). The negative perception of BIM implementation costs took third place in this descending list, followed by lack of knowledge of BIM adoption as the fourth most influential barrier and, finally, inadequacy of standards such as sources of knowledge and instruction.

To summarise, BIM barriers, technological obstacles, lack of trained and experienced personnel, cost barriers and lack of standard processes for collaboration can be named as the main issues negatively affecting BIM implementation.

A review of Table 2.2 reveals that there are three commonly identified barriers among the selected research, namely:

- "steep learning curve and lack of skilled personnel" or "lack of training and technical support";
- "extra file acquisition costs" or "high cost of implementation" ; and
- "lack of collaborative work processes and modelling standards" or "lack of understanding of interoperability limitations and abilities".

Therefore, more succinctly, technical support, cost and collaboration can be identified as the three main BIM barriers.

In addition, another factor noted by Howard and Björk (2008) was that the application of BIM tends to be by large property owners in the public sector, which raises the question of whether BIM is applicable only for a particular type of project. Hence, lack of technical support and collaboration problems, in addition to implementation costs with a long timeframe before gaining the benefits of adoption, are all serious barriers to BIM involvement in the private sector of construction.

## 2.5 Project Scale

A recent study by Matthews (National BIM Report NBS 2016) regarding government support of BIM involved the level of Technology Investment by different sectors. This report shows that construction, in comparison to other industries, has a very slow rate of investment in technology. As Figure 2.1 illustrates, the construction sector (with a 3.33 score) is between the stages of rudimentary digitisation and very little investment, while the average of 2.8 over all sectors lies between "very little" and "partly" in regard to investment. Hence, it is obvious that the non-public sector of the construction industry has more barriers to its investment in technology, specifically because the contractor firms are more paper-based than technology-based, whereas architectural firms generally have greater investment in technology.

Due to a reasonable growth rate of technological investment in construction (Figure 2.2) and upcoming national programs, the study expects that this sector will step up until 2020, with a significant proportion likely to "*move from 'digitally naïve' to 'digital natives'*" (Matthews NBS 2016, 12). This movement has been predicted based on national programs; thus, improvement of the non-public sector or smaller scale projects in involvement with technology is an unavoidable part of reaching those goals.

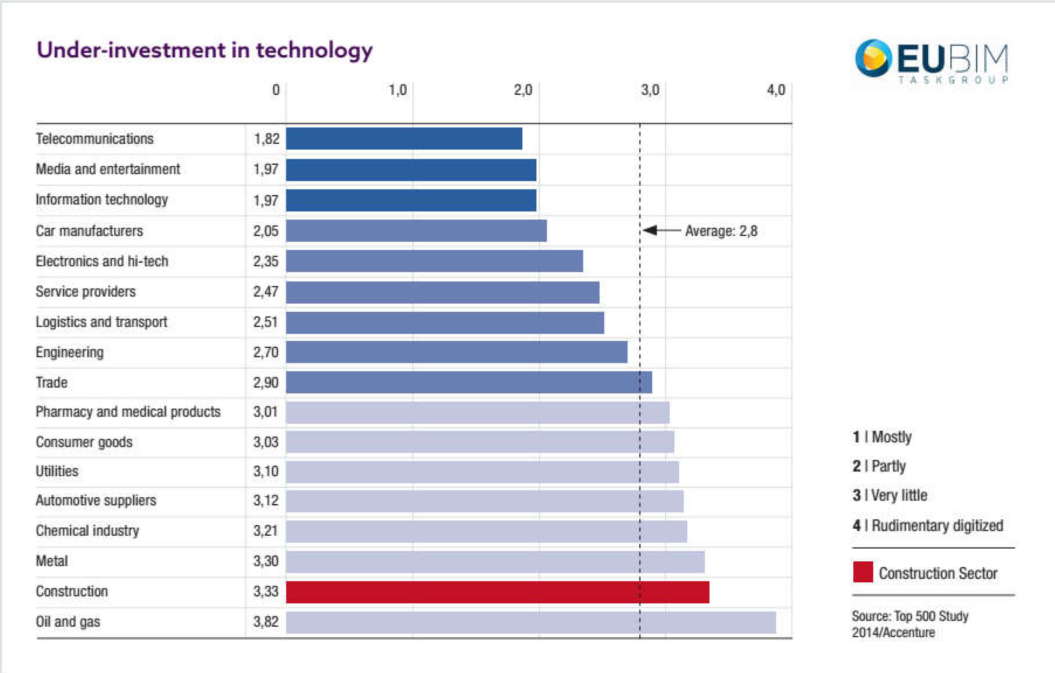



Figure 2.1 Under-investment in technology (NBS 2016, 9)

According to a report of the Australian Government (2015) a vast majority of Small to Medium Enterprises (SMEs) are involved in the construction industry. The number of SMEs in the construction industry of Western Australia (WA) is dramatically higher than for other sectors. Therefore, BIM implementation, as a part of the national technology movement, will inevitably require the involvement of SMEs.

Some findings of the experimental report by Gledson et al. (2012) revealed differences between SMEs and larger organisations in that the former had lower levels of BIM awareness.

By the same token, SME contractors mostly had no plan for BIM implementation, at least for the next 5 years, while large organisations tended to have an adoption plan for BIM during the next 3 years.

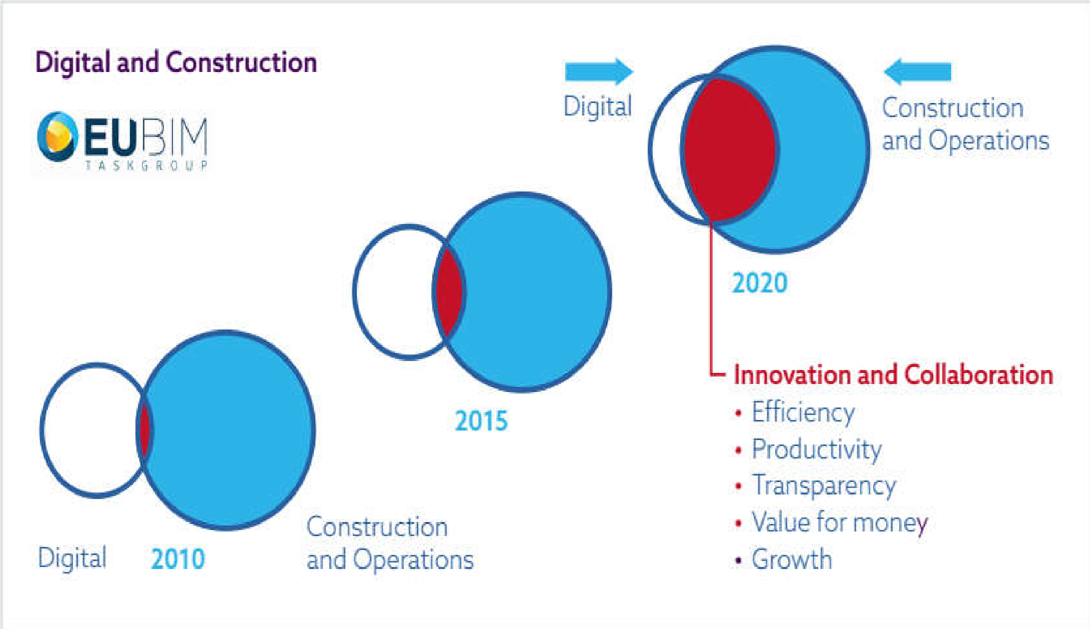



Figure 2.2 Under-investment in technology (NBS 2016, 12)

The research by Gledson et al. (2012) also highlighted the opinions of SMEs in regard to the cost and time savings delivered by BIM implementation. SME organisations believed that cost and time saving "...*would be passed down to the supply chain from the larger contractors to the benefit of both groups, with the belief from some of the SME organisations that this would ultimately lead to reduced income levels*" (Gledson et al. 2012, 106).

Their last finding was that the timescale allocated by SMEs "...*would not afford enough time for BIM processes to be successfully implemented into their working practice*" (Gledson et al. 2012, 106).

The findings of another research study, regarding project size, established that SMEs and large organisations are very close to each other in BIM adoption, if some minor differences can be dismissed, but that different barriers which exist for each sector are pushing them further apart, which could result in a "BIM-only construction elite" leaving SMEs continuing to rely on 2D drawings (Loveday and Scott 2016).

Therefore, according to the predicted upswing in technology for the construction industry in addition to BIM's potential for SMEs, there is a requirement for more research in this field to fill the existing gaps.

For this purpose, a review of SMEs and their existing methods and applied processes could provide a better understanding of BIM adoption in projects of that scale.

## 2.6 Small to Medium Enterprises

Australia, as a growing country in the BIM global market, needs to implement BIM within the construction sector. The Australian-National BIM initiative report (buildingSMART 2012) emphasised the need for collaboration between industry and government to maximise the economic returns when adopting BIM in Australia in order to remain competitive within the growing global market.

Later, buildingSMART Australia (2016) advocated for all federal, state, territory and local governments to adopt BIM maturity of users based on: open standards of information exchange throughout all public building procurement; establishment of performance measurements based on effective BIM adoption; establishment of a joint government and industry rapid-response taskforce; and identification of public project exemplars that show the effectiveness of BIM adoption (buildingSMART 2016, 3).

Residential projects are a major part of the construction industry, and many firms which specialise in domestic construction are ranked as Small to Medium Enterprises (SMEs). The term 'SME' is defined as: "*micro-businesses, small businesses and medium sized firms. A small business has less than 20 employees; a medium business* *has between 20 and 199 employees and SMEs have less than 200 employees*" (Small Business Development Corporation WA 2016).

While SMEs are small business units, collectively they comprise a significant proportion of the construction sector and are an important economic driver for the prosperity of Australia (SMEA 2015). According to the SMEA (2016), the construction sector accounts for the largest proportion (19%) of the total of SME companies within WA, demonstrating what a significant role they play within the state's economy.

While construction SMEs can work on a wide range of projects, the majority of this sector is focused on residential jobs rather than larger commercial or industrial projects. Taken together, these findings support strong recommendations to develop guidelines for high level BIM adoption within the residential sector. However, to date, there has been little research within the context of Australian SMEs in order to identify the main contributors to their perceived slow adoption of BIM.

BIM has not been widely adopted by homebuilders because many believe that the technology is not suitable for rapid scheduling (Eastman 2012, 263). However, an accurate building model that allows a smoother and better construction process has major advantages for all construction sectors, offering the potential to save time and money, and to reduce errors and conflicts (Eastman 2012, 263). Engineers Australia reinforces this potential and suggests that small to medium projects, due to their shorter duration, present many opportunities for the more frequent use of BIM implementation (Engineers Australia 2014).

## 2.7 Collaborative BIM-enabled Processes

The essence of BIM implementation is the collaborative working process (Succar 2009), which potentially increases both efficiency and effectiveness and enables project participants to reap the maximum benefit from its implementation. BIM provides a collaborative platform for all stakeholders to share their knowledge resources and information, which helps to increase effective communication during the project life-cycle (Figure 2.3). Effective communication allows stakeholders to exchange accurate, up-to-date and reliable information with decision-makers (Lu et al. 2013).

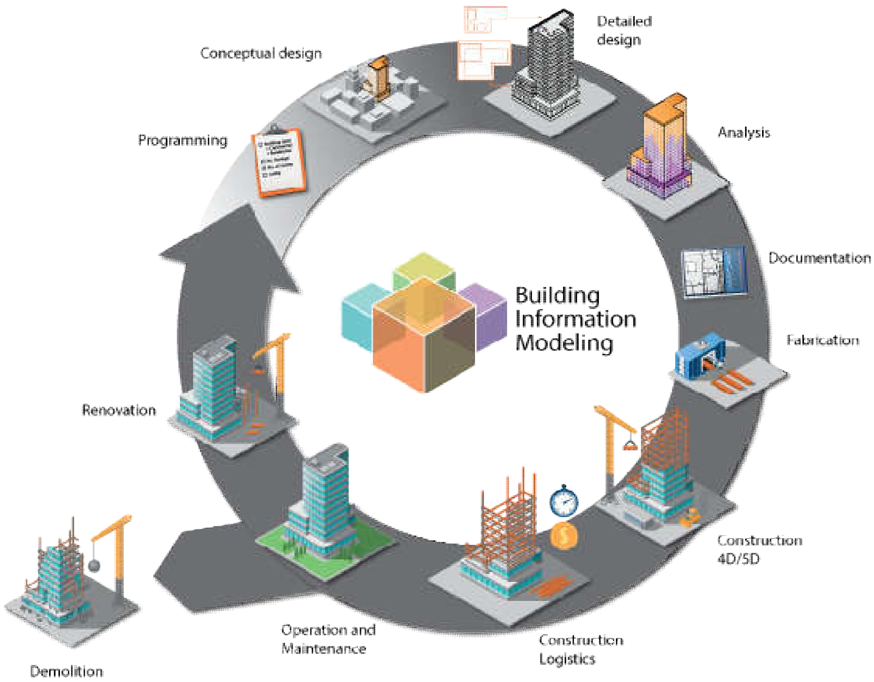



Figure 2.3 BIM-enabled process diagram (collaborative working); (Moscardi 2016)

In order for effective collaboration to take place in a BIM-enabled environment, contractual arrangements need to be available that support and clarify stakeholders' relationships and responsibilities. The lack of legal and contractual agreements that support collaborative work environments has been identified as a BIM implementation barrier by many sources (Ku and Taiebat 2011). Also, for any legal and contractual progress to occur for large scale projects, much attention must be focused on the complicated partnering amongst project parties. Whilst, implementing BIM for smaller scale projects needs to have the required knowledge of BIM to compete with demands for the Design-Build (DB) or Design-Bid-Build (DBB) project delivery methods. The knowledge is based on the business models that are required to analyse the extent of implementation costs and contractual agreements (Ghaffarianhoseini et al. 2016).

## 2.8 Project Delivery Methods Within the SME Sector

The DBB method is a popular, prevalent project delivery system employed among private sector clients. According to the Design-Build Institute of America (DBIA 2007) just under 90% of public buildings and approximately 40% of private projects used the DBB method during 2002. The DBB approach was succinctly described by Levy, Sidney M. (2010, 6):

> "An owner engages an architectural or engineering firm to produce a complete set of plans, specifications, and specific project requirements. These documents, referred to as bid documents, are distributed to a selected list of general contractors, who are prequalified as far as construction experience and financial strength is concerned. These contractors will submit their price to complete the work as outlined in the bid documents."

The DBB approach has two major benefits, which are: "more competitive bidding to achieve the lowest possible price for an owner; and less political pressure to select a given contractor" (Eastman 2012, 4). Alongside the documented benefits, some problems have also been identified with this approach. These are summarised below (Eastman 2012):

1. Conflicts, errors and ambiguity within design documentation make offsite fabrication of materials challenging. Construction onsite costs more, takes longer and is inclined to result in faults that would not happen if the work was carried out in a factory environment where costs can be minimised and quality can be better controlled.

2. New errors or missing information, unforeseen site conditions, changes in the supply chain, new client requirements and emerging technologies result in many changes being made to the design. To resolve these issues the architect, or relevant party, needs to find a design solution through the Request for Information (RFI) procedure. Subsequently, a Change Order (CO) is issued to notify all impacted parties of the change, which is packaged with the required changes in a reissued drawing set. These changes and associated resolutions often result in additional costs and delays and can lead to legal disputes.

3. The competitive nature of the industry can result in contractor's bidding lower than the estimated cost in order to secure the job. In order to recoup losses incurred from the original bid Contractors subsequently abuse the change process, often leading to further disputes.

4. Additionally, the DBB method requires that materials cannot be procured until the bid is approved by the owner, and as a result any items with long lead times may impact on the project's schedule. If all of the information is provided to the owner in 2D, the task of handing over all the relevant

information to the facility management team for maintenance and operation of the building is considerable.

5. The final phase is commissioning the building. Depending on the requirements of the contract, all the changes are incorporated into a final "as-built" drawing set, which is handed over to the owner with all the installed equipment manuals.

The most notable limitation of the DBB approach is the increased propensity for conflict due to fragmentation throughout the project. In the DBB method, the design team creates the construction plans with very little external influence. The contractor then bids on these documents without any mechanism for constructive input. Through this approach, the design and construction teams have hardly any interaction during the construction phase unless a conflict occurs (Stauffer 2006). Therefore, many of the above problems associated with the DBB method stem from poor collaboration among project teams. This has resulted in the method acquiring a reputation for being time-consuming, prone to error and costly in comparison with the other alternatives.

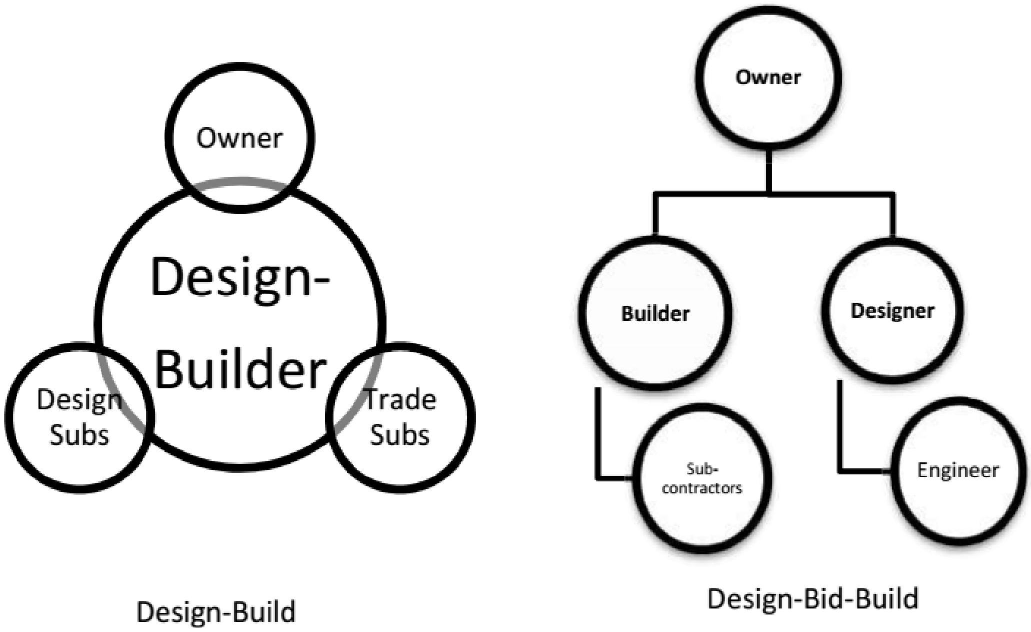



Figure 2.4 Schematic diagram of design-build vs. design-bid-build, adopted from Stauffer (2006)

In contrast to the DBB method (Figure 2.4), DB simplifies the administration of tasks for the owner by allocating the responsibility for both design and construction to a single contracting entity (Beard et al. 2005). This method is very similar to the turnkey approach, in which the appointed turnkey contractor takes a client's specification brief, develops a total project design and construction package, and finally hands over a commissioned, functional asset. The turnkey subcontractor often has the capacity to deliver an integrated design and delivery solution with high levels of novelty and intellectual property that the client and other potential competing turnkey consortia may lack (Brady et al. 2005).

The principle of Design-Build is to place both design and construction in the hands of one firm: the designer-builder. The Design-Build (DB) method is one alternative that has become more commonly used, particularly in the Australian residential construction sector (Holzer 2015).

Some design-build firms have been created when a general contractor has employed architects and/or engineers to provide a full-service organisation. Others have formed a joint venture with an architectural firm or have subcontracted architects to perform the design work (Levy, Sidney M. 2010, 5). In both cases, the designer-builder, with the design and construction staff in a single firm, is well placed to engender collaborative working processes across project phases.

DB is the choice of procurement method whereby the owner contracts with the DB team and, usually, an architect/designer leads the progress of the design and construction teams. In this method, the procurement is based on consultations with the owner about the requirements of the commissioned project. Early on in the process, the owner and DB team negotiate the contract which will govern the design and construction of the project. When the design is approved by the owner, the design-build team takes responsibility for construction and coordination between teams (Stauffer 2006).

The co-location of teams allows some flexibility for design and construction to overlap and, as a result, the “build” team can procure materials and equipment and appoint subcontractors earlier, resulting in a significantly shortened schedule for the entire project. A shorter schedule results in lower construction financing, which is more costly than permanent financing. The DB method allows for changes to be made to the design early on, when they are relatively cheap and easy to accommodate. Consequently, owners using design-build experience less change orders, another benefit of this project delivery system (Eastman 2012).

Once the construction process commences, the DB contractor assumes responsibility for any subsequent changes to the design (within predefined limits) (Holzer 2015).

This is also the case for any errors or omissions. These simplifications can result in faster completion of the project, a lot less legal complications, and even a reduction in the total cost. However, it's worth noting that once the initial design has been approved, and the contract sum agreed, there is very limited scope for the owner to make changes (Eastman 2012).

Figure 2.5 illustrates how increased collaboration between design and construction in the Design-Build method (B) potentially reduces project time due to some parallel design and build activities. It can be concluded that changing the project delivery method from DBB to DB for SME projects will provide a more collaborative context for BIM implementation.

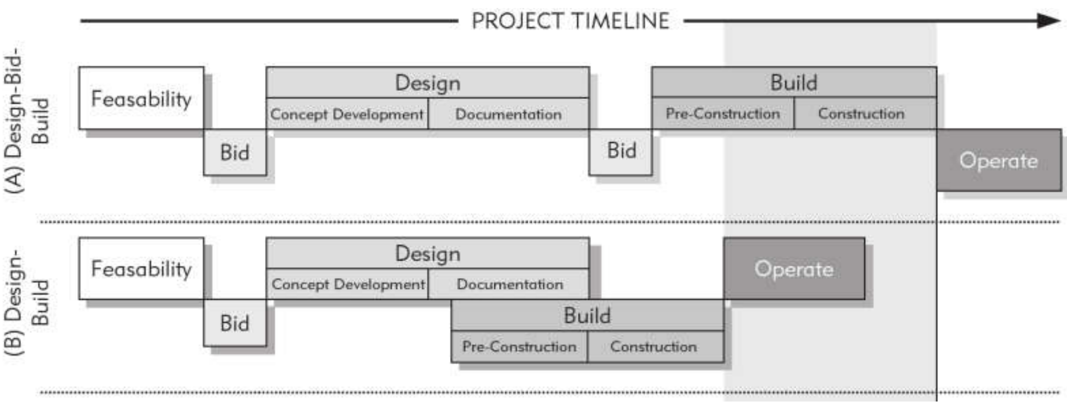
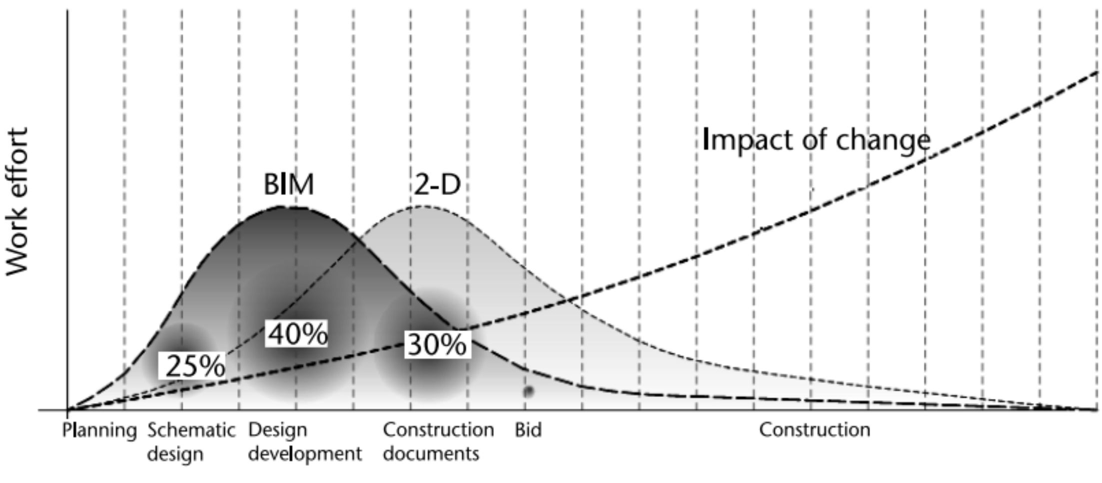



Figure 2.5 Diagrammatic comparison of two different delivery methods (Eastman 2014, 116).

## 2.9 Traditional vs. BIM-enabled Methods

The traditional (2D) breakdown of workload at each pre-construction stage of a project has been estimated as: schematic design, 15%; design development' 30%; construction documentation including specifications, 50%; and 5% for bidding (Erika 2012). The introduction of BIM has had an impact upon this traditional breakdown, requiring a heavier workload in the earlier stages of a project. This particularly impacts on the architects, engineers and consultants whose workloads shift from the documentation phase into the schematic design and design development phases, as shown in Figure 2.6 (Erika 2012 - adopted from Macleamy Curve). This is significant because it allows for any required changes to be made much earlier in the project cycle, at a time when the cost impacts of the changes are minimal.

In effect, it has been estimated that a BIM-enabled workflow allows the design process to be 10% faster and 80% more accurate than the traditional design method (Czmocha and PĊkalaa 2014, 213) and allows a project to be virtually constructed prior to any work starting on site. BIM allows for any errors or clashes to be detected before work is handed over to the construction team.




**Planning, Design and Construction Schedule**

Figure 2.6 Macleamy Curve (Erika 2012) - BIM work effort shift. Shift of work for architects and engineers during design and documentation stage

In addition, the bidding stage of a project can be started earlier and any required design changes managed centrally within the BIM database. Once construction has commenced, the contractors can collaborate with subcontractors through the virtual model, which can help to manage the costs and scheduling of the work, labour and materials. This transition to a BIM-enabled workflow, while at times challenging and initially costly, if managed well can lead to increased cost effectiveness and an improved end product. BIM allows for "*simplification of many tasks and considerable savings both in terms of money and time*" (Czmocha and PĊkalaa 2014, 215).

## 2.10 Construction Management

Construction management as a discipline can be traced back to the 1950s, with the advent of computerised scheduling methods such as PERT and CPM for managing complex projects. Construction management services became institutionalised during the '60s and '70s when public sector clients divided general contracts into multiple packages that required more coordination. Later, construction management became a widely accepted delivery technique (Robert et al. 2000) and construction management services could include the provision of architects, designers, building contractors and other third-party entities to the client.

Construction projects, due to their unique nature, are often associated with significant uncertainty concerning duration (Sidwell 1984). The construction manager aims to reduce the risks associated with this uncertainty through time management tools that can be used for time planning, time estimating, time scheduling and schedule control (Mackenzie 1990). These tasks are often conducted by a project planner, who will define the work specifications, determine the quantity of work and estimate the resources required to successfully deliver the project (Scott and Assadi 1999).

There are a number of tools and guidelines available to project planners to help create a baseline for monitoring and measuring project work. To be effective, the tools must be able to capture and manage time at both the individual (resource) and task (work) levels (Mcgraw and Leonoudakis 2009). Construction project planners design the project path prior to construction commencing ( Figure 2.8), often based on company-specific guidelines, including a standardised work breakdown structure, which enables project progress to be monitored, controlled and measured.

## 2.11 Work Breakdown Structure (WBS)

A Work Breakdown Structure (WBS) splits the overall work within a project into several, smaller, more manageable tasks that are hierarchically structured (Figure 2.7, 1-Activity definition). The level of detail needs to cover the entire project, while keeping each tasks manageable (Norman, Bortherton and Fried 2008). A top-down procedure is usually adopted for the design of a WBS. Initially the top levels of the WBS are broken down into coherent groups of work, followed by the next level down and so on (2-Activity sequencing). To be able to control a project, the decomposition needs to continue until a structure has been attained which gives an acceptable level of control (Devi and Reddy 2012).

Once this is achieved, the lowest-level component of the WBS can be scheduled and its cost can be estimated, monitored and controlled. It is much simpler to control a series of small entities, than to control the whole project as a single action. The WBS enables planning and control of the project through allocation of resources (human, material and financial), (3-Estimating activity resources) and assigning time constraints to each task (4-Estimating activity duration).

The WBS is an essential part of any project's life-cycle and timeline, which helps to identify how the project will flow (5-Schedule development) within a planned timeline set by the project planner. The final process is related to the construction stage of a project and it controls project progress to comply with the developed schedule (6-Schedule control) – Figure 2.7 (PMBOK 2008, 22).


Figure 2.7 Time management subdivision (PMBOK 2008, 22)

## 2.12 Construction-oriented Modelling

Therefore, in construction projects, as in other areas where projects with substantial uncertainty surrounding their duration are executed, it can be very beneficial to cover time scheduling by use of a more efficient BIM method.

While BIM has the potential to transform the way the construction industry works, the required workflows and processes that support this collaborative way of working are still emerging. This is particularly true in the SME sector where designers and planners remain compartmentalised and provide their outputs individually during different stages of a project's timeline.

SMEs are currently at quite low levels of capability for innovation due to their fragmented nature, limited use of collaboration and risk-averse attitudes (Goodridge, Haskel and Wallis 2015) and breakthroughs can only be achieved through BIM implementation (MGH 2014). In order to engender a collaborative method for project delivery, team members need to collaborate as early as possible and continue to do so for the project's duration.

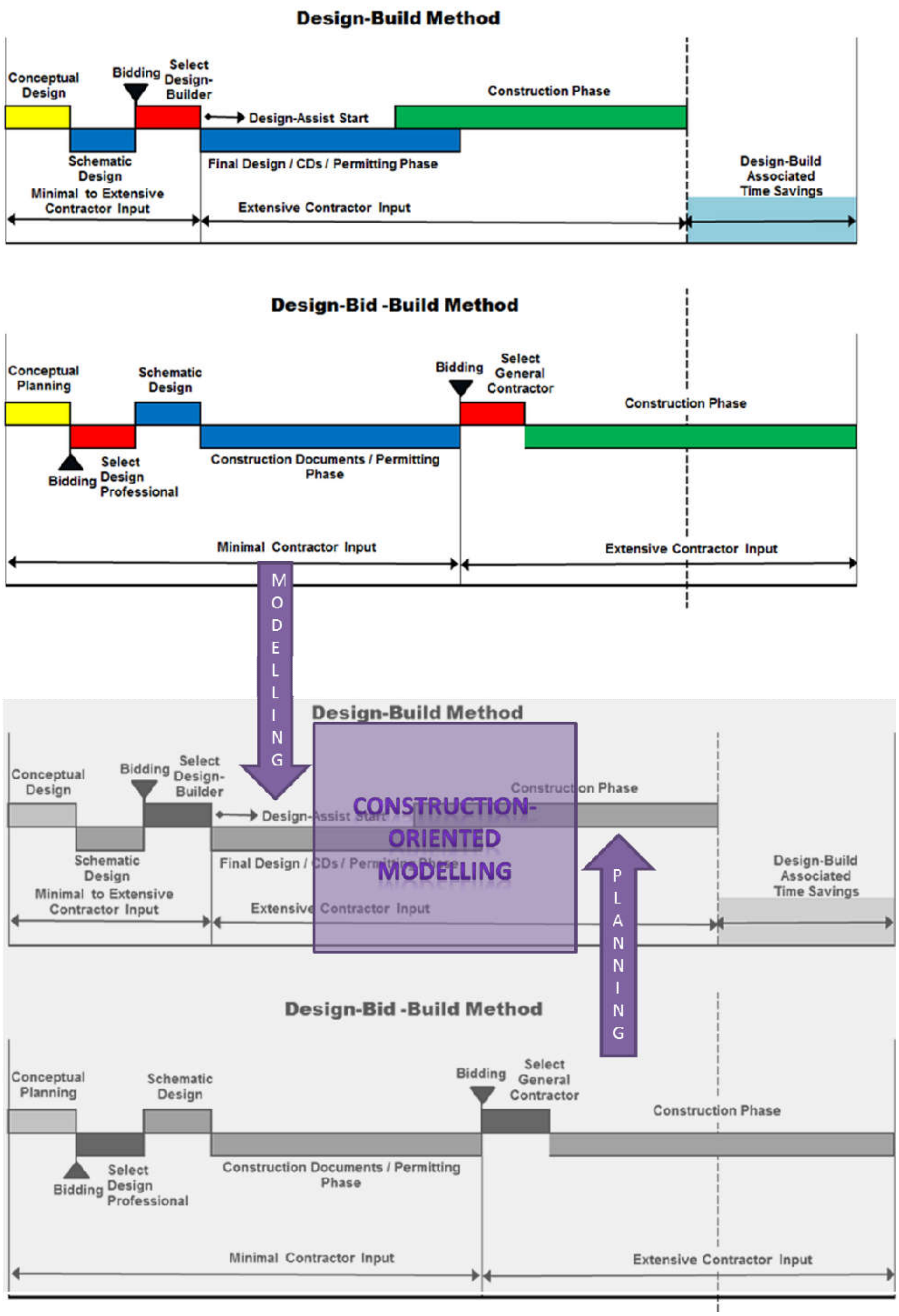



Figure 2.8 Construction-oriented modelling in a collaborative method

In a BIM environment, the model is established by the architect during design and it forms the basis of a shared central model to which additional project information can be added. However, the design team's perspective and focus is often very different to that of the contractor. As a result, the model produced during design may not be well-matched to the needs of other disciplines. For example, a designer may view a floor slab as a single component, whereas a contractor will view this as a number of tasks that might involve several different trades.

In order to improve the collaborative potential of the shared central model, the design team and planning team would need to start working together much earlier in the project timeline to share their requirements and agree on common or aligned work breakdown structures that could accommodate the needs of the construction team as well as the design team. The resulting 'construction-oriented model' would enable BIM collaboration across the whole project life-cycle. Figure 2.8 shows this process in the context of the DB project delivery method.

As the 4D BIM (the 3D BIM model extended with one extra variable – Time) creation steps will show, re-organisation of the 3D model is a cost- and time-consuming step that could be moderated through construction-oriented modelling. By omitting this rework step, a considerable amount of time and money will be saved. Rework means: "*the unnecessary (task) of re-doing work that was incorrectly undertaken the first time*" (Love 2002). This definition in digital context includes edition and re-modelling of existing file that takes time and money.

## 2.13 4D Scheduling

Lately, the wave of enthusiasm for technological applications to every industry also has included the construction sector and "*the application of Information Technology*

*(IT) to construction project management (CPM) has become crucial to the completion of projects in accordance with the specifications of time, quality and costs*" (Brito and Ferreira 2015).

While BIM adoption is on the increase, its current use in the SME sector has focused on the design phase, using 3D modelling, with virtual walkthroughs of a project as it is to be built. Research conducted by Gledson et al. (2012) confirmed that project size is a factor that impacts upon BIM adoption because the timescales assigned to smaller projects in typical contractual procurement processes do not allow adequate time for BIM processes to be implemented into working practices.

In particular, smaller contractors have less awareness of the potential of BIM and put fewer resources into planning for future BIM implementation (Dainty et al. 2015). Although both SMEs and large scale firms have recognised the potential for improved coordination of design, including the benefits of clash detection and enhanced collaboration, the research highlighted that SME organisations felt they had insufficient resources to justify investing in new processes and technology, due to their significantly lower profit margins (Gledson et al. 2012).

However, as its adoption matures within the SME sector, the potential for new construction-oriented information to be appended to a model has become a reality, including time-construction sequencing (fourth dimension), cost information (fifth dimension), facility management (sixth dimension) and so forth, with additional dimension embedding more information about the project in the model.

As BIM adoption increases, much effort has been focused on extending its use beyond design, into construction, through the inclusion of time to create a 4D model for simulating construction scheduling. The American Institute of Architects

(AIA,2015) has defined 4D BIM as "*a 3D model linked to time or scheduling data. Model objects and elements with this data attached can be used for construction scheduling analysis and management. It can also be used to create animations of project construction processes*."

The McGraw-Hill Construction report, which simply defines 4D modelling as "*linking the work breakdown structure to project elements in the model*" (McGraw-Hill 2008, 22), indicates that the program scheduling functions within BIM are an emerging benefit. Although the design capabilities of BIM have been widely adopted by users, the SME sector is still in the early steps of adopting BIM for scheduling. This is likely to be due to the large investments that firms have already made in project management software (McGraw-Hill 2014). Even though contractors have been slow to implement BIM, the research shows that their adoption rate is set to grow faster than any other users, indicating that greater use of 4D can be expected in the near future.

4D BIM has the benefit of *"...enabl(ing) us to compare the problems they faced as a result of using the original schedule to the problems that were detected through the 4D model"* (Koo and Fisher 2000, 64). This includes the ability to *"detect the incompleteness of the original schedule, find inconsistencies in the level of detail among the schedule activities, and discover an impossible schedule sequence"* (Koo and Fisher 2000, 251–260).

As noted by Russell et al. (2009), these tools help identify effective construction approaches to shortening project duration, examine workability and review the overall quality of a schedule. This is exemplified by, Ma et al. (2005) who developed an integrated site planning tool that aimed to integrate project schedules, geometric models, resources and site spaces, with 4D technology, to provide 4D visualisations for construction site planning.

The BIM process can potentially remove the guesswork surrounding how the more complex components of a building come together. Projects can be digitally constructed in a virtual environment, highlighting any possible conflicts within the schedule prior to construction commencing; this is a particularly effective tool for communicating information to owners and displaying models for future construction. If delays arise, the model can be updated and can help to determine any necessary deviations to the schedule.

### 2.13.1 4D BIM Creation Steps

The actual process of preparing a 4D model has been defined through six steps (French and Khanzode 2006):

1. *Establish Work Breakdown and Flow*

   The first step in the creation of a 4D model is to identify how the work will be broken down and how it will flow through the project for the various subcontractors. This process involves working with the project's planner and construction team. The critical activities, the work sequencing and the work stream throughout the project need to be determined. It is important to decide the purpose of the 4D model at this stage, to clarify the required level of detail of the 3D model and the project schedule.

2. *Establish Installation Sequence*

   The installation sequence is prepared by the project consultants, the sub-trades and the project planner to identify the activities that need to be executed by the different disciplines and the relationships between project's activities. The installation sequence needs to be determined so as to ensure that each crew can achieve maximum productivity.

3. *Reorganize 3D Models*

After the installation sequence, there is often some remodelling required of the 3D model so that the WBS activities and sequencing defined in the previous two steps can easily be linked to the correct components in the 3D model. This may involve all the design disciplines, including architectural, structural, mechanical, plumbing and electrical information. This can involve a significant amount of work, particularly if there has been little or no communication between the design and construction team. This essential step is typically the most time-consuming part of developing a 4D model. Ensuring that the 3D model can facilitate 4D modelling, particularly in terms of how objects are layered and modelled, helps to minimise the effort required to reorganise the design perspective encapsulated within the 3D model and to align it with the construction perspective documented in the schedule.

As discussed earlier, early collaboration between the design and planning teams (resulting in a construction-oriented model) could help to minimise the impact of this step through reducing the need to re-model. The schedule may also require refinement at this stage in order to represent the actual sequence of activities for each work area and to represent a more detailed sequence of activities.

4. *Link 3D Objects and Activities*

During this step, the 3D models and schedule models are imported into a common object-oriented environment. Here, 3D objects within the model can be grouped to align with the appropriate schedule activity created in the third step. Navisworks *Timeliner* is one of the software packages that can be used to create the 4D model.

5. *Refine 4D Model*

The final step involves refining the appearance of the 4D simulation to suit the purposes of the 4D model. This might include the use of colour, transparency, time intervals, filtering or sub-sets, labelling, orientation, etc. French and Khanzode (2006, 402) suggest that "*Typically, it is useful to create multiple simulations to show all the different perspectives (e.g. interior work and exterior work) and to communicate to different stakeholders (e.g. owners and subcontractors)*".

4D BIM has matured significantly since the commencement of its adoption and it is rapidly becoming a practical option for project parties. As Table 2.3 shows, 4D modelling requires close collaboration between the design and planning teams. Aside from its benefits, 4D modelling has some challenges. For example, the shelf-life of the 4D information is limited and is only useful while the model and activities are continuously kept up-to-date. In addition, and particularly when used on larger scale projects, problems can arise with managing the progress of internal activities. It's important to note that the use of a 4D model is not an automatic solution to all construction sequencing problems, and it relies on individual experience and levels of knowledge (Koo and Fischer 2000; Russell et al. 2009)

### 2.13.2 The Potential of 4D Modelling

The potential benefits of 4D modelling for the management of construction projects, as categorised by Brito and Ferreira (2015, 378) and French and Khanzode (2006, 403) are summarised in the following table.

Table 2.3 4D modelling potential

| 4D MODELLING POTENTIAL | Brito & Ferreira | French & Khanzode |
|---|---|---|
| Reduces effort in visualisation | ✓ | ✓ |
| Communicates work flow over time | ✓ | |
| Helps identifying potential conflict and sequencing problems of space and time prior to construction | ✓ | ✓ |
| Shows the status of construction at any time in the project and visualisation of possible impacts caused by changes in planning | ✓ | ✓ |
| Supports the insertion of equipment, construction site elements and resources into spaces for planning analysis | | ✓ |
| Supports the sequencing and intended schedule suitability of scheduled work rate | ✓ | ✓ |
| Eases integration and communication among all project stakeholders | | ✓ |

There is much evidence to show that BIM use in Australia is significantly increasing. For example, BIM implementation among Australian firms has increased from 29% of firms with very heavy BIM implementation (meaning involvement of 60% or more of their projects with BIM) during 2013 to 48% of firms at the same level only two years later (McGraw Hill construction 2014, 9). However, there is still a tendency for disciplines to continue working in "silos", because efficient workflows and processes for data sharing and exchange have not yet matured, resulting in much unnecessary digital rework. However, firms typically deepen their level of engagement with BIM as their experience and skill levels increase (McGraw Hill construction 2014). While design professionals currently report the heaviest level of implementation of BIM, contractors have been much slower to make the change. Accordingly, designers are modelling projects in isolation from other parties, often resulting in "branching" models and the duplication of effort and double-handling of data through inefficient processes (McGraw Hill construction 2012). Even though later research has reported design professionals as leading contractors in its use, with six out of ten (61%) currently using BIM on 30% or more of their work, versus only one-third (33%) of contractors (McGraw Hill construction 2014, 4) the production of accessible guidelines for 4D BIM implementation would make a valuable contribution to supporting this change, particularly if targeted at the SME sector.

### 2.13.3 Industry Foundation Classes (IFC) Format

One of the major concerns in the BIM process is the interoperability of the model data among project teams. In this regard, buildingSMART (Liebich et al. 2010) developed the Industry Foundation Classes (IFC), which is becoming a *de jure* standard supported by commercial BIM tools for building structures. The IFC is an open and freely available object-oriented file format that facilitates interoperability in the building industry. "*Industry foundation classes (IFCs) include object specifications, or classes, and provide a useful structure for data sharing among applications. For instance, an IFC door is not just a simple collection of lines and geometric primitives recognized as a door; it is an 'intelligent' object door which has a door's attributes linked to a geometrical definition*" (Vanlande et al. 2008, 2).

IFC classifications can add additional information, such as internal or external location and the structural significance of any object. Objects can be embedded with any kind of information deemed to be useful at some point in the life-cycle.

There are many programs now available for BIM modelling and management, such as ArchiCAD, Revit, Tekla or Navisworks, all of which use objects with associated parameters, where a parameter is "*an independent variable that describes a characteristic of the object*" (Erika 2012, 44). Objects can have more than one parameter, and this information can be embedded by users throughout the project's life-cycle. The parameters can describe the object geometry; for example, a roof as an object requires physical information like width, length, depth and slope to be created as a component of the virtual model. Also, parameters such as manufacturer, material, cost, time, GIS information and much more can help to accurately describe an object.

### 2.13.4 Parametric Objects

Parametric objects enable BIM users to make required changes quickly and accurately. Through a hierarchical structure of instances and types, parameters can be defined on different levels. When defined at the 'instance' level, changing one or more parameters has no effect on the other instances of the same type of object. However, when defined at the 'type' level, changing a parameter on one instance will simultaneously change all other placed instances of the same type. This powerful function enables a simpler and faster process when compared with replacing non-parametric objects such as those in traditional CAD environments, where a single change may need to be manually updated across several different views or files.

Another example is a chair. If the guest chair in a project is changed to another manufactur with increased width and it now has arms, the 3D object is automatically changed to the new model. This parametric object has a unique set of characteristics that fully describe it. In the virtual model, the increased size change may now affect some of its locations by being too large for the space (Figure 2.9). Periodic use of rule-based applications that can check for clashes and minimal space requirements of each object can be used to confirm how well a change, such as this chair, will affect the project. The full extent of a change's impact on a project can be assessed. The responsible team members can view the impact by items, furniture costs or project costs. Whatever the impetus behind the change, the entire team is updated, with protocols notifying the team members whose work is affected by the change (Erika 2012).

Figure 2.9 Example of how a chair as a 3D object makes changes to a project

## 2.14 BIM for SMEs

BIM offers many benefits to SME-scale projects, as it does for large scale projects. There is no doubt that BIM represents an exciting technology with the potential to improve the efficiency, connectivity and performance of any construction process. However, many SME-scale firms are equipped with the necessary software and tools, though they often still choose to follow paper-based communications and remain digitally disenfranchised. Indeed, BIM plays a central role for the current reform movement among the construction industry as a method of reconnecting the fragmented delivery network, which elevates the technology to an almost ideal status within the industry (Dainty et al. 2015).

More research being focused on this sector of the construction industry could help to offer workflows suited to SMEs to reduce remodelling and to extend the use of models into the construction phase and the widening gap between the espoused intentions of its use and the realities of its implementation. A study of existing project delivery processes within SMEs may clarify some of the hidden aspects of barriers to BIM implementation for small scale projects and may ensure that recommendations made are appropriate for BIM adoption by SMEs, resulting in streamlining of workflows and efficient collaboration among project team members.

## 2.15 Chapter Summary

BIM adoption and implementation is transforming the construction industry, and different aspects of BIM utilisation within projects have attracted many studies and researchers. A comprehensive and in-depth review of the existing knowledge in that regard has provided this research with a proper context and foundation to study BIM adoption by SMEs.

The concepts that are essential for this research were introduced, including definitions, benefits and barriers, construction management and project delivery methods, work breakdown structures and 4D simulations. In addition, the existing context and methods for 4D BIM, with their related formats, were reviewed.

In summary, according to the reviews presented in this chapter, further research regarding BIM for SMEs will make an essential contribution, specifically to the firms equipped with the required software and tools but still utilising the traditional methods.

# CHAPTER 3: RESEARCH METHODOLOGY AND DESIGN

## 3.1 Chapter Introduction

The research methodology provides the overall strategy to achieve the aims and objectives of a research project. This study includes both theoretical (secondary) and practical (primary) research. The theoretical development started with an extensive literature review based on secondary information from scientific sources and other reliable electronic and paper-based publications. The primary research focuses on a case study of a real-life project and consists of two main parts: information modelling and analysis, and a series of semi-structured interviews. The research has been conducted over a one-year period, which covered the whole life-cycle of the selected case study project. While the main source of primary data collection is the interviews with project key members, analysis of prepared files, observations and regular site visits were also conducted in parallel.

## 3.2 Justification

Regarding the research methodology, three major dimensions were considered: the underlying research philosophy, the idea or reasoning behind the research, and the actual data (Guba and Lincoln 1994; Fellows and Liu 1997; Sutrisna 2009).

Each of those three dimensions of research methodology can be viewed from two different perspectives, namely objectivism and constructivism. Sutrisna compiled the characteristics of each perspective to present two extremes of a "continuum" for research methodology. One extreme includes objectivistic philosophy, positivistic ideas, deductive reasoning and quantitative data. The other is based on constructivist philosophies, interpretive ideas, inductive reasoning and qualitative data (Table 3.1).

Table 3.1 Research methodology

| The "Continuum" | |
| --- | --- |
| Philosophy | Objectivism ------------- Constructivism |
| Idea | Positivism ------------- Interpretivism |
| Reasoning | Deductive ------------- Inductive |
| Data type | Quantitative ------------ Qualitative |

### 3.2.1 Research Continua and Data Levels

These two research continuum extremes differ in their approach to defining the research objective or purpose, sample selection, data collection and data analysis, as well as the desired outcome. The constructivist method of research is used to expand understanding of the underlying motives and reasons surrounding a topic. It also provides insights into the definition of a problem, generating ideas and/or hypotheses for later quantitative research, as well as uncovering common trends and current thinking on the topic area. In contrast, the objectivist method is useful when data from a population sample needs to be quantified and the results generalised, to measure the prevalence of different attitudes and opinions. It can often be followed by qualitative research that is used to further explore the findings.

Both qualitative and quantitative methods involve selecting an appropriate sample, but they differ in the number of cases. The qualitative method usually involves a smaller non-representative sample that is selected to fulfil a pre-defined quota, while the quantitative approach often uses a large number of randomly selected cases that represent the population of interest.

Data collection and data analysis are also different in these two methodologies. In the qualitative approach, data collection is generally unstructured or semi-structured through, for example, individual detailed interviews or group discussions, and the data is analysed without the use of statistical tests. Findings are descriptive in nature, and cannot be used to create generalisations about the population of interest. However, the data collection methods used by the quantitative approach are very structured, for instance online questionnaires or on-the-street or phone interviews. The analysis of data is quantitative and statistical, with data often presented in a tabulated format; findings through the quantitative approach are conclusive in nature.

Qualitative results are useful for developing an initial understanding and provide a solid foundation for additional decision-making, whereas quantitative results usually lead to recommendations for a final course of action. Sutrisna (2009) defined the qualitative approach thus:

> "Qualitative methods are focusing on the qualities of phenomena being investigated rather than their numeric measurement. Qualitative researchers believe that real-world phenomena need to be assessed from within the context of that reality, taking into account the subjective dimension of reality" (Sutrisna 2009, 55).

Qualitative research is based on the "*assumption that there is no singular objective reality and hence the observed reality will be related to the researchers' interaction with the phenomenon*" (Sutrisna 2009, 54). The qualitative approach is based on deductive reasoning and should start with a literature review of the current body of knowledge (Sutrisna 2009).

### 3.2.2 Research Questions

Research within the field of Construction Management often seeks to gain new understanding of the underlying reasons and motivations surrounding a topic. The qualitative method is preferred for studying new areas where there is not much available data, or only a small group of people with experience and knowledge in that regard. Through this method, it is possible to gather more in-depth knowledge through interviews with selected people than would be gained through a questionnaire. Using the qualitative method, the research action happens through gaining a proper understanding and insight of its context; therefore, in fields such as built environment, where the context of a project can often have a significant impact on the outcomes, this method is generally preferred. Moreover, the use of a case study strategy is a well-established approach in building science, which support a qualitative methodology. Research in a relatively new and evolving topic such as Building Information Modelling requires the study of actual samples in order to identify real issues among users.

There are a growing number of technologies and tools used within the construction industry that aim to enable collaboration between designers and builders. BIM, like many technological advances, brings both potential benefits and potential risks. Many questions emerge in this regard, such as how to measure success in implementation, why some firms choose not to implement BIM, how to ensure utilisation on smaller projects, how to increase the level of acceptance among users, or how to streamline BIM adoption. An in-depth case study of a carefully selected single project in the building industry could reveal some insight and develop both an initial understanding and sound base for further decision-making. This study, therefore, uses a qualitative case study to explore BIM implementation in SMEs.

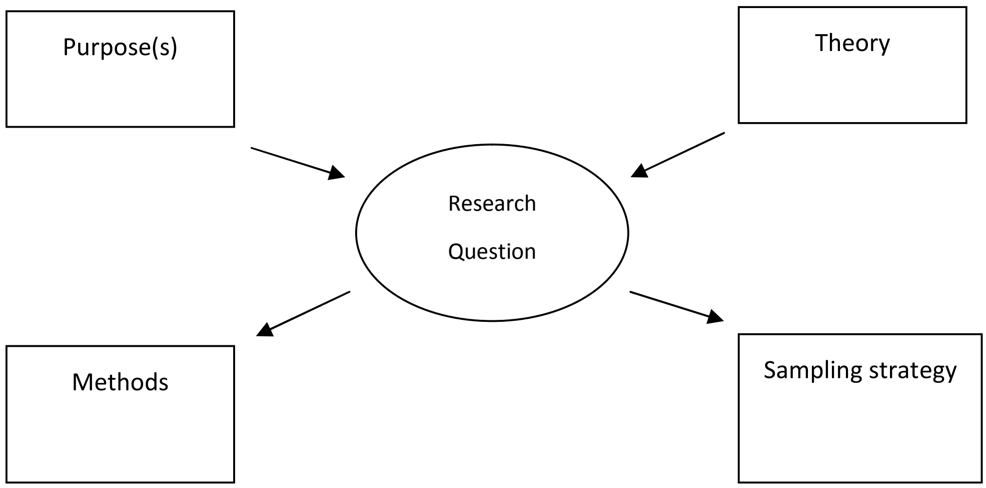



Figure 3.1 Robson's framework for research design (Robson 2004, 82).

Robson (2004) describes research methodology as a research design framework used to turn research questions into research projects. His framework considers five components: Purpose(s), Theory, Research Question(s), Methods and Sampling Strategy.

The modelled framework has directionality; the purpose and the theory feed into the research questions. The research questions then lead the process into the method and the strategy for sampling (Figure 3.1).

In this way, the research methodology is derived from the research questions. This framework is designed to be flexible and it is expected forall aspects will be reviewed and amended, if appropriate, during the research. This is in contrast to a fixed design that is "*tightly pre-specified*" (Robson 2004, 81).

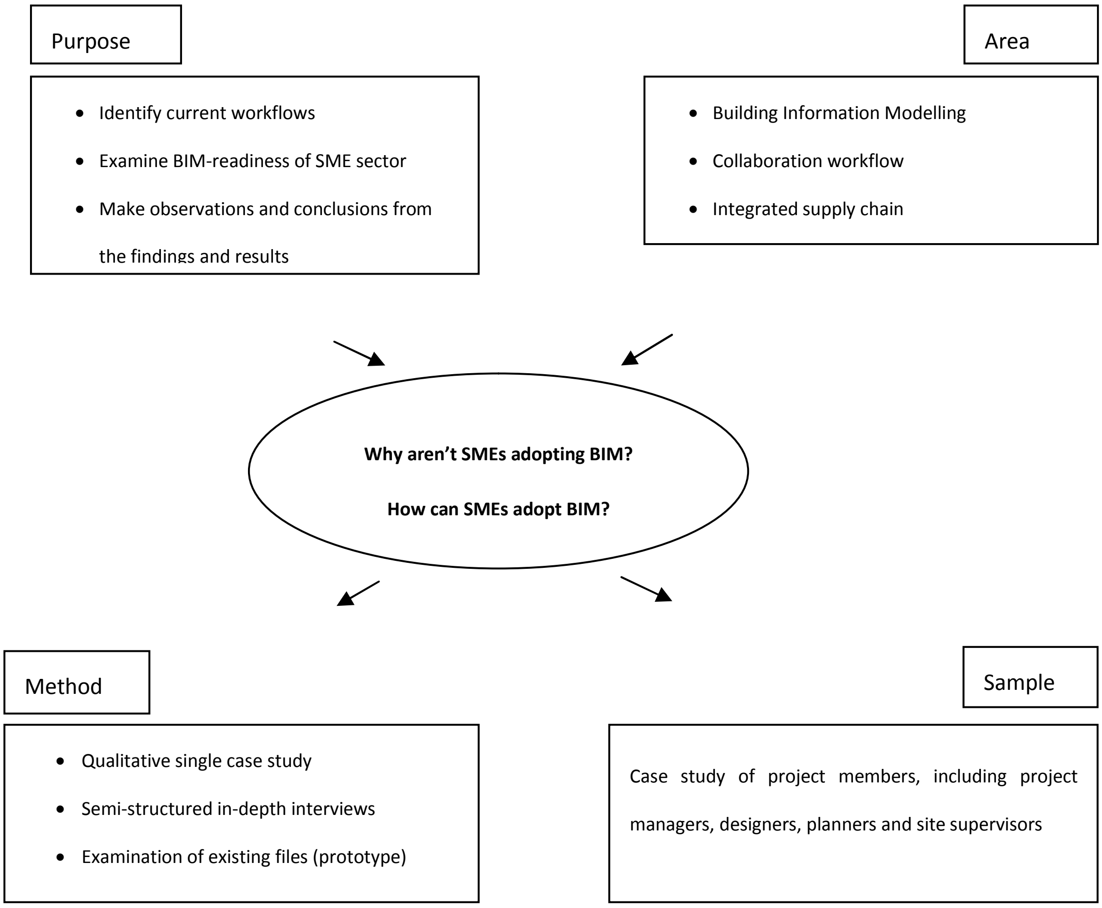



Figure 3.2 Specific research design process based on suggested framework by Robson (2004).

The purpose of this study is to suggest a workflow that will streamline BIM adoption for SME firms, reduce remodelling processes and achieve more integration between project phases, based on the theory of BIM and 4D BIM. Those two components feed into two research questions: "Why are SMEs not adopting BIM implementation?" and "How can SMEs adopt BIM?" (Figure 3.2).

## 3.3 Case Study

Selecting a case study was among five major strategies of research in social science, entailing the review of three conditions, according to Yin (2003, 4): *"(a) The type of research question posed, (b) the extent of control an investigator has over actual behavioural events, and (c) the degree of focus on contemporary as opposed to historical events*." Table 3.2 displays the above three conditions in relation to the five research strategies, which are: experiment, survey, archival analysis, history and case study.

A deeper exploration of the case study strategy defines its technical features and characteristics, including the scope of the case study. According to Yin (2003), a case study is an experimental investigation of a contemporary phenomenon in its actual context, particularly where the boundaries between the phenomenon and the context are blurred. Also, a case study investigation is capable of dealing with situations where there will be more variables of interest than data points. Case studies often rely on multiple evidence sources, with the data brought together using a triangulating method. As a result case studies will benefit from the development of theoretical propositions as a guide prior to data collection and analysis.

In some situations, more than one strategy could be used, or strategies could be equally attractive for the topic.

Table 3.2 indicates that there are three strategies suitable for addressing "How, Why?" type research questions, namely: Experiment, History and Case Study. In order to choose the most appropriate of these three, it is required to review them all.

Table 3.2 Relevant situation for different research strategies (Yin 2003, 6)

| **Strategy** | **Form of research question** | **Requires control over variables?** | **Focuses on contemporary events?** |
|---|---|---|---|
| | | | |
| **Experiment** | How, why? | Yes | Yes |
| **Survey** | Who, what, where, how many, how much? | No | Yes |
| **Archival analysis** | Who, what, where, how many, how much? | No | Yes/No |
| **History** | How, why? | No | No |
| **Case study** | How, why? | No | Yes |

This study aimed to propose new ways of working that require identification of current/traditional workflow and process within a "real" industry context, rather than a controlled environment; therefore, experiment and history strategies were not preferred in its methodology. Instead, the case study strategy presented a distinct advantage (in comparison to the other strategies) when the "how" or "why" questions were asked about an existing set of events over which the research has very limited control (Yin 2003).

The case study approach is more justifiable when the contextual conditions of the phenomenon are important, and when controlled laboratory conditions or selection of particular samples are not necessary variable. In addition, in real-life research, a case study and the context are not always distinguishable; therefore, data collection and data analysis of a case study are incorporated into the approach and do not form a design feature or tactic.

Investigation of BIM adoption by SMEs requires consideration within a real-life context to clarify reasons for lack of SME involvement. Theory suggests that BIM can provide benefits to any type of project, regardless of the size of the project. However, practice has demonstrated that uptake among SMEs is considerably lower than within other sectors of industry (McGraw Hill 2014). In order to understand the differences between theory and practice, the problem needs to be studied alongside its context.

Yin (2003) categorised four types of case study design (Figure 3.3), as follows:

1. single-case (holistic) designs,
2. single-case (embedded) designs,

3. multiple-case (holistic) designs, and
4. multiple-case (embedded) designs.

| | **Single-case deign** | **Multiple-case design** |
|---|---|---|
| **Holistic (single units of analysis)** | **Type 1** | **Type 3** |
| **Embedded (multiple units of analysis)** | **Type 2** | **Type 4** |

Figure 3.3 Basic types of case study design

The primary decision when designing case studies is choosing whether to conduct a single or a multiple case.

The holistic or single-case study is commonly used and is justifiable with the following conditions (Yin, 2003):

1. Where the case meets all conditions to test a well-formulated theory.
2. Where case exemplifies an extreme or unique case.
3. When the case reveals something that was previously unknown.

These three justifications serve as the major drivers for conducting a single-case study. This study focused on BIM adoption within the SME construction sector to find out why the SME firms generally are not adopting BIM and how they can implement BIM more easily, so the BIM-enabled theories (in comparison to the traditional design-build method) could be considered through a typical SME firm, ideally handling both construction and design. A single-case design is of particular value when the aim is to deliver an in-depth record and to explore the phenomenon as closely as possible. Therefore, selecting a single case study that allows a thorough investigation of the stages, from planning through to completion, is an ideal context in which to explore “BIM readiness”. A single case study, in comparison to multiple case studies, will provide a deeper understanding of the phenomenon than "thin" descriptions of more cases.

It should be noted that there are other circumstances where a single-case study might be conducted as a precursor to additional study, for example a case study might be used as a fact-finding device or conducted as a pilot case (Yin 2003, 41). Despite the number of firms that are using new software, reports show that BIM adoption is rare among those firms; therefore, BIM implementation within a domestic project can be used as a case and also as preliminary preparation for later project involvements.

As shown in Yin’s matrix above, two categories of single-case study have been described: all-inclusive, or holistic case studies, and cases which use embedded entities, where the same case study may involve the analysis of more than one entity. For example, where a case study may be about a single public program, the analysis might include results from several distinct projects within that program. In contrast, if the case study looked at the overall nature of a program, or an organisation, it would have used an holistic design (Yin 2003, 41-42). The technically distinct situation of BIM implementation within domestic SMEs requires a holistic case study of the whole life-cycle from design through to completion. Additionally, an appropriate case for this research is required to be both domestic and in the SME category, with participants at the same level of experience and having an overview of all disciplines; that cannot be found through questionnaires or telephone interviews.

Robson (2004), reinforcing Yin's design selection, describes the case study as a flexible (qualitative) research method and defines it as "*Development of detailed, intensive knowledge about a single 'case', or of a small number of related 'cases'.*" He describes this method of research as follows (Robson, 2002):

- Selection and development of an in-depth analysis of a single case (or small number of associated cases) of a set of circumstances, an individual, or a group of interest;
- Examination of the case within its context;
- Gathering of information (data) through a variety of data collection methods (multiple sources) including archival records, observations, interviews, documentary analyses and physical artefacts;
- Data analysis through description, themes and assertion; and
- Narrative form, i.e. in-depth study of a 'case' or 'cases'.

In investigating complex situations, such as construction projects, it has been demonstrated that a qualitative case study approach is a reliable method to capture the rich information required for the purpose of the study, including the project's characteristics, and provision of authentic project data. In addition, a case study method is most suitable for the study of business benefits of emerging technologies such as BIM adoption, when compared to formal experiments and surveys (Barlish and Sullivan 2012). In Flyvbjerg's (2006), article "Five misunderstandings about case study" the following was stated in regard to the single case study approach:

> *"One can often generalize on the basis of a single case, and the case study may be central to scientific development via generalization as*

*supplement or alternative to other methods. But formal generalization is overvalued as a source of scientific development, whereas 'the force of example' is underestimated"* (Flyvbjerg 2006, 12).

A single-case study design has been used in a number of construction-related research projects. For example, Love et al. (2015) designed a single-case study methodology for a study of the system information model (SIM) that is akin to BIM for managing electrical, control and instrumentation assets, and examined recent international efforts to standardise methods of data collection for meeting the objectives of owners. Yin (2003, 9) states that "*the single case can then be used to determine whether a theory's propositions are correct or whether some alternative set of explanations might be more relevant*." While the most often-cited limitation of the single-case study method is the difficulty of generalising findings to different settings, Yin (2003, 36-47) states that while "*the single case can represent a significant contribution to knowledge and theory-building such a study can even help to refocus future investigations in an entire field*".

## 3.4 Data Collection

The data collection method should be appropriate for the overall research methodology and the research question that the study seeks to answer. Interview and observation are multiple data collection methods commonly used within the case study approach. The interview, as a qualitative data collection methodology, has three different types, which are fully structured interviews, semi-structured interviews and unstructured interviews, and each is connected to some extent to the depth of response sought.

Fully structured interviews have "*predetermined questions with fixed wording, usually in pre-set order*" (Robson 2002, 270), whereas a semi-structured interview "*has predetermined questions, but the order can be modified based upon the interviewer's perception of what seems most appropriate. Questions' wording can be change and explanations given; particular questions which seem inappropriate with a particular interviewee can be omitted, or additional ones included*" (Robson 2002, 270) and an unstructured interview has "*a general area of interest and concern, but lets the conversation develop within this area*" (Robson 2002, 270).

The semi-structured interview is widely used in flexible, qualitative designs as the sole data collection method, or in combination with others. In this method the interviewer has a list of topics, but has the freedom to choose the order of the questions, or maker adjustments to the wording, time and attention given to each subject. The interview plan is expected to include the following:

- Introductory comments (probably a verbatim script);
- List of topic headings and possible key questions to ask under these headings;
- Set of associated prompts;
- Closing comments.

The Interview method can help to get answers to research questions quickly by asking people directly, but it is a time-consuming method that requires time-planning and time-budgeting skills in order to be successful.

## 3.5 Triangulation Method

Within an in-depth case study it is often common to utilise more than one method of data collection, referred to as a mixed research method, or defined as the triangulation methodology. The term triangulation refers to using multiple ways to collect, analyse and interpret the various aspects of a research topic to enhance understanding of it. In contrast to a single data collection method, which may not adequately shed light on a phenomenon, triangulation provides a deeper understanding, which is desirable in a single case study.

One advantage of using triangulation as a methodology is that this approach can facilitate the integration of research findings. It also helps researchers to clarify their theoretical and practical findings and the basis of their results. In addition, this method can offer improved understanding of the connections between theory and practical findings, allowing theoretical assumptions to be challenged and in turn facilitate the development of new theories.

BIM adoption by an SME, as the chosen case, invokes its own required methods that can be considered through the triangulation method. In this study, triangulation is achievable through in-depth semi-structured interviews, in combination with the observation of different project's workflows and documentary sources of 4D modelling (Figure 3.4). The major advantage of observation is its directness, specifically in an informal observation approach. "*Informal approaches are less structured and allow the observer considerable freedom in what information is gathered and how it is recorded. It would include note-taking and generally gathering information from (an) informant*" (Robson 2002, 313).

This method allows this research to look at the issue of the implementation of BIM by SMEs from various angles.

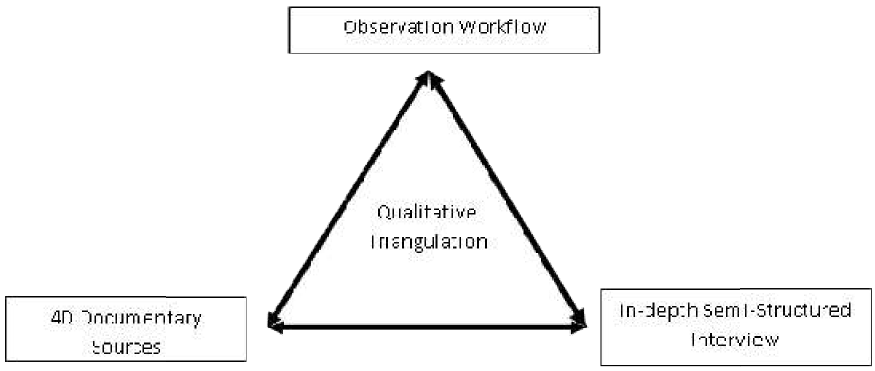



Figure 3.4 Triangulation methodology for research data collection and analysis

## 3.6 Detailed Research Design

Research design is a process that connects the experimental data to the research's initial question, then logically to the research findings and finally to the research conclusions. Fundamentally, the research design defines a path that shows the methods taken to find answers to the research questions, which includes different steps of collection and analysis of relevant data (Yin 2003).

The research design illustrated in Figure 3.5 presents the aims and objectives of this research and the detailed design of the path to achieve each objective.

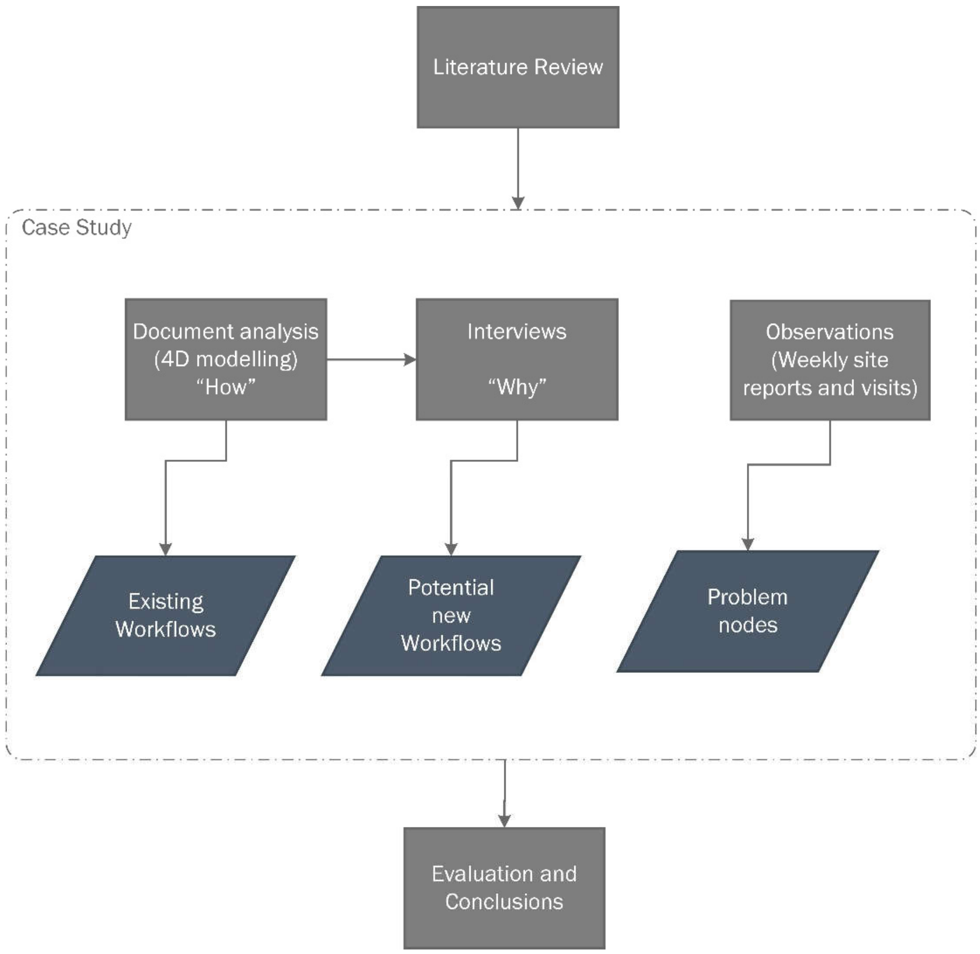



Figure 3.5 Case study design

The research process starts with a literature review of existing methods for BIM implementation and existing practices within the building industry that are specifically applicable to SME-scale projects. This is followed by an in-depth examination of a selected case study project. The project files, including a 4D model, were analysed to establish the current context and to identify existing workflows. Key project team members were selected and interviewed to yield a deeper understanding of existing workflows in order to develop a proposal for future BIM-enabled workflows. The findings have led to a new workflow for BIM implementation in SMEs that could reduce digital rework and help to implement a collaborative and efficient delivery method. Finally, the proposed workflow was evaluated through observation and comparison.

### 3.6.1 Case Study Design

The selected construction company (the 'firm') is an SME with approximately 60 employees. Their primary sector is domestic construction and the Design-Build method is their de facto project delivery method. As the literature shows, this project delivery method has the required potential to engender collaboration with BIM.

The firm was already using the latest version of Autodesk Revit® for the development of construction drawings, as well as Microsoft Project® for time management and project control; this ensured that the firm was ready to move towards a collaborative BIM-enabled implementation and, therefore, benefit from this research.

In order to have the maximum impact, a case study with "standard" local details for residential construction, including brick walls and sloping roof, was selected. This ensured that the results of the study would be applicable to the majority of new build residential units in Western Australia. The case study project is an eight-unit multi-residential complex located in Doubleview, northwest of Perth in Western Australia. It is designed as two blocks, each containing four units built over two storeys, with an overall area of 1,800 square metres. The construction cost is approximately $2,000,000. (See appendix A for the drawings.) This project size falls within the small to medium range for residential development in Perth and allows the study of BIM implementation on an SME residential scale with the involvement of both the design and operation teams using a Design-Build delivery method.

The firm coordinates all of the work and hires subcontractors for different parts of the project. The project duration, from concept to practical completion is approximately 16 months, with the construction phase lasting for approximately 10 months.

### 3.6.2 4D Modelling

The success of a project delivered through the Design-Build method is often measured through timely completion. Residential developments, such as these units, are often pre-sold and therefore need to be completed within the planned timeframe to hand over to the client in order to avoid significant financial penalties. Therefore, the monitoring and meeting of construction milestones is crucial to project success. While both a design Revit model and a Microsoft Project construction program were developed for the project, these were separate and sequential tasks with little collaboration between the design and construction teams. In order to examine how to improve the existing process and move towards a collaborative BIM environment, a 4D model of the case study project was developed and analysed by the researcher. This included examining existing "silo" information in order to integrate this into a

4D model with shared discipline knowledge. This modelling process highlighted bottlenecks, inefficiencies and problem areas for potential collaborative workflows.

To prepare the 4D model, the existing Autodesk Revit® 2015 model, developed by the designers, was used in addition to the time schedule, produced in Microsoft Project® 2010 by the planner. The 4D model was implemented using Autodesk Navisworks Manage® 2015 (Figure 3.6).

Throughout the 4D modelling process, interoperability issues were analysed, particularly between the two disciplines. These results highlighted the requirements within an SME context for collaborative BIM implementation. The 4D modelling process involved the following steps:

- Export Revit model into a format that Navisworks can import
- Export the Project program into a format that Navisworks can import
- Link design elements to the construction tasks with Navisworks
- Identify and analyse any problem areas

Examination of this process was used to clarify the level of detail and the adopted work breakdown structure that each discipline currently uses for their models and programs, as well as to assess their level of readiness for BIM implementation.

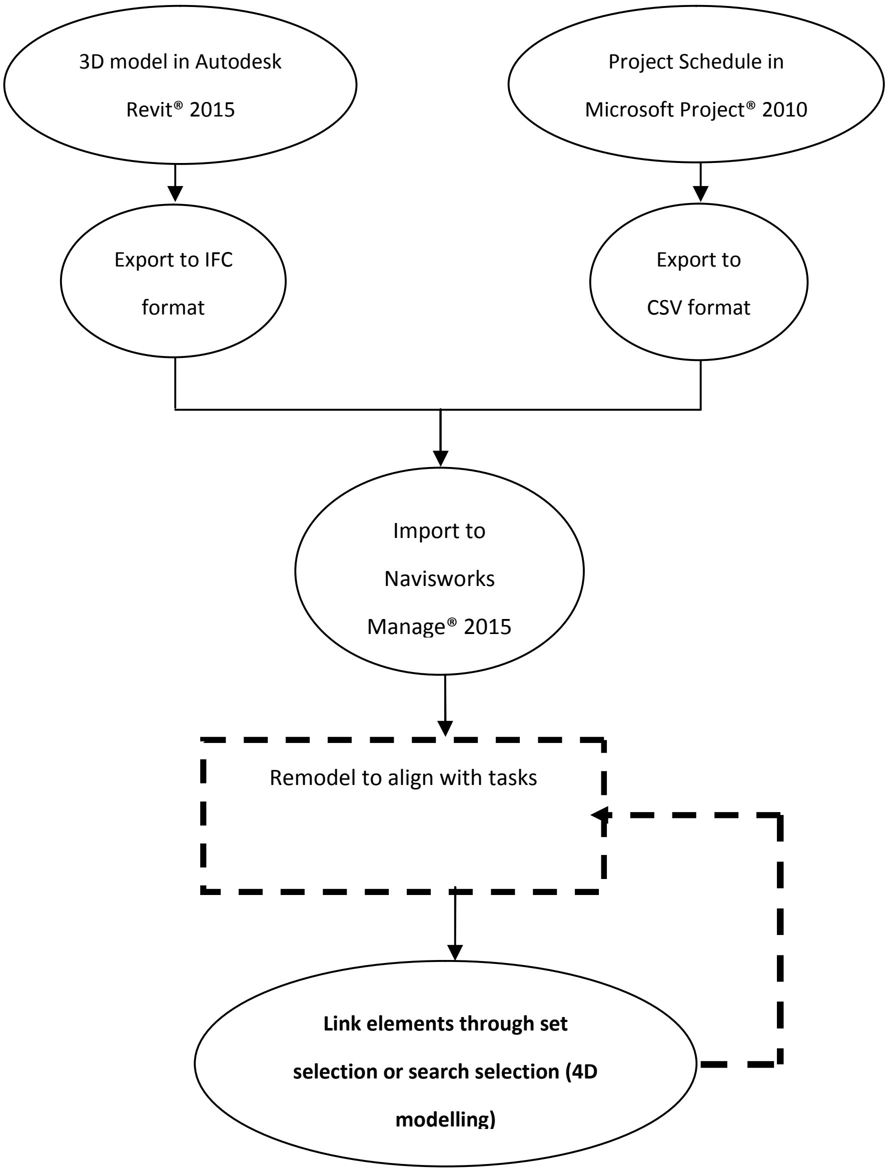



Figure 3.6 The 4D modelling process based on 3D model and project schedule

Figure 3.6 illustrates the 4D modelling process. It is a common misconception that 4D modelling is simply the pushing of a button. Changes and revisions are an inseparable part of construction projects. To accommodate the inevitable changes throughout a project life-cycle, both the model and the program will need to be updated and revised. The developed 4D modelling process sought to minimise the impact of this change and reduce the need for resulting digital rework on the 4D model. In all projects, the purpose is to minimise change and maximise predictability prior to commencement of the project on site, and one of the simulation's benefits is identifying conflicts before actual construction. In order to have a practical 4D model, it is necessary to keep the model updated to reflect the project's actual process and site information. Therefore, all updates need to be modelled immediately.

### 3.6.3 Interviews

In this research the participants were selected from each of the case study project's core disciplines including managers, designers and construction team members, with the aim of identify existing limitations and opportunities for BIM implementation. The interview duration was planned to be approximately 40 minutes, but the actual duration was dependent upon the participant's area of knowledge and interest. Each interviewee was given the topic areas prior to the interview, and all interviews were recorded and transcribed verbatim to facilitate detailed and systematic analysis.

The Interview questions were designed to collect an SME perspective on future BIM adoption and to assess the potential for implementation of collaborative BIM within the firm. The participant's role in the case study project and his/her background was recorded in order to analyse any differences between discipline views on BIM implementation. Each participant was also asked to define the existing project process or life-cycle and any possible changes that might improve the current workflow.

The interview questions were designed to align with each of the research objectives. The initial section of the interview focused on the interactions between the design and construction disciplines and examined opinions about any areas where collaboration could be improved.

Towards the end of the interview, the prepared 4D model of the case study project was presented to the participants in order to stimulate and collect their ideas on how 4D models may be used for future projects. The use of the 4D model also facilitated discussion around existing workflows and processes from each individual participant's perspective.

Finally the audio recordings of the interviews were transcribed in preparation for the qualitative data analyses. All interviews were initially read from start to finish. They were then subsequently revisited to identify emerging themes and patterns. The transcripts were organised around these themes using Microsoft Word, and, where appropriate, were further coded with sub-themes.

### 3.6.4 Observation

During the construction phase of the selected case study, observation of project progress, with particular attention on problems arising which impacted schedule, were conducted through regular weekly site reports and site visits.

## 3.7 Evaluation and Conclusion

Results from the literature review, 4D modelling and observation, and the semi-structured interviews were triangulated in order to answer the following research questions:

1. *Why aren't SMEs adopting BIM?*

   Building on the results of the literature review, which indicated some resistance to BIM adoption within the SME sector, the interviews with selected participants were analysed through identification of "themes" in order to identify any perceived barriers to adoption and to what extent project members are prepared and willing to start using BIM to assist their projects (Identify existing situation). In addition, the examination of existing documents and the construction of a 4D model helped to identify the level of readiness of the project parties to move towards an integrated and collaborative implementation of BIM.

2. *How can SMEs adopt BIM?*

The results of the literature review indicated that, while much attention was focused on BIM implementation, most of the efforts to date have been directed towards supporting large-scale project implementation. Using this knowledge, the examination of existing documentation and the process of creating a 4D model helped to identify existing problem nodes for small-scale implementation. The results were utilized in the design and development of a new workflow to improve current processes and to reduce remodelling through BIM implementation.

## 3.8 Chapter Summary

In this chapter, the research methodology and design have been described and justified based on the research objectives. In that regard, the case study approach that was selected from among five major strategies was justified. In addition, the semi-structured in-depth interview was selected as a data collection method to cover the greater area of analysis required by the research objectives. Also, the triangulation strategy was selected and discussed, which comprised of in-depth, semi-structured interview, 4D documentary sources and observation of existing workflows. The findings derived from this research methodology and design are described in the following chapters. Finally, the results will be discussed in Chapter 6 and conclusions drawn in Chapter 7.

# CHAPTER 4: DATA COLLECTION - INTERVIEW

## 4.1 Chapter Introduction

Although the number of firms adopting BIM is growing, implementation isn't a common or easy process. Recent research suggests that new changes in work practices and business processes are a necessary accompaniment to BIM implementation; however, there is still limited knowledge on the appropriate type of change required by any firm, as a whole, and an acknowledgement that these changes may vary among different firms.

## 4.2 Interview

The focus of this chapter, as shown in the research processes diagram (Figure 3.5), is on the two objectives of: (1) Identification of the existing context for future BIM implementation; and (2) Identification of existing workflows, in order to finally propose fit-for-purpose guidelines for implementation of a 4D BIM suitable for SMEs undertaking predominately residential construction. With that in mind, an SME-scale design and construction firm based in Western Australia was identified as a suitable candidate for the case study. This firm has approximately 30 employees with a main focus on residential construction projects. Table 4.1 shows interview questions and the area of research objectives that each question covers.

Table 4.1 Interview questions and the area of research objectives

| | **Interview Questions** | **Area of research objectives** |
|---|---|---|
| **1** | Could you please tell me about your experience in the construction Industry? | Identify Existing context |
| **2** | Could you describe in detail, the information sharing processes between disciplines on a standard project? (Project life-cycle workflow) | Identify existing workflow |
| **3** | Could you explain the different file formats that project parties use to share information? | Identify existing workflow |
| **5** | Do you think current process might be improved and if so how? | Identify existing workflow /Develop new framework |
| **4** | When is the perfect time for the project programmer to get involved in the process? | Develop new framework |
| **6** | Have you ever heard about Building Information Modelling? What you have heard about it? | Identify existing context |
| **7** | What is your expectation from the project schedule? | Develop new framework |
| **8** | How could the visual simulation of a construction sequence be useful? | Identify existing context /Develop new framework |
| **9** | In what stage 4D model might be developed? | Develop new framework |

All projects' designs are prepared using the Autodesk Revit authoring platform, from initial concept to detailed design. In addition, this firm uses Microsoft Project as a time management tool. Although it is not currently using 4D BIM, it has the potential for its future adoption. The project delivery method for the majority of projects in the selected firm is Design-Build and, according to their capacity, there is a requirement to outsource some design works that makes the BIM collaboration method more applicable.

To achieve a deeper understanding of BIM adoption by SMEs and to find the answers to this research question of "Why aren't SEMs adopting BIM?" it is required to gather the team's ideas and thinking related to BIM adoption. Therefore, the research methodology of the interview was deemed to be most appropriate for discovering the existing attitudes and contexts of BIM in the selected firm.

To explore the points of view, experiences, ideas and motivations of individuals in a particular area, interviewees were selected from core functional roles within the case study, such as managers, designers and construction team members, to identify existing limitations and opportunities for BIM implementation. Interview questions were designed to cover the current potential for implementation of BIM and also to collect ideas of SME people in relation to future BIM involvement.

In this regard, participants' areas of work and their backgrounds were questioned in order to find the views of different project parties about BIM implementation. The project process, or life-cycle, has been defined by participants and they also have been asked about desired processes and any possible changes that may improve the current processes.

The connection point between design and construction was focused upon by framing interview questions to discover participants' thinking about the missing links in the whole process. By the same token, the planner's role in the project life-cycle, along with the question regarding the perfect time for the project programmer to get involved in the process was raised as another topic. The BIM awareness levels of the participants were assessed, as well as their probable experiences with BIM projects beforehand.

Current information sharing methods and their satisfaction levels with the application of existing file formats were discussed, as well as current issues or problems, as a precursor to whether BIM implementation would be able to resolve any of the named issues. Finally, a prepared 4D model of an existing project was presented to all participants in order to collect their ideas about using a 4D model for projects in the future. Their suggestions for a suitable time to start 4D model development for use in the future projects also were canvassed. Table 4.2 shows the semi-structured interview questions. In total, 13 interviews comprising design team members (n=3), the operational manager (n=1), project managers (n=2), site supervisors (n=2), the construction planner (n=1), directors/owners (n=2), the town planner (n=1) and the procurement officer (n=1) were undertaken.

Table 4.2 Interview questions

| | **Interview Questions** |
|---|---|
| **1** | Could you please tell me about your experience in the construction industry? |
| **2** | Could you describe, in detail, the information-sharing processes among disciplines on a standard project? (Project life–cycle/workflow) |
| **3** | Could you explain the different file formats that project parties use to share information? |
| **4** | Do you think current processes might be improved and, if so, how? |
| **5** | When is the perfect time for the project programmer to get involved in the process? |
| **6** | Have you ever heard about Building Information Modelling? What you have heard about it? |
| **7** | What is your expectation from the project schedule? |
| **8** | How could the visual simulation of a construction sequence be useful? |
| **9** | In what stage might a 4D model be developed? |

## 4.2.1 BIM Awareness Level and Experience

The literature review highlighted a lack of BIM awareness as one of the barriers to BIM adoption. The participant's role on the case study project and their background was audio recorded in order to analyse any differences between discipline views on

BIM implementation, following table shows more details about interviewees (Table 4.3).

Table 4.3 Interview details

| Interviewee | Function | Years of experience | Area of work |
|---|---|---|---|
| 1 | Project Manager | 43 | Construction/Estimation |
| 2 | Design Manager | 10 | Design |
| 3 | Architect | 6 | Design |
| 4 | Owner/ Director | 18 | Management/ Construction |
| 5 | Planner | 10 | Programming/Construction |
| 6 | Site supervisor | 3 | Construction |
| 7 | Project manager | 18 | Construction |
| 8 | Operational Manager | 23 | Construction |
| 9 | Town Planner | 16 | Design/Planning |
| 10 | Design Manager | 15 | Design |
| 11 | Site supervisor | 34 | Construction |
| 12 | Procurement Officer | 5 | Procurement/ Estimation |
| 13 | Owner/ Director | 16 | Management/ Construction |

During the interviews, the participants were asked a direct question: "Have you ever heard about BIM?" In response, more than half replied, "No", despite all projects within the firm being executed with BIM-friendly software.

Although participants were selected from different stages of a construction life-cycle, (i.e. feasibility stage, design stage, construction stage) it is worth noting that there were varying levels of awareness of BIM among the different teams. To address this, three different levels of awareness were defined (Figure 4.1):

- Aware
- Somewhat aware
- Not at all aware

| **Discipline** | Design | Owner/Manager | Construction and procurement |
|---|---|---|---|
| **BIM Awareness Level** | Aware | Somewhat aware | Not at all aware |

Figure 4.1 Levels of awareness

"Aware" includes the people who have knowledge or previous experience of BIM and are ready to become more involved with BIM. The "Somewhat aware" are people who have a good concept and understanding of BIM but no experience or practical skills. The last group is "Not at all aware" who have not even heard about it.

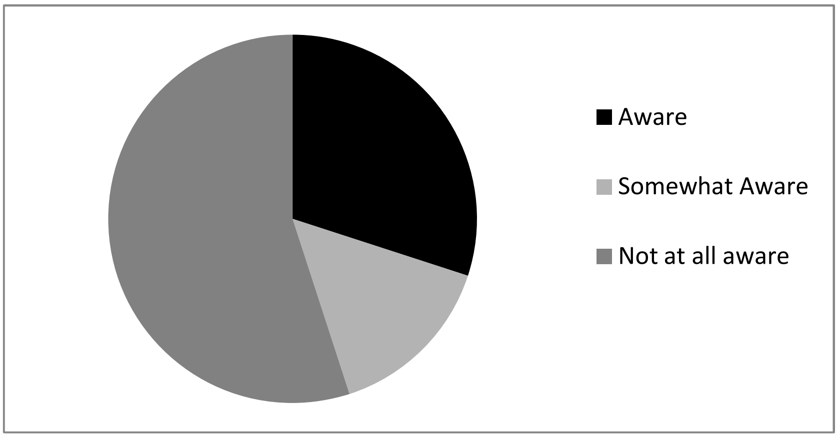



Figure 4.2 ‘Awareness of BIM’ among SME participants

The levels of awareness among respondents of this research were: more than a quarter were "aware", less than one quarter were "somewhat aware” and over half of the participants were “not at all aware" (Figure 4.2). The awareness level was highest among the design team and was lower among directors and the construction team.

The understanding of BIM as a concept was relatively well-developed within the design team. The majority of respondents involved in design were familiar with the fundamentals of BIM utility, i.e. integration, 3D models and collaboration. For instance, a designer stated:

> “… as far as I know, that’s, sort of… Revit’s the beginning of it and moving forward. It’s also included in, like, take offs of materials and quantities, stuff like that. And also integration of other disciplines into the same model.”

One designer explained BIM as an “intelligent model” and stated:

> “I’ve probably worked on a couple of projects in some way that do it. The way I’ve heard it works is you build an intelligent model, which has accurate information as part of it, and then the engineer or the builder uses

> that … takes that information, and you share it with them and that helps [make] their process quicker so they can do their calculations directly off their 3D model; they don't have to make their own 3D model, which saves time. You don't have to draw the structure; they draw the structure. And then you put it in your model, which saves time."

The participants from the design team had a more detailed idea of the potential for collaboration among disciplines, particularly its adoption by subcontractors. In this regard, one of the designers stated:

> "… and the big saving is at the end when it comes to all the sub-contractors and they can do their measurements very accurately so they know exactly how many cubic meters of concrete and all the rest. And then we also got to the point where we were looking at doing shop drawings for window fabricators - sending it straight to their CNC machines. We started to do that a little bit in M [Company]. We started doing the shop drawings for the metal … the cold metal stud maker. We were doing that in-house … and that was working in together with the Revit model."

While the design team were very aware of the benefits of collaboration across disciplines, they also described difficulties associated with collaborative work. An architect with some BIM work experience stated:

> "… The architecture side of things could be doing it but none of their engineers have it, so they can't use it. So then you're, sort of, limited to using engineers that do the BIM as well. So I think it will be a long time

> before it's across the whole industry and everybody knows what's going on and is doing the same thing."

In addition to collaboration across disciplines, concerns were raised about interoperability across software platforms:

> "I suppose the biggest problem would be whether everyone is using compatible software to be able to do it."

Those who had experience of BIM were also aware that processes needed to change in order to support collaboration across disciplines. This becomes even more complicated if not all team members are using compatible software.

> "… (Working on central model) changes would be updated and the next time somebody else saved they would pick up the changes you had made. But with consultants and things they obviously don't pick up those changes automatically, so it would be a matter [of] would you have to re-link files on a daily basis? Or do you wait? [Or] do it once a week and just notify them of all the changes that have been made so that they're aware of it?"

In general, the design team, due to their experiences of working with Revit, were more aware of potential obstacles in comparison to other groups. For example, a participant from the design team stated:

> "…the main one [issue] would be not everyone using the same software as each other and people … everyone uses it so differently to the next person. I use it very differently to how B does, so when you've got bigger groups

> of people using it then there's more changes and more, I suppose, differences in how things are done."

The directors' commitment to BIM is a key factor for BIM implementation because they make the final decisions to adopt and support the team appropriately. There was some awareness of the potential of BIM from the directors within the firm, although this was limited when compared to the design team.

> "I wasn't happy with our levels of wastage and procurement and so I revisited how the guys were going about doing that and then I thought, 'Well, surely [when] we're doing 3D models of this building there must be an easy way to rip off quantities'…. I find it amazing that in this day and age, with the software that's there and what-not, that we have a business where we draw things down to the millimetre and then my estimators and my schedulers and my procurement guys go through and use a ruler to take off what the quantities are. I find that absurd."

There were some concerns about the benefits of BIM, as their experience of cost and procurement management using Revit had been unsuccessful.

> "If you've got a process that seems to be working and that's relatively efficient, you don't know how efficient it is in comparison until you've actually seen the comparison or understand the comparison."

While this director was not happy with the initial attempt at using Revit, he still believed that there was potential for BIM to reduce the level of waste and to improve the level of estimation accuracy.

> "I'm sure that if we got the right people looking at things we'd be able to save considerable costs in terms of whether it's material or labour hours or anything like that. I do find it frustrating that the people that are doing that don't realise … I'm pretty sure that people don't understand the power of what they're ignoring."

This realisation of the potential benefits of BIM was reinforced by another director within the firm who, despite having little exposure to BIM, still saw some potential benefits.

> "I've heard about it. I'm not very familiar with it. My understanding is that it is more about having all of your, effectively, take offs managed and really understanding all of your components of the project. So, being able to build ... ultimately, being able to build the entire project with all of your materials as well. So having, you know, the output of that being a lot of your take offs, which are used for budgeting and trade estimates and material estimates and, ... but I don't know a lot more about it than that."

It is clear from these quotes, that the directors' definitions of BIM were focused on cost modelling and using the Revit model for procurement take offs. Even though, their previous experiences of extending the use of the 3D model to disciplines other than design had been unsuccessful, they could still see the benefit of doing so.

The younger generation working on the construction side also had a good concept of BIM potentials, and one of them described it as, *"...from an estimating point of view and even from a project management point of view whereby you would analyse the* *constructability of a project"* through BIM; that shows an excellent perspective of BIM adoption in future projects.

However, the least awareness of BIM was recorded within the construction team, with the majority having never heard of it. Despite a lack of exposure, those that did have an awareness of it had a wider view of BIM. One site supervisor responded:

> "... yes, I have heard of it…. I guess it's… allowing a contractor to view a project, instead of in 2D plans, but in 3D drawings, in multiple different views which can incorporate… or include time in the analysis of the actual building plans and durations of the tasks. … I guess you can involve costs in it as well."

When asked what BIM could offer future projects in particular, a participant from procurement stated:

> "I guess it provides a platform to analyse a lot of the areas involved in construction, ranging from costs, duration, 3D models and walk-through examples, or something like that. Just to give the client a better understanding as to what exactly they will be getting and [it] allows the contractor to see issues that might arise during the construction."

The results in respect of BIM awareness reinforce those reported by McGraw Hill (2014). They indicate that the level of BIM application during residential construction in Perth (WA) is still very low.

Overall, increasing the level of awareness could be a helpful factor to make BIM popular among SME firms. Also, BIM knowledge at the level of owners and management will increase the chance of BIM implementation and BIM training in SME firms.

### 4.2.2 Current Workflow and Standard Processes

The second interview question focused on the participants' experiences and explanations of the standard processes of sharing information among disciplines in order to clarify the existing workflow in a design-build firm.

Of all the respondents, those involved in project management had a more comprehensive view of existing workflow. The first project manager described the workflow for their "standard" design-build project:

> "… the project comes through at [the] design stage, so, a client comes in with a brief; we go through the design process. During that stage the construction people should be involved and also the estimator on [the] commercial side. So, they put input into the buildability issues, that sort of thing; looking at the site. We then bring in the consultants, and the consultants should only be brought in once we've made up our own minds how we're going to build it."

The next step, as the participant explained, would be regular meetings with consultants and safety officers while the project design is progressing. Although scheduled, these regular meetings do not always happen. However when *"…each part of the process plan is developed, it needs to be signed off and [we] make sure everyone's comfortable with it*", which may happen through individual confirmation rather than a group meeting.

Before submission of the building permit application to the related authority, the client's confirmation of the final design is required. At this stage, the project is handed over from design to construction through a meeting *"and at that point, the design people should tell construction everything that they think is an issue"*.

Many of these issues are not formally documented, and are typically communicated through less formal channels, to be managed either in pre-construction or on-site.

> "So, there'll be things that they're [design team] aware of that aren't necessarily on their documents that they need to [be made aware of]. So, they then give all of that information to construction. Construction, through the office, through the commercial side, will then relay to the site any of those sorts of issues and, then, the only relationship between site and office, at that point, is to do with the actual process of the work, which is planning. So, the office monitors the progress on site through the plan."

The described process is illustrated in the Figure 4.3; importantly, the project life-cycle or process does not finish at the construction stage. Feedback from the construction process is gathered through "post-mortem" meetings. The main areas of review during these meeting relate to:

> "I'd like to see some communication back from the sites to the design people to say that there [are] things that are not done all that well. So, that's where we get our lessons learnt: at the end of the project. But, ideally, we do that as we go through. Once we get to the end there should be a post-mortem where the estimator is advised of any cost overruns that he wasn't aware of. The design guys are advised of any design faults that

> they didn't like and the site staffs are advised where they've blown budgets based on what they've done to get things done."

The above process has been converted into a flow diagram to identify the existing workflow process of the firm for design-built projects and is shown in Figure 4.4. This will form the basis for the suggested workflow for BIM implementation in subsequent sections.

While the overview of the project workflow was provided by the project manager, supplementary information was described by other team members.

The standard workflow, from the perspective of a design manager, reinforced the process described by the project managers; however, more detail, particularly around the earlier stages of a project, including mechanisms for sharing information, were provided:

> "We'll set up, like, a central model so that multiple people can work on the model within the office, [as] we have with one of our engineers. Previously the engineers didn't use the same software as us so the information sharing was not as easy. We'd basically give them CAD files or basically print-outs and they'd give us DWGs back, which doesn't integrate into Revit well; it does, but not very well. We've got one [engineering company] that we've used in a few jobs now that also uses Revit, so we're able to give them the model."

An interviewee from the design team described their involvement in pre-construction as:

> "… once they're [the clients] happy with the concepts, we do a planning application… after the planning application is approved we then go to do, ah, building license or construction documents… Normally, once I've done the building license and construction drawings, then that's pretty much the last I deal with the project, except for the odd problems."

An interviewee from the construction side provided detail of the same process from that perspective as:

> "A normal project, say, an eight-unit project, starts with the planning, through the design and collaboration with the design[er], to make sure we can actually build what they're designing. From there, really we have to start looking at some of the regulatory bodies, so, your Water Corps, your power, your councils and what their requirements are."

These regulatory considerations and feasibility studies are vital to identify potential site issues, and the results need to be input into the construction program. Also, this information helps to inform the safety team, as well as consultants, about the requirements of the project. The participant continued:

> "Once we've done that, then we can start the build process as such. The first step really is to look at the site - where it's located - make sure that we've not got any contamination issues, there's no retaining issue or water … storm water issues, and then we can look at designing the building around any that there are."

Once the design team has completed the construction drawings and handed over to the operation team, the site monitoring starts. This process was described as:

> "… from there I guess, yeah, we start our construction… the site is managed on a daily basis for us by a site supervisor. It's managed in the office by the project manager who will then look at the costings, forecasts, timing; making sure everything's still on budget and still on time."

The findings from different disciplines confirm a similar workflow and existing process. Some of the participants were very open to make changes to improve the existing process. One of the more experienced participants stated:

> "…it's still a market place that's very conservative. We don't like change very much. We don't have a lot of old buildings so, therefore, there's not a lot of culture in what we do. So, I think, in Perth, there's an opportunity in the next, probably, decade for some new innovations to come in."

This openness to change also extended to the directors, who indicated a willingness to review the workflow:

> "… I'm quite a keen… I like technology and I like the functionality that I think is becoming available. I haven't looked at it myself for a while. I think we would benefit from a review… One of the things, as a company, [is] where we're always pushing to deliver and we're delivering with the tools and resources we've got available at the moment, so it's hard to justify or to try and do … business."

However, there was also an acknowledgement that change, if undertaken, needs to be considered in order to make sure it will deliver benefits.

> "...it's really about doing a business case for change and someone spending time analysing what tools are available - what tools would make

> the process and the time more efficient. And what the … cost benefit analysis is around that."

When compared to the Design-Build workflow identified through the literature review, it seems that the existing process within the studied SME firm is very similar, as shown in Figure 4.3. This is especially true of the early involvement of the commercial team during the conceptual stage and feasibility study. However, there are differences, particularly around the integration of the design with the construction teams. In this case, the handover from design to construction is usually done through a meeting, with some subsequent follow-up if problems are encountered. This is a deviation from Figure 4.3, which indicates a more gradual handover conducted at a slightly earlier stage. It can, however, be concluded that the conceptual workflow in this study has potential for BIM implementation as a sample SME-scale case study.

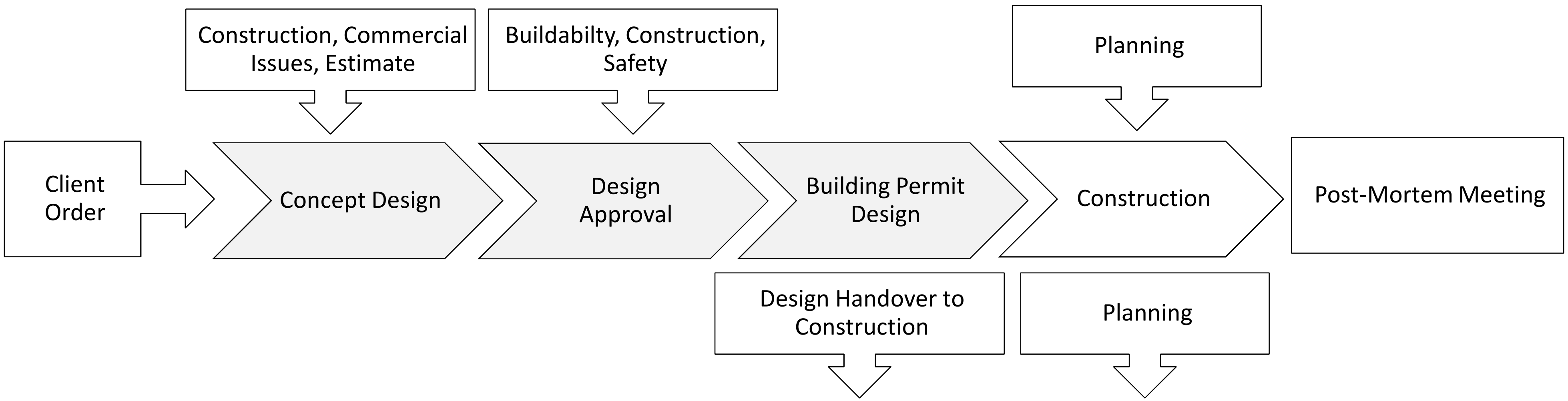



Figure 4.3 The identified workflow of the case study firm

### 4.2.3 Sharing Process and Sharing Formats

The construction industry, due to its “fragmented nature”, has the potential for improvement though more collaboration and successful process integration. File format plays a dominant role in the integration of central “shared” models that facilitate collaborative work. Thus, the next part of the interview focused on the following indicative questions:

- Could you please tell me about your experience in the construction industry?
- Could you describe, in detail, the information-sharing processes among disciplines on a standard project? (Project life–cycle/workflow)
- Could you explain the different file formats that project parties use to share information?

The aim of these questions was to clarify participants’ ideas and experiences about a central model and working with other disciplines, and also to reveal hidden barriers or issues.

The design team in this study were responsible for the initial creation and later updating of the central model, which was authored using Autodesk Revit. This includes generating outputs from this source to share with other team members who may not have access to the central model. One of the participants from the design team stated, with regard to issuing information:

> “…the main one is probably PDF, which everyone gets, whether they’re a consultant, client,... planner, ... trade for planning and then council.”

While the design team work on a shared central model, not all consultants are working in compatible authoring platforms. For example:

> "…most consultants such as Hydraulic Mechanical, they're all still working with AutoCAD or a similar software, so we'll just give them our files in DWG format as well as PDF."

The design team share information with each other through the central Revit model, but also use DWG as a sharing format with other external consultants. Most of the other participants indicated PDF as the main sharing format and confirmed that they rely very little on exchanging paper documents:

> "[It's] really all PDF, DWG and Revit [that] are the main ones that we use. And then there's not a lot of print documentation that we, sort of, send..."

However, for the design team, sharing through the DWG format is restricted to one-way collaboration. That is, once the information is issued to the consultant in DWG, any changes they make cannot easily be integrated back into the central model. In some instances, some external consultants (usually structural) are also working in Revit. This allows models to be directly exchanged:

> "As I mentioned we've got a couple of consultants that will use Revit, so we're able to, like, file share with the Revit model, which we normally do via Dropbox or something like that."

However, the structural model is rarely integrated into the design team's central model.

Apart from designers and some consultants, the other project disciplines generally use DWG format and 2D files that are not properly prepared to be integrated with the central model. In some particular projects, the structural consultant provides 3D models, designs and structural files that are sent to the site supervisors separately, and they use model viewers to open the files.

On the question of "Do you add all received information to the final model before sending it to construction?" one designer stated this about information flow:

> "Not really. We've - in the past - all we've done is, once we've handed over to construction, is give them PDFs and hard copies and the guys on site have their iPads and stuff that they can look at the PDFs. But recently,… two site managers have both downloaded the Tekla BIM."

This means the central model is not accessible by other project parties. Using Dropbox or any other file-hosting services for sharing files means that, although the model is shared with other users, it is not working as a central model. This is despite the fact that the Autodesk package has the capability of offering online workspaces for project teams to work together more easily through a cloud-based solution called Autodesk 360.

It is worth noting that the sharing process during the design phases is focused on interactions between the design team and consultants. As the project progresses, all the project information finally needs to be lodged with the authorities. One of the participants, in that regard, stated: *"The council will get PDFs if we have an electronic submission…"*. This shows the potential role of authorities to encourage firms to have standardised model-based exchange formats.

Among participants from the design team, some of them had previous experience of working with central models; one of them explained some of the benefits of such a system and stated:

> "… where you've worked from a central file and synchronised the project, we did it with the other disciplines, and then some people would be in a different work[place], and each morning you would just open it from a central file but everybody could work on it at the same time and then, when you saved, it would just simply synchronise. So, your changes would be updated, and the next time somebody else saved they would pick up the changes you had made."

Another interviewee, regarding the central model, alluded to the broad spectrum of available software and some of the problems associated with this:

> "… it's more widespread in architectural practices, or in ours, than it is in engineering at the moment. And mechanical and other kind[s] of consultants but the main issue is that there's such a broad spectrum of different software that everyone uses, and it doesn't integrate easily with… each other."

He also added:

> "I've given them, like, the structural model as one model so they can run through that in 3D when they're erecting their steel, and also their architectural Revit models, so they can, sort of, get a better perspective of that as well."

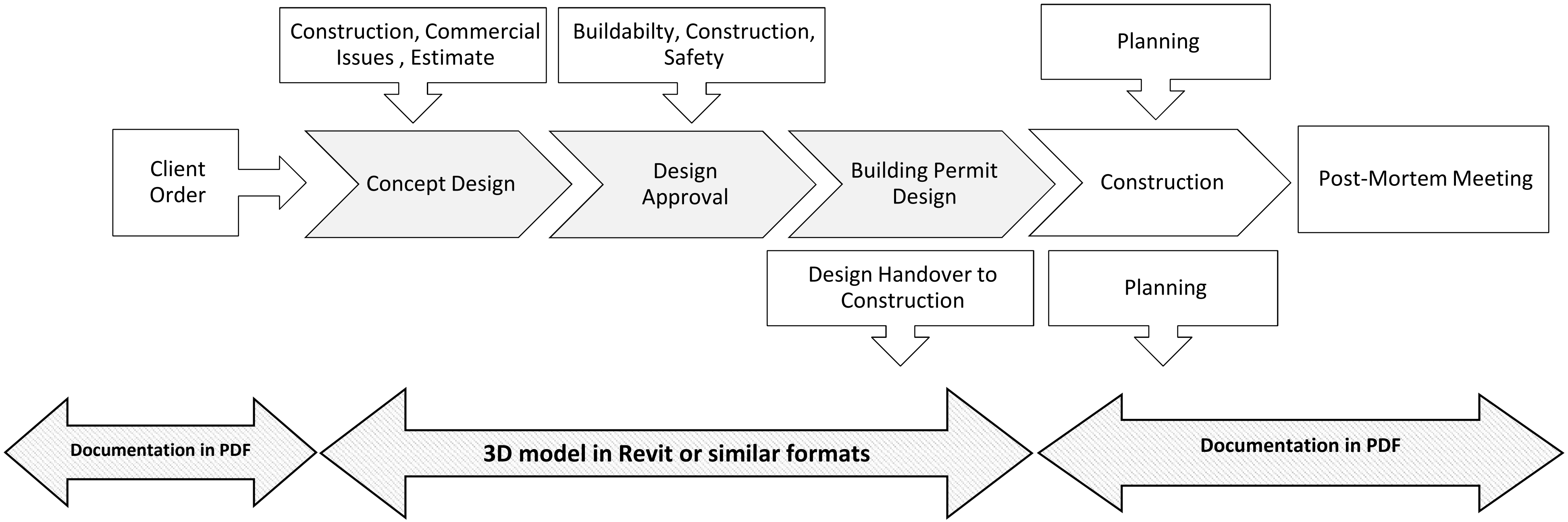



Figure 4.4 Sharing format during project workflow

The exchange of models and files through Dropbox, while an improvement on paper-based exchange, also has some problems associated with it. In particular, the time delay between exchanges, with work continuing on separate discipline models in between, has resulted in some coordination problems. One participant noted:

> "I think a lot of the sharing that's done with external consultants, like the engineers and fire or acoustic engineers, is done in sharing either PDF drawings [that] are … emailed or Dropbox CAD drawings, depending on the consultant… and then, the trades [have] varied [methods]. We used to have a lot of issues with version control of drawings and having consultants and people work on things at the same time."

Figure 4.4 shows a summary of the exchange formats aligned with the work process within the firm.

The results of the interviews show that, although the firm is equipped with the exact software and trained team members, the model is still only used by the design team and is rarely shared with other internal disciplines. Consultants and trades prefer to share information through the DWG format.  Other team members only use PDFs, and occasionally hard copies, to share their information. Figure 4.5 shows that the only common format among all disciplines is PDF.

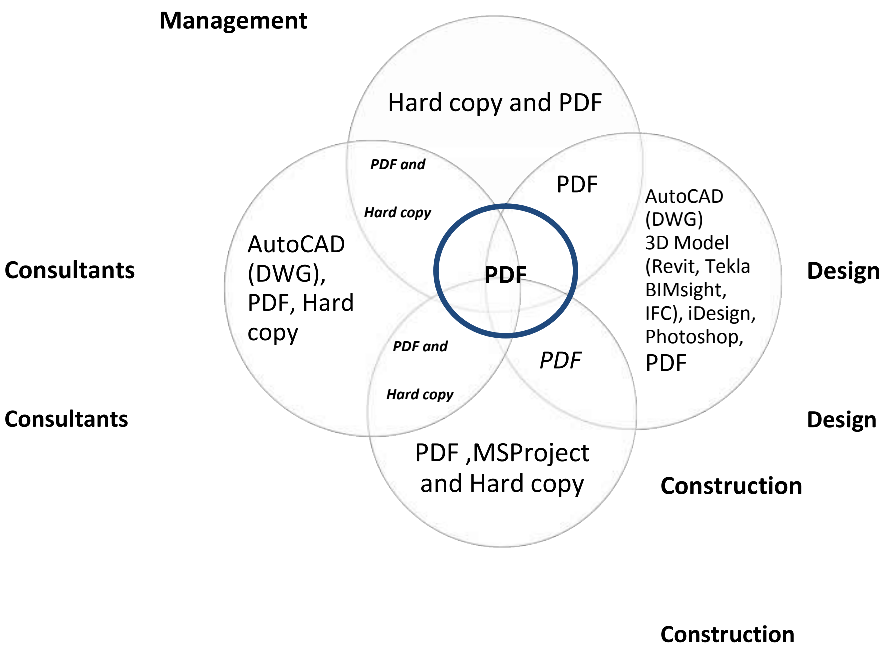



Figure 4.5 The file format and software that each discipline uses and shares with the others

A serious weakness with sharing through PDF format, however, is that it gives the users no choice to select their preferred scale, or even the ability to trust the shown scale. This has serious implications, for the estimation team in particular. One of the participants from the estimation department stated:

> "I always work on PDFs. It's the only way that you're sure of what you're getting. My biggest issue has always been with scale. …quite often I'll get a file sent to me by an architect. You print it out, thinking it's to scale. When it gets to you, it's 95%. It's not enough. If it was completely different, it's easy. When it's fairly close, it's not enough to show the difference."

Although paper exchange is not common, it does have its uses on site, where access to digital formats is limited. The site supervisors expressed their satisfaction with using hard copy, printed from PDF files. However, they were still dependent on the design group to get more detailed information when needed. A site supervisor stated:

> "[for] any information, we can usually phone the office and get it. I haven't had any real issues. There are quite a few measurements that are missing off our plans but it's a case of phoning the design guys, and they'll give it to you in two minutes. Their tool information, I think it's just overlooked, just because they have so much detail in the plan already. They miss the size of a wall, or they miss the size of a window."

Another weakness of the current method of sharing information between design and construction is that, at the end of construction, there will not be an accurate record or as-built model of the building. The ability to support facility management and construction tracking are added values that BIM offers, and documentation of each project can be important for any future changes (Figure 4.6).


Figure 4.6 PDF format-sharing problems

In conclusion, lack of both integration and compatibility of shared file formats, and inadequate knowledge of software capabilities, have resulted in project members resorting to the "lowest common denominator" file format (in this case PDF). This is further compounded by poor coordination of information exchanges and insufficient familiarity of external consultants and tradespeople with the new generation of software. Despite the firm having many of the BIM building blocks in place (e.g. software, trained staff) the real BIM potential of the firm is not currently being realised.

### 4.2.4 The Planner's Role in Collaboration

So far, this section has focused on identifying the existing workflow and exchanges within the firm. Now, it will focus on potential improvements to the existing workflow, particularly relating to the planner's role. The aim is to identify what the participants viewed as the "preferred time for the planner to join the project and prepare the program" as well as their expectations of the "planner's role". The following questions indicated this section:

- Do you think current process might be improved and if so how?
- When is the perfect time for the project programmer to get involved in the process?
- Have you ever heard about Building Information Modelling? What you have heard about it?
- What is your expectation from the project schedule?

The overall responses to these questions were very positive. More than one third of participants believed that the planner's role should start from the concept's design and extend through to the end of the project. Three participants believed that the planner should engage with the project directly after the concept design stage, which is relatively early in the identified workflow. Overall, it can be concluded that more than half of participants agreed with the planner's involvement being at the early stages of a project. In response to these questions, construction team members agreed more on the planner's role starting after the design completion stage. A procurement officer, in that regard, stated that the planner should *"…typically [be] involved… once the design and specifications have been developed and completed."*

On the other hand, an architect thought that planning could start earlier and stated:

> "Probably, right at the very beginning, well, it definitely helps us when we've got a specific date that certain tasks have to be finished. Yes, the sooner the better that they're involved."

The remaining participants suggested that the planner should join the project after the building permit design stage, or before the start of construction. Figure 4.7 shows the time, as suggested by the majority of respondents, for planners to join the project.

Regarding the planner's role and involvement, there were a variety of ideas from participants. A project manager viewed the planner's role as integral throughout the project:

> "I would say pretty much from the start. No point coming halfway through. For us here, the planner would be involved right from day dot of a project being awarded or a contract signed with a particular client. The planner will then schedule in our regulatory bodies… when all that information has to be lodged. They need to be in contact with the site supervisor or construction manager to develop a program so everyone knows what timing is involved with the project, and that someone's accountable for that."

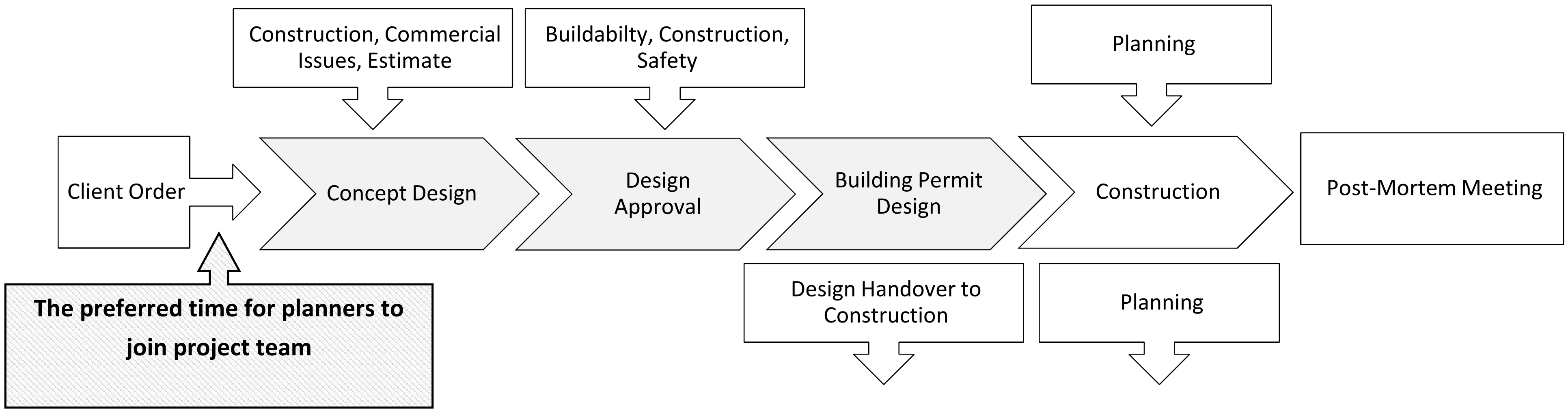



Figure 4.7 The identified workflow of the case study firm

A wider view regarding the planner's earlier involvement comes from an owner who said:

> "...it's dependent on the knowledge and skill levels of both … everyone has input into the plan. So, the planner, the supervisor, or… procurement or construction manager - I think having those people all working together at the early stage and thinking about how the project is put together."

That is in agreement with collaborative thinking at an early stage but, as a clear explanation of the planner's role, he stated:

> "I think what the planner brings to that process is understanding [of the] critical path and being able to look at a project and go, 'Alright, it might make sense to build block A, block B, block C.' and to be really analysing the critical path is when you're planner's needed. And even to the point where… it could have an impact on some of the design or site access or… there are probably some big decisions that the planner could provide input on that would change the overall way the project is developed. So, I think they need to be developed… as early in the… planning and construction phase as possible."

A project planner believed that they should be "*involved right at the very start of the project*" while an architect had views on the project size affecting the involvement of planners. In that regard, he stated:

> "I think on a simple project they [the planners] can probably come in, sort of, once you start your building license drawings. I think on a more complicated project they can probably come in a lot earlier. If you're

doing a complicated tower, you get the… building planners in straight away, and you can have their input and redesign the building so that you can save a few months on the construction time."

The planner's role is in relation to almost all of the project's members, and the fact that most of the interviewees agreed on earlier involvement is a good sign for implementation of a collaborative method. Although some participants associated the planner's role with project size or believed in them joining at the construction stage, improving the level of awareness and introducing the benefits of BIM may help to develop the proper concepts for BIM adoption.

### 4.2.5 Construction Sequencing/4D Modelling

In order to examine the possibility of extending the use of BIM into the construction teams, a 4D model of one of the ongoing projects was created and presented to the interviewees for them to achieve a deeper understanding of the potential for BIM implementation within the firm. The final section of the interview focused on the attitudes of the interviewees to construction sequencing using BIM. The use of a model from an existing project provided a more tangible scenario for the interviewees than, for example, a general marketing model, as this was something they were familiar with through their work activities. They could easily follow the process and compare it with what they had experienced or would expect on current projects. Once the prepared 4D simulation had been presented to the interviewees, they were asked:

- How could the visual simulation of a construction sequence be useful?
- In what stage might a 4D model be developed?

In response to the first question, four of the respondents from different disciplines indicated that 4D simulation had potential as a *"good marketing tool"*. For example, a project manager stated:

> "… I see it more as a marketing tool for us than something … we can use in construction, other than to look at the progression of how it's going to be built."

In particular, the simulation was seen to have a lot of potential for improving communication with stakeholders, who might not be familiar with reading 2D drawings or construction programs, and who might not have easy access to the site to view its progress.

> "It's going to be great to show to our clients and say, 'This is how it's going to be built, this is where we're up to today.' I can bring you out to site and have a look [but] that puts us in a precarious position."

Participants also stated that the simulation would be *"awesome to present to investors"*. This was especially in respect to attracting their attention and building trust. It was also stated that the simulation had potential to positively impact on the cash flow of projects as a tool to communicate with *"decision making authorities"* because it allows a clearer understanding of projects and their anticipated progress.

It was also suggested that the simulation would give the firm a competitive advantage within the market:

> "I would suggest that, if we could sit down with a potential client and say, 'This is how we build your project. This is the time.' That would be awesome. Yeah, that would put us ahead of others."

It was also noted that this advantage would exist when competing for work, suggesting a need to have this at the very early stage:

> "So, that would bring it right forward to [the] tender stage… where we're working on speculative matters."

In addition, one of the owners suggested that the 4D simulation had potential as a marketing tool to advertise the capabilities of the firm:

> "… a great marketing tool as well. I'm looking at it going - that would be great - on the website. You know, you have a little video going and you can play it back and see it being constructed."

While directors acknowledged that early introduction of the simulation would be really useful, they also highlighted that maybe the necessary data wouldn't be available to the planner at this time. This would need additional levels of collaboration between the planner and design team in order to be successful:

> "...there could be an argument that said doing it really early in the design phase would add some benefit to the project, but I don't think you've got your [planning] files at that stage to be able to set something like this up. So, you're then relying on, you know, your design guys or the operation guys to look at a project at concept stage and make some of those decisions."

Despite the additional up-front effort required to introduce the simulation early in the process, the project manager acknowledged that introducing the simulation once construction had started would mean that many opportunities would be missed.

> "So, I think some of the decisions that would benefit from having the model up have already been made by the time you get to this stage."

In addition to marketing and providing a competitive advantage, the site supervisors saw value in the simulation as a tool for planning the work on site:

> "...most of it is fairly logical but I think, in terms of actually understanding your site and visualising what's going to be happening on your site, I think that's really, really valuable."

This was partly due to the ease of access of the information through the 4D simulation, which combined the drawings and program into one easy-to-interpret format.

> "I think it would work. It would give you a bit more of an overview of how it would [look] … instead of looking at the program, which is spread over a sheet of paper this big, it's a lot easier to see it when you've got something happening in front of you."

The operational manager reinforced this but added that it might also save time, particularly when managing multiple jobs:

> "I think that's wonderful… especially when the supervisors are running multiple projects. If they're running one project, then not as much, but running multiple [projects] where they're not able to spend as much time on each project, then I think [it's] a valuable tool."

He also compared the traditional method of using the project program with what a 4D model could offer, not just as a tool for his management of operations, but also as a tool for explaining implications of delays to other workers.

> "When you're following your critical path through, they send a sheet of paper that's five foot long. You print them and then you're shuffling paper constantly. Whereas, if you can have something like that with a program that you can look at as well, you can slow that down and then you can actually see, on there, how it was going to work."

The benefits of the single simulation, when compared to multiple paper sources of information, were supported by a project manager who stated:

> "Obviously [that type of] visual is a lot better for people to understand how we want to build it rather than trying to interpret something else on a piece of paper or on a spreadsheet on the screen."

The project manager also saw the potential of the simulation as a collaboration tool to bring the disciplines together and to provide a common understanding of what needed to be done. This would ultimately improve productivity.

> "… if they all knew this is how we're going to plan it - they all get it in their head - you could have a round house table where you go, 'Right guys, slow it down a little bit. We're going to build this, then this, then this.' And that may take half an hour, and so be it. …We want to move from one section to another and they can see that we've done some planning to try and keep trades busy and working. You know, so there's a bit of flow through the project."

The supervisor thought that the simulation could be *"an extremely useful tool"* for optimising the construction sequence and stated:

> "I imagine we can run different scenarios then. If we take different directions, change … change our critical paths and watch the model develop and look for any flaws or any issues."

This was reinforced by another site supervisor who explained that it would be useful to introduce the simulation during "…very early stages", so that problems could be identified before work started on site:

> "Once you set a rough program … so, after we get a look at the concepts and before program's finalised maybe. So, before we've actually been given our actual timeline it would be handy to see that - look at that - see it step by step and then say, 'No, that's not going to work like that.'"

The simulation was seen as having the potential to highlight problems that wouldn't be easily identifiable in the traditional paper formats through, for example, time-based clash detection:

> "…that can be changed before the programs actually cast and that's what we've got to work to. It would be handy to see something like that and see where something isn't in step. Like, you could have something down here and then all of a sudden it could jump up here. Whereas, on paper, you don't notice that is happening."

One strong finding was how collaboration is ingrained within BIM implementation. When the construction participants began to think of 4D BIM, they also imagined how team members could be more integrated, through collaboration and communication across disciplines. The project manager, in that regard, stated:

> "I'd say it's definitely a good idea to do it in consultation with your sub-contractors that you're intending [to use]; the project manager, construction manager, contract administrator and schedulers."

The construction team could see a wide spectrum of benefits in using 4D BIM from the earlier stage by consulting with all project teams to the end of project via day-to-day site management:

> "I can see all sorts of uses for it. I mean, particularly with the day-to-day management. If you know what particular tasks and what construction work is meant to take place that day, or over a week, you can visualise it before it actually happens and, if it's available to the contractors as well, I think it would be an excellent tool."

While the architect was in agreement about the stakeholder communication benefits of the simulation, he also saw potential for supply chain management through the model.

> "…it's definitely something that I think would help the client anyway, and possibly other schedulers, or possibly helps the ordering process of things."

There was a general consensus among the design team that the 4D model could have a positive impact on the design process, increasing awareness of constructability issues at a time when they could be easily addressed.

> "…there's a lot of detail that can inform the design of where things don't work well within the construction sequence, so then you can adjust the design."

Overall, all participants agreed on the fact that 4D simulation has significant benefits, ranging from a marketing tool through to a mechanism for improving communication and collaboration.

However, the stage at which the 4D modelling is prepared is an important issue as well. Having established the potential benefits, interviewees were asked about the appropriate time for preparing the model.

While there were some differences in opinion, the majority of respondents felt that preparation should be early on. The construction team felt that the optimum timing for introduction was just prior to commencement of construction:

> "I think I would like [it] probably in the first stages … as soon as we are pre-construction - after design is complete and approved - as we then start to work it into a construction document…"

A project manager, regarding the benefits of early-stage simulation in the project process, commented:

> "I would suggest this could come in before we start on site … I can see there are some real benefits to looking at … the construction guys as to how we're going to process this. They can then see quickly the ramifications of falling behind in a particular area … I think ideally I would be having this before we start [construction]."

The project manager reinforced the timing of the suitable introduction for 4D modelling by adding:

> "I believe the construction program should be done broadly when the building permit documents are ready to go in. By that stage, if we don't know how we're going to build it, we're in trouble anyway. So, the program should be at least sequenced and then - once the building permit goes in - then the construction team can look at durations and things like that."

Supporting the idea, a site supervisor believed that *"…this model should be prepared prior to the commencement of the project."*

As with the construction team (supporting the literature) the designers reported a strong relationship between BIM implementation and increased collaboration among project parties:

> "I mean, they're [the sub-contractors] always, you know, for them quite often they operate in isolation. You know, 'What's happening next week?' or… 'What are all these other people doing on site?' - that type of thing. So, for them to have an understanding of the whole construction progress and how their part fits into the program would be beneficial."

These perceived benefits of a shared model also extended into managing the supply chain and logistics on site through collaboration with sub-contractors:

> "That way they can obviously get long lead time items ordered prior to those certain tasks starting and, I guess, to prevent double-handling of materials and stuff like that. Also, organising the logistics side with the

sub-contractors, as well [as] ensuring you have those resources planned to arrive on site when you need them."

While there was some variance in opinion, the overwhelming majority in all disciplines agreed that, to gain more benefit from the 4D model, it is required to be introduced at the earlier stages, through initiating the project program as early as possible.

All the participants were impressed by, and satisfied with, use of the simulation model for projects, and could all see potential benefits, both within their own disciplines and through collaboration across disciplines.

The only point of disagreement was the precise stage at which to start the 4D model. Almost all of the construction members would prefer to have that model just before construction commences, at the stage of building permit approval. The remaining project participants could find some benefits to introducing it even earlier, at the planning approval stage. While there are undeniable benefits to introduction at the time of planning approval, there are some obstacles that could potentially impede this, including the lack of necessary detail in the design model to prepare a reliable construction method. A simulation at this stage would only really be of value as a marketing tool because it would be based on too many assumptions to be of use during construction. To maximise the potential benefits to the project, without introducing additional effort or overheads, the 4D modelling step should be introduced between design approval and building permit approval in the identified workflow of the case study firm's projects; at a point where there is enough information about the project for the simulation to be helpful as a construction planning tool. Given that the planner's role, according to the same group of participants, starts before the conceptual design, initiating the 4D model after design approval and progressively updating it up to the building permit stage would be meaningful and achievable (Figure 4.8).

The results show that there are both tangible and intangible benefits of 4D scheduling. Tangible benefits, which could potentially be monitored on projects, are the potential to save time, both through more efficient working processes and the streamlining of construction tasks, the easier and more effective communication with subcontractors and the project technical team, and improvements in risk reduction through the ability for all team members to review the program before the start of construction. An important intangible gain seems to be the ability to use the 4D model to communicate project parameters to non-technical stakeholders and, in doing so, to obtain their timely buy-in.

### 4.2.6 Managing the Change

During the course of the interviews, a number of participants noted that, in order to realise the potential benefits, some changes would need to occur in the current work practices. These findings show that, in order to implement BIM, current processes would need rethinking and some support would need to be put in place to alleviate people’s concerns and to ensure that the adoption process was a smooth transition.

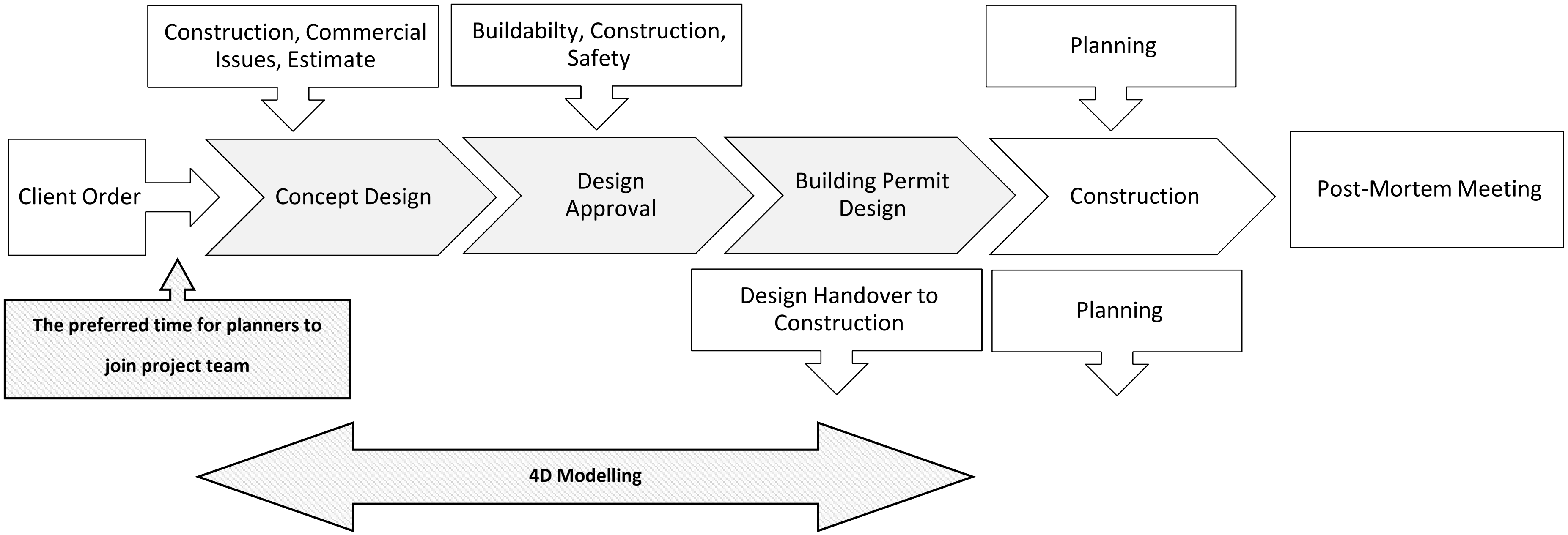



Figure 4.8 Suggested stage for preparing the 4D model of project, based on the interview findings

One of the directors had some concerns about what might be required to be changed in the contracts in order to share responsibilities. He explained that the problems surrounding this need to be reviewed before BIM can be fully adopted:

> "I think we're doing pretty well as far as Revit use with architects but it's not really picked up with the builders and engineers just yet. There's a lot of legal problems with that because, if the 3D model has a problem with it and then they build the wrong thing, then there's liability issues. So, the contract arrangement is a lot different. It's a lot more robust. So the architects need to charge a bit more, yeah. And then there's a saving at the end, but the clients don't always agree to it."

Another director also was concerned about the amount of change required at all levels and how much benefit BIM adoption would bring to the firm. He stated:

> "I think it's hard to … to get everyone engaged and to get everyone supportive of it from all the directors and also G [General Manager] and the teams that are doing it. If you've got a process that seems to be working and that's relatively efficient, you don't know how efficient it is in comparison until you've actually seen the comparison or understand the comparison."

In addition, there was some concern within the design team about the level of detail required for effective 4D modelling. Once the model is shared among disciplines, the accuracy of the model becomes even more important. The time constraints, particularly in the early stages, often mean that bad habits can emerge as pressure mounts. If the collaborative benefits are to be realised, the need to spend more time up-front needs to be acknowledged.

> "... I think it's always best to try and model things as accurately as possible.... people will, sort of, use short cuts to model things. I think at the beginning stage of a project… especially when you're put under pressure by people to have things done on time - 'Quick!  We need it today!' - sometimes it's too tempting to quickly model something to just make it look right for the purpose of a plan looking good or getting it done quickly. But things like that can always be forgotten about and later, down the track, you go to change it or move it and it's not the right thing.  You then spend a whole day fixing something. I think modelling them correctly from the start, and accurately, would be the best.  But, there's always so many time pressures - you can't always do it."

Overall, it can be concluded that, in order to realise the benefits of BIM and have a positive impact on key decisions at the beginning of a project, more time needs to be allocated at the earlier stages. Acknowledgement of this is key, from the business directors, because they will need to instigate a change in mindset to shift away from the need to save time at the beginning by doing the model quickly, which results, at best, in digital reworking within the project model or, more likely, reworking on site during construction.

# CHAPTER 5: 4D DOCUMENTARY SOURCES AND OBSERVATION

## 5.1 Documentary Sources Introduction – 4D

The aim of this section is to explore the existing nodes of BIM implementation through examination of existing files, including Revit models and MS project construction schedules, for the selected case study. Thus, any possible barriers for the firm to commence implementation of BIM will be identified. In addition, the coordination among departments that are involved with the development of the final model will be considered.

Examination of existing files will help to answer the second research question: "How can SME adopt BIM?" For this purpose, a 4D modelling exercise of the case study was conducted and any problems that were encountered were documented and analysed. In order to prepare this 4D model, it was necessary to commence by linking the time schedule to the 3D design model.

The 4D BIM implementation is based on the link between design and construction for each item. It is therefore necessary to clarify what the differences are between an architectural Work Breakdown Structure (WBS) and a construction WBS. There have been efforts to standardise the breakdown of work in both the design and construction fields, but with limited success. Most recently, Jiang and Leicht (2016,) linked a product information model, which was suitable for architecture, with a construction WBS. The defined architectural model was a hierarchical classification comprised of levels of detail about building information, such as class, design attitude and information decomposition, that indicated the design decision points. This product model was designed to review a project's constructability at the design stage by decomposing the design from its high-level completed form down to the detailed product information. The top-down hierarchical approach of such design information contains different levels, progressing from the early stages of design and evolving into more detailed information. The decomposition indicates systems-level classes at the top, to sub-systems below, then to components and elements at the lowest level. The breakdown process in the architectural model and the construction model are similar in that they break down items from major areas into more detailed tasks. The construction WBS typically starts from top-level areas that can be divided into several major areas for delivery and management. The construction WBS represents the project at the highest level, with major areas at the next level, each divided into the main disciplines, then disciplines that are broken down into tasks and components. The next level is activities, which are divided into sub-activities. Finally sub-activities in the lower level are associated with the scheduling function and refer to the work presented in a schedule diagram, such as a Gantt chart (Halpin et al. 1987).

The architectural model, in comparison, divides at the top into the two main categories of permanent systems and temporary systems. *"Permanent systems are defined as the systems that remain in situ for the life of a building, for example, a building's facade systems. On the contrary, temporary systems are those built in place temporarily to enable the construction of the final product, such as scaffolding or formwork systems"* (Jiang and Leicht 2016, 461). Both temporary and permanent systems are divided into lower levels areas that include architectural, structural and engineering systems. Each area divides into sub or super areas. Then, each system is decomposed into sub-systems and, finally, into the level of components and elements, including design information that evolves as part of the detailed design process.

Although the project's WBS is different from the perspectives of planners and designers, both break projects into deliverable items that can be designed, measured, managed and controlled; and these items need to be linked, through the 4D linking process. The following diagram shows the design and construction WBS decomposition methods, adapted from Jiang and Leicht (2016), and highlights the differences in the levels of detail.

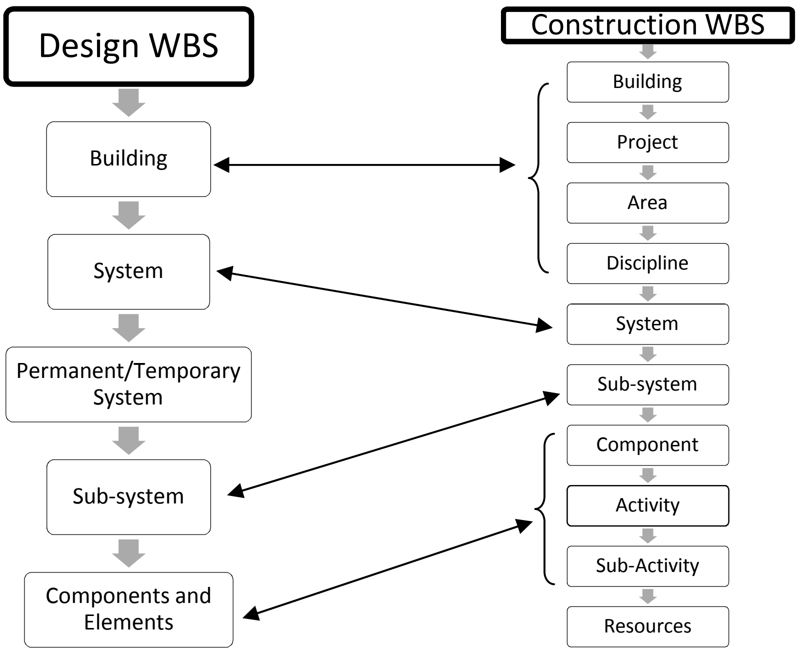



Figure 5.1 Design and construction WBS method

The above diagram illustrates that the decomposition of a project is significantly different in the design and planning disciplines. In particular, linking at the lowest level (i.e. components), which is the level required for 4D modelling, could be problematic, due to the differences in the levels of detail between the different WBSs.

The selected case study follows a WBS during construction that is in alignment with Figure 5.1. However, the design team were not following a standard WBS at that time.

In the following section, the practical problem nodes encountered during the process of creating the project's 4D model are discussed. The usability of the 4D model was evaluated during the design and construction stages of the case study and recommendations for future similar projects are made, based on the findings.

## 5.2 (4D) Model Creation

The project design 3D model was created using Autodesk Revit software. For conversion to a 4D model, the 3D Revit model was exported to the IFC format (Figure 5.3, step 6.1) then imported to Autodesk Navisworks Manage 2015 (Figure 5.3, step 6.3). As discussed in Chapter 2, the IFC format is an open standard format for BIM collaborative work and gives users access to a common way of cooperating across different software platforms.  The project time schedule of 48 working weeks duration was prepared in MS Project; the schedule was exported from MS Project to Navisworks through the CSV format (steps 6.2 and 6.3). Navisworks is designed to link 3D models and time schedules through its *Timeliner* function. Figure 5.2 shows the third step of the 4D modelling process (step 6.3) when the Revit model and time schedule are imported into Navisworks.

Some minor remodelling had to been done on the 3D model to align the model breakdown with the schedule of tasks. However, there were some tasks and components that could not be easily linked, due to differences between the design and construction WBSs.

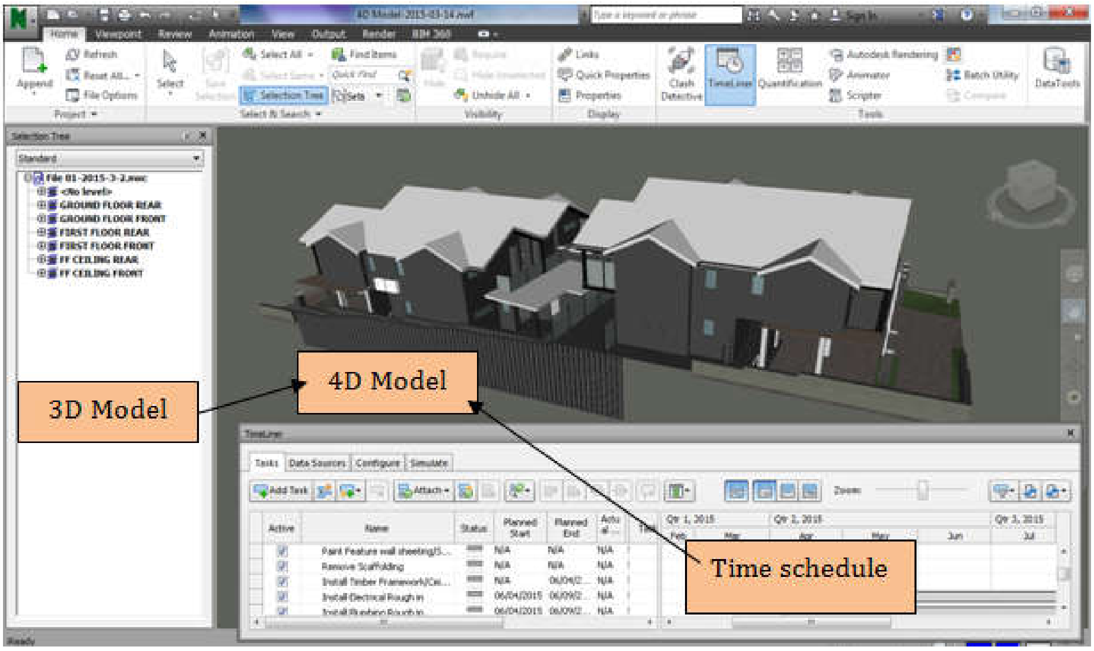



Figure 5.2 4D modelling, starting with the 3D model and time schedule imports

The following section is a review of the steps required to create the 4D model in the selected case study, which relates to the steps as considered in the literature review section (French and Khanzode 2006, 397-404):

1. *Establish Work Breakdown and Flow*

   During this step the time schedule of a project is prepared using the standardised Work Breakdown Structure (WBS) that subdivides the project into phases, work packages and deliverables. The project schedule at the lowest level of breakdown refers to tasks. Each task presents a "doable" or measurable activity, which results in progression of part of the project.

2. *Establish Installation Sequence*

   Then, the required time and resources are allocated based on relationships, and the project process predecessors and successors. The project schedule could be designed and controlled by Primavera or Microsoft Projects (MSP) or similar software.

3. *Reorganise 3D Models*

A 3D model of a project is a collection of components that are comprised of elements with meaning in construction, such as floor, roof, column and so forth. Those elements are not limited to architectural items and it is necessary to include structural, electrical and mechanical items as well. At this stage it is required to represent a construction view of the project. This stage is usually the most time-consuming stage because it needs reworking to be done on the existing model to reorganise it so that the WBS activities and sequencing in the two last steps can easily be linked to the right components in the model.

4. *Refine Schedule*

This step is a reworking of the project schedule to prepare more details and the sequencing of activities to link them to the components.

5. *Link 3D Objects and Activities*

Then, the 4D association process between time scheduling tasks and 3D model elements or components is undertaken.

<table>
<tr><td rowspan="11">4D BIM CREATION STEPS<br>(Adopting from: French and Khanzode 2006)</td><td colspan="2">Steps</td></tr>
<tr><td colspan="2">1.Establish Work Breakdown and Flow</td></tr>
<tr><td colspan="2">2.Establish Installation Sequence</td></tr>
<tr><td colspan="2">3.Reorganize 3D Models</td></tr>
<tr><td colspan="2">4.Refine Schedule</td></tr>
<tr><td colspan="2">5.Link 3D Objects and Activities</td></tr>
<tr><td rowspan="5">6.Refine 4D Model</td><td>6.1. Export 3D file in a format that BIM software can import</td></tr>
<tr><td>6.2. Export construction time schedule file in a format that BIM software can read</td></tr>
<tr><td>6.3.Bring two files into BIM Manager as 3D model and task Timeliner</td></tr>
<tr><td>6.4.Rework design model to prepare components that align with scheduled tasks</td></tr>
<tr><td>6.5.Link elements of the model to the items in the tasks</td></tr>
</table>

Figure 5.3 4D BIM creation steps

6. *Refine 4D Model*

   As was highlighted in the Research Methodology and Design section, the 4D modelling, after preparation of files, is made up of the following steps:

   6.1 Export 3D file (Revit) in a format that BIM software (Navisworks) can import.

   6.2 Export construction time schedule file in a format that BIM software (Navisworks) can read.

   6.3 Bring the two files into BIM software (Navisworks Manager) as 3D model and task *Timeliner*.

   6.4 Rework the design model to prepare components that can align with the scheduled tasks.

   6.5 Link elements of the model to items in the tasks.

This procedure has been designed for 4D BIM creation and, as discussed before, this study's purpose is to trial BIM implementation in a sample case study project at an SME scale.

## 5.3 Case Study and Plan

The selected firm typically focuses on medium–density, low-rise housing and there are usually four to five such developments ongoing at any one time. The development selected for this case study is a two-storey, eight-unit, residential project in Perth, Western Australia.

The case was selected over other residential projects because the development was comprised of two separated blocks, with access from both the front and the rear. This meant that construction could commence on both blocks simultaneously and, so, the planning of the construction sequences would be more complex than usual. Each unit is made up of a concrete slab, brick walls, and a truss roof in two levels. The site features led the structural engineers to design piling. The construction duration was 48 weeks in total. In addition, this size of residential project is becoming very popular among residential builders. It is not a single storey but is not too big for an SME to handle this project size. Hence, the results of this research could be extended into many similar projects. Additionally, the project's duration was around one year, which allowed the construction life-cycle to be followed from beginning to completion and the 4D model to be tested during some section of construction. The project's team members were available for the whole year of construction. Also, this project had all the drawings in a 3D model format, in addition to a time schedule in MS Project, so it was ready for 4D modelling examination. The project delivery method was Design-Build and the construction process started immediately after all construction licences had been received.

## 5.4 Problem Nodes

### 5.4.1 Missing Elements – Problem Node 1

One striking finding to emerge from the linking process was that there were several tasks with no modelling equivalent components. Those tasks could be categorised into two sub-groups: (a) Construction activities and (b) Temporary activities.

a) Construction activities include tasks that are part of the build process where the result is part of the final building. These activities are named as "permanent systems" in the architectural WBS shown in Figure 5.1.

   For example, the construction schedule started with the "site works" activities that include earth works, site preparation, site levelling, fencing, retaining walls and piling. All the tasks are a permanent part of the project, but only the piling and retaining walls are modelled in the final model.

   Some of the tasks, such as earth works and site preparation, require a site survey (currently only done in 2D) to be converted into a 3D topography with contour modelling. As this is not currently part of the process, those tasks do not have any equivalent modelling components to attach to. This resulted in 12 days at the beginning of the 4D model when nothing appeared to be happening prior to the piling process commencing on day 13 (Figure 5.4).

   Another example is the "electrical and plumbing pre-lay" task that is related to the preparation and installation of electrical and plumbing requirements before the floor concreting stage. This task is a predecessor to the pouring of concrete and the components remain as permanent items. However, this task also does not have any equivalent component to be modelled.

   In order to have a practical 4D model, the modelling process would need to include topography and site works components as well as the Mechanical, Engineering and Piping (MEP) components.

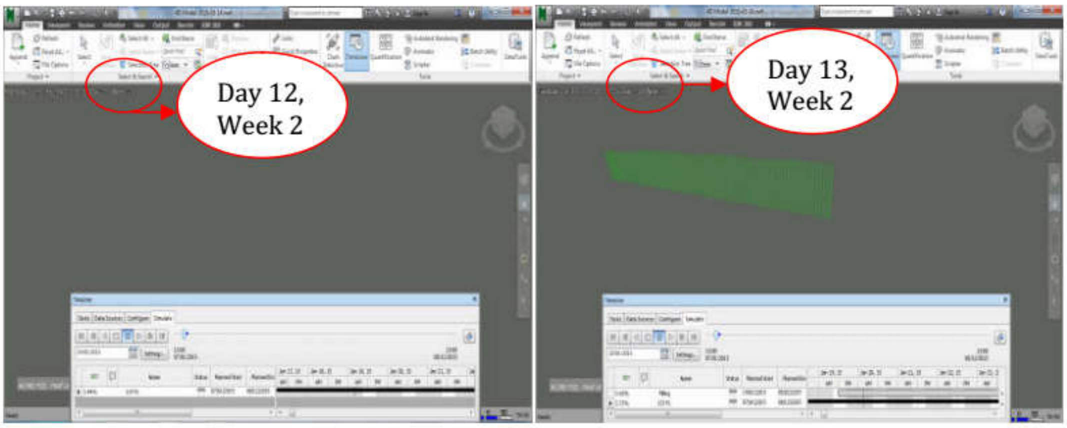



Figure 5.4 Tasks without equivalent modelling items appearing in the 4D model

b) Temporary activities include tasks that are part of the build process but where the result will ultimately be removed from the final project. These are defined as "temporary systems" in the proposed architectural product model shown in Figure 5.1.

Scaffolding is an example of a temporary activity because it is required in order to complete other tasks but will be removed from the project once the tasks have been completed. In this case study the scaffolding has not been modelled. The result is that the 4D model does not show any progress during the scaffolding-related tasks and it seems that the site is inactive.

The concreting process is another example; it has four steps including preparation, concrete pouring, concrete curing and formwork removal. What the 3D model shows is only the completed concrete slab; however, the *schedule* shows a more detailed breakdown of tasks for concreting, namely: formwork installation, supporting or back-propping, MEP pre-lays, post-tensioning, concrete pouring, curing duration and removal of formworks. Formwork and supports are temporary items that will not stay after completion of this stage and, therefore, can be categorised as type (b) missing elements. The importance of these missing components increases when the construction sequencing is intended to be used for safety purposes or site traffic control.

The simplest, but not the most accurate or useful, way to handle the issue is to select the floor slab component and attach all concreting related tasks to it. In this method there will be no seemingly idle time, but the floor slab item will be presented as a single task in the 4D model, instead of the separate sub-tasks. However, it is clear that these sub-tasks are to be completed by several different disciplines, each with specialist knowledge. It would be unrealistic to expect the design team to model these specialist components without input from the construction team. Therefore, all disciplines' knowledge is needed early in the project in order to produce a model that can support accurate time planning.

It is worth noting that the modelling of the back props as temporary items would be extremely useful for site traffic management and safety issues.

In addition, if the missing scaffolding cited previously had been included in the 4D model, it may have prevented a conflict within the program that arose during construction. The program indicated that the construction of the first floor roof of the rear block could proceed prior to the scaffolding being removed. However, in reality this was not possible, as indicated in Figure 5.5. Furthermore, the scaffolding needed to remain in place for access to finish the roofing, painting and installation works in the top level, but the ground floor works could only continue after the first floor had been completed. This error in the program was undetected until construction of the roofing began on site. As a result, the electrical work and plasterboard installation tasks were delayed and the project timeline extended.

Importantly, this conflict could have been identified if the scaffolding had been defined as a temporary system and modelled in the architectural WBS. This would have allowed the project to be modelled from a construction perspective and would have facilitated alignment with the main tasks of the project's schedule to avoid any future conflict.

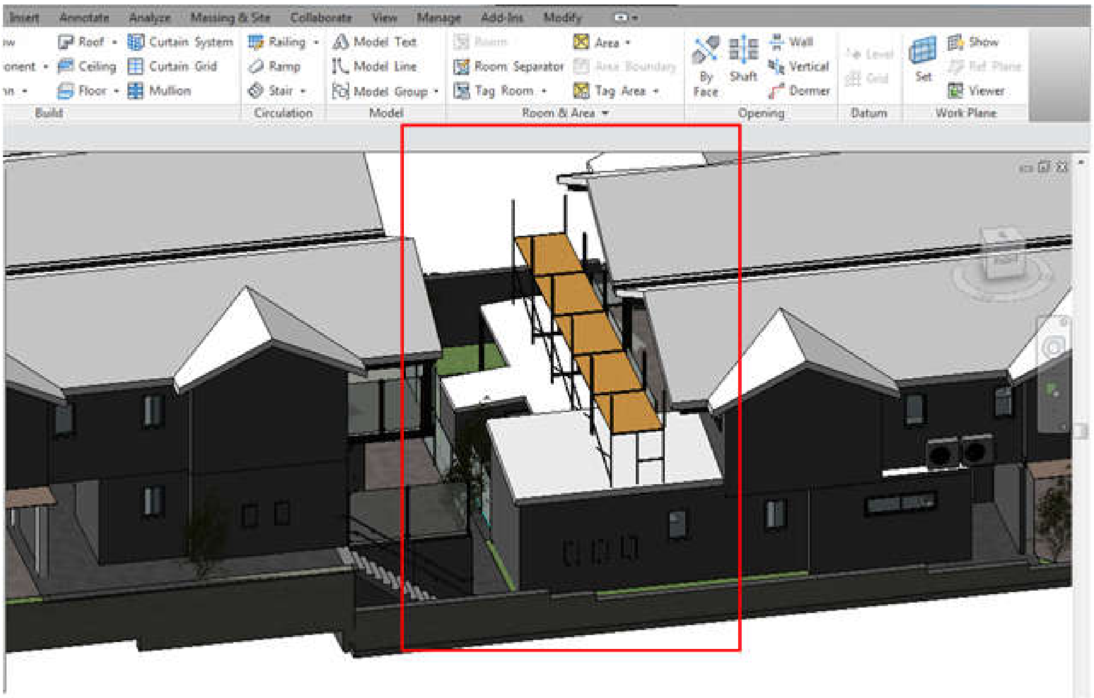



Figure 5.5 Scaffolding and ground floor roofing conflict

### 5.4.2 Level of Detail – Problem Node 2

Another finding from the 4D modelling process is related to the modelling method of the designers. In this case study there was no standardised method for modelling components and, so, the results often varied from modeller to modeller. Within a

BIM environment it is common practice to create a library of repeatable types of components (a "family" in Revit) that allows the modeller to re-use a component as many times as required instead of preparing it from scratch each time. In addition, many manufacturers provide pre-prepared families to represent their products for ease of use in project models. However, in this case study the prepared families were modelled as design components. So, for example, a wall was modelled as a single family, made up of a core of two basic masonry brick layers with a cavity, in addition to internal and external finishes. However, when constructed, the wall represents work tasks for a minimum of three different trades (brick-layer, internal finisher and external finisher) who work at different stages of the project. In this example, the requirements of the project model from the designer's perspective are rather different to the requirements for construction purposes. In other words, the WBS and associated levels of detail of the project model are different between the designers and the planners.

The roofing components provide an additional but slightly more complex example of this issue. In the case study, the roofs were generally modelled by two disciplines: architectural and structural. The architectural design is usually modelled as one family, which includes all the roof layers such as roof sheeting and finishes. However, the structural model includes individual beams, rafters, purlins and so forth. The construction of all the structural components is sequential and uninterrupted and, therefore, is represented as one task in the construction plan. The construction of the architectural components occurs in at least two distinct steps and, therefore, is represented by two separate tasks in the plan. In addition, there are many electrical and plumbing activities that happen during roofing installation but the electrical and plumbing components were not modelled in 3D in the case study.

Both of these examples demonstrate that, in order for successful 4D BIM implementation, a multi-disciplinary 3D model is required for linkage to the project construction plan. In addition, there is a basic requirement of modelling for construction purposes that involves agreement by all disciplines on the level of detail required at the early stages of preparing the WBS. In this case study, the level of detail was not initially balanced, with some areas of the construction WBS potentially being too detailed and some areas of the architectural WBS lacking in detail. It was obvious that an alignment of all project disciplines' WBSs and preferred levels of detail would help to prepare a construction-oriented model and reduce digital and construction remodelling works.

### 5.4.3 Multi-disciplinary Collaboration – Problem Node 3

The 3D model is the outcome of different disciplines' designs. It is created initially by the architects but the structural, electrical and plumbing design teams need to be involved in the development of the model for it to be a complete, integrated representation. In this case study, the structural team had some input into the central 3D model but the electrical and plumbing disciplines had very limited interactions.

While some structural components, such as piles, footings and concrete slabs, were modelled in 3D, others were not. A review of the structural construction documents showed that many structural components had been prepared only as 2D drawings and had not been modelled in the final representation of the project. For instance, the main beams and roof trusses were available in 3D, while rafters, joints and other connection elements had not been modelled. Given that the structural process is subject to regular site inspection during the construction works, a lack of these items in the 3D model does not necessarily cause any issues during construction. However, from the construction sequence perspective, the items of structural work that are not included in the model are not visible in the 4D simulation, since the related tasks in *Timeliner* are unaccounted for.

If we now turn to the electrical and plumbing documentation, examination of the 4D modelling process reveals that the level of electrical and plumbing collaboration through BIM is non-existent, with all of the documents being provided as 2D drawings. On residential or small-scale projects, the MEP consultants and subcontractors do not allocate the time and resources required to create a 3D detailed model. Moreover, they do not have the training resources to up-skill staff for 3D model creation. As noted in the literature, at the SME scale of projects, many subcontractors are not prepared for BIM adoption and there is little guidance available as to what level of detail is required for this scale of project.

The architectural team in this SME firm displayed the highest level of readiness for BIM adoption. Some processes were already in place for partial modelling within the structural domain, but there was a need for improving the level of collaboration between the structural and MEP firms, or subcontractors and the design team, in order for the 4D modelling to be complete and, therefore, fully useful.

## 5.5 Recommendations

Collectively, this examination of documentary sources outlined three main problem nodes encountered throughout the 4D modelling process using the existing 3D model and time plan:

- Missing elements

- Level of detail
- Multi-disciplinary collaboration

In addressing all these problems, the early definition of a project WBS is the key to successful BIM implementation across both design and construction. While this may vary across projects, depending on the individual requirements, the evidence presented in this section suggests that more collaboration at earlier stages of the project, particularly between designers and planners, is essential to address the first problem node. This earlier collaboration would allow team members to agree on the required level of detail in the 3D model to allow its alignment with the breakdown levels of the time schedule. In particular, modelling of key temporary components, such as scaffolding, formwork or props, would help to identify construction issues prior to work starting on the site.

Even though the designers, when compared to other project parties, had a better level of BIM readiness, there were still areas of work where some basic actions could have facilitated more efficient and effective modelling and, in so doing, helped to address problem node two. If designers, through collaboration with the construction team, could model project components with a construction mindset, the resulting model would be suitable for use throughout the design and construction phase. Construction-oriented modelling is a way to reduce the need for digital remodelling through integration of project information and would provide the required context for 4D BIM implementation. It is worth noting that this would also enable future dimensions of project information, such as cost, to be added.

This collaboration needs to be bi-directional so that the planners, while working with the design team to clarify the construction sequence, would gain a better understanding of the project's progress through the resulting simulation, as well as a more accurate BIM tool for controlling project progress.

Problem node three identified that, in order for the model to be complete, all disciplines need to contribute to the shared model. However, in SME-scale projects the majority of the structural and MEP firms cannot easily meet the minimum requirement of a BIM model. This could be due to several different reasons, including the time required for up-skilling, the cost of training and software, and a lack of incentive to change. Given that the MEP component of this case study was outsourced, there is little opportunity to influence that change. Nonetheless, over time, as the new technology becomes more embedded in education and industry, the investment required to make the change will decrease and the incentives will continue to grow. It is expected that, eventually, the BIM technology and collaboration processes will mature and, even at this scale, there will be MEP information in a 3D model. By the same token, modelling for construction purposes, or construction-oriented modelling, would help a firm to have a powerful concept model that could be connected to other disciplines easily. This preliminary readiness will help to enhance the project model with some basic steps.

## 5.6 Observation: Benefit of BIM in Practice

This section aims to integrate the practical findings of the observations throughout the project process, from start to completion.

As discussed previously, the 4D simulation was prepared based on the existing files for the selected project. The project progress was monitored through regular weekly site reports and visits in order to compare the simulation to the real construction process. Any issues that arose on site were analysed to establish whether a more collaborative BIM process could have identified the problem at an earlier stage.


One of the issues reported from the site at the beginning of the project was the location of a temporary power pole that had been installed in conjunction with retaining walls. This issue was reported by the site supervisor and resulted in construction stopping for approximately three weeks to relocate the power pole. This problem could easily have been identified earlier if temporary items had been modelled during the design stage (node 1)

Figure 5.6: Case study project’s site plan (From googlemap image)

Subsequently, when the second storey scaffold was due to be installed, another issue was raised with the same power pole. The minimum safe distance between the power pole and the scaffold had not met (Figure 5.7). In this instance, the scaffolding had to be re-erected to comply with the safety requirements.


Figure 5.7 Case study project's power pole and scaffold location

Once again, inclusion of temporary items in the 4D model would have helped to find an appropriate location for the power pole. This issue also demonstrates that the 4D model should be able to support the decision-making process during the construction of the project and that a more accurate and detailed model helps to support safer construction.

An additional construction issue that was observed related to the conjunction between the scaffold and ground floor roofing of the back block. This stopped the ground floor work from progressing because of the need to complete the first floor facade prior to removal of the scaffolding. This problem could easily have been identified earlier through the inclusion of temporary items in the 4D model. In all of the above instances, modelling of temporary systems would have identified clashes before construction commenced and, as a result, helped significantly to save time.

As well as problems identified in the 3D model, underestimation of some tasks' durations was another finding, identified through site visits. This issue mostly involved tasks that needed inspection in order to progress. These inspection milestones are booked in advance and are difficult to rearrange. On this project, a small delay in the reinforcement bar installation for the first floor slab meant that the inspection deadline was not met and resulted in a ten day delay on the project. For such tasks, which involve many teams working together to complete a task for inspection, a small delay by one team can have significant impact on the project timeline. Identifying these sorts of potential issues is dependent upon the level of detail within the 3D model as well as the project schedule (node 2). However, if the 4D model is updated regularly with the re-planned schedule for the project, problems can be identified and addressed throughout the construction phase. This capability of an updated 4D model is also useful for dealing with any other delays during construction, such as bad weather conditions.

Overall, it can be concluded that BIM implementation offers benefits even to small-scale projects and helps to reduce errors and to promote construction methods, saving time and costs. Findings from the 4D BIM implementation examination clarified that the existing context of SME projects has the potential for BIM adoption and that some practise in the main areas and more collaboration among the project teams could enable streamlining of BIM implementation. The present study has confirmed previous findings in that regard and has contributed additional evidence that emphasises the findings of the McGraw Hill report that BIM implementation provides benefits, including reduction of modelling errors and construction problems, regardless of the project's scale. It also promotes the image of an industry leader in the final product, as well as improving collaboration among project parties and, finally, offering new services (McGraw Hill 2014, 4).

# CHAPTER 6: DISCUSSION

## 6.1 Chapter Introduction

This research set out to answer the following questions:

1. Why aren't SMEs adopting BIM?

2. How can SMEs adopt BIM?

This was achieved through an in-depth literature review, followed by a case study of BIM adoption by an SME within the Australian context. Semi-structured interviews, examination of existing project files and observation of the construction process on site with interaction between interview participants were used to explore and investigate why SME firms aren't using BIM as well as to propose mechanisms for how they can adopt BIM. Through this case study of the current practice of an SME, a new workflow was proposed to streamline the process of implementing BIM and to achieve more integration between project phases. The major findings and outcomes of this journey are discussed and summarised in this chapter.

## 6.2 Why Aren't SMEs Adopting BIM?

As detailed in the literature review, BIM adoption is still maturing and there are many unresolved issues. The review of the existing research revealed that project scale was one of the factors affecting the implementation rates among different projects, with the result that BIM adoption among SMEs to date has been slower than that of large firms. However, in order to achieve the productivity goals of the industry (i.e. heavy/very heavy level of BIM adoption) SME engagement with BIM is essential. This research specifically targeted small-scale projects to identify the main reasons for the reluctance to adopt BIM. This was achieved through an in-depth case study that examined a project through its digital records, interviews with staff and observation of the actual construction process.

While the selected case study firm was fully equipped with the required software to implement BIM across both design and construction, the engagement with BIM stopped once the design had been completed. Despite the existence of opportunities for early collaboration, the planning and control of the construction process only commenced at the beginning of the construction phase. In this context, the interview questions focused on identifying the main reasons for not adopting BIM, as well as establishing the existing workflow for both design and construction.

A key finding from the in-depth semi-structured interviews was that the level of awareness and experience of BIM among the selected SME firms was very low, and limited to the design team and directors. The lack of awareness of BIM and its relevance to the SME sector is a key barrier to BIM adoption on projects of this scale. The literature review indicated that less than 30% of non-design team members in SME firms are aware of the potential benefits of BIM. Understanding these benefits across a project's life-cycle and, importantly, communicating this to all disciplines involved, is the first step towards SME sector engagement with BIM. To date, much of the focus has been on implementation in regard to large-scale projects, with little detail available on how best to adopt it at the scale of SMEs.

The interview results also indicated that the initial attempts of the directors to extend the use of Revit and the 3D model beyond the design team had been unsuccessful, resulting in a failure of confidence in the new technology, a return to "business-as-usual" and a continuation of the traditional paper-reliant processes. Results of the literature review confirm that collaboration on BIM across disciplines requires a change in processes, as well as communication and training, to understand the implications of collaboration on a shared central model. In this instance, the data input into the model by the design team was not compatible with the information needs of the procurement team, which resulted in incorrect quantities being ordered. This issue confirms the barriers identified in the literature review, namely, unfamiliarity with BIM's breadth of abilities and the associated lack of applications experience in programming. Therefore, in order to engender a collaborative workflow, training is needed to raise awareness of the needs of other disciplines.

In addition to a lack of awareness, the cost of change was also seen as a barrier to making that change happen. Importantly, this is not the capital costs of software or hardware that are often cited in the literature, but the cost of training staff and implementing new workflows across disciplines. The selected firm had a full suite of BIM software but only used a small selection of the available products, even then for design only. Therefore, managing and sustaining the change requires comprehensive support from directors and managers, as well as a proper context to support that change.

The results of the interviews also revealed that, despite having access to a full 3D design model, the sharing of information between disciplines was always via PDF format. Rather than a two–way, BIM–enabled, collaborative workflow, the issuing of information through PDF forces disciplines to work sequentially within their discipline silos and requires significant double-handling of information. By the same token, the literature review indicated that one of the key benefits of BIM implementation is reducing requests for information and change orders (up to 40% elimination of unbudgeted change), while sharing through PDF format impedes benefits to the firm of using a central model. Also, the literature indicated that reducing the cycle time of workflow is one of 15 benefits (table 2.1) that BIM implementation offers to businesses (section 2.3), especially smaller business.

Although sharing project information in PDF format is a simple method to overcome the information transfer bottleneck among disciplines using different software, there are potential issues hidden within this process that were identified through the interview, in addition to the impediment it presents to saving project information within the central model. One of the identified issues was keeping the correct scale of drawings during the sharing process because the file receiver may import the required information using the wrong scale, or the data itself may be close to reality but not accurate enough. On the other hand, one of the benefits of BIM implementation noted in the literature review is reducing costs by improving the accuracy and speed of cost estimates; that is achievable through a central model and the collaborative method. The other potential problem of using PDF format is dependency upon the original source of information, which was revealed by the interviews. According to the participants, any further details or required information always necessitate contact with the original source; whereas, according to the literature, the collaborative method offers a faster and more efficient process, with faster regulatory approval cycles. Interviews with team members also revealed that sharing information through PDF format causes problems for tracking the information from different disciplines, especially at the end of projects, and many projects have no as-built drawings or their drawings are not accurate enough. In that regard, the literature review shows that BIM allows projects to benefit from more traceable data over a project's life-cycle. Therefore, despite the existing resources within the studied firm, the lack of integration and compatibility of shared file formats resulted in the real potential of BIM for the firm not being currently realised.

The literature indicates that the delivery method of a project has a significant impact on the context of BIM. Implementation of BIM as a new methodology for project delivery has its pros and cons, which have been studied in the earlier chapter. Reviews have shown that the design-build method, which is more common among construction projects, is a suitable method for implementing BIM. Also, diagrams have illustrated that both the BIM-enabled method and the design-build method utilise collaboration between design and construction with the differences only in the stage and intensity of integration. Therefore, identification of the current process used by the selected firm was one of the aims of this research. Findings from the interviews determined that the existing process was very similar to the design-build project delivery method. As the following diagram (Figure 6.1) illustrates, the identified workflow is an appropriate context for BIM implementation, and the earlier collaboration between design and construction should streamline the adoption process.

The diagram evolved throughout this research journey and, based on the participants' feedback, it was clarified that benefit would be gained if the planner, as the construction representative, joined the project team at a very early stage. The interviewees' responses to the questions of, "Is there any

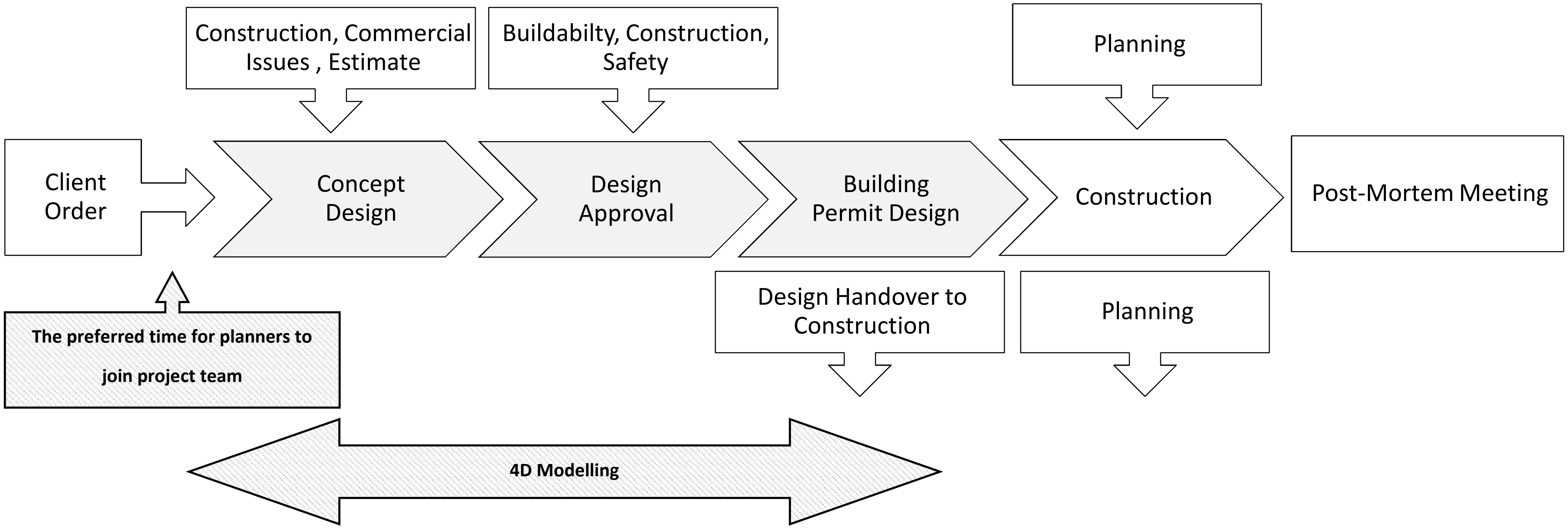



Figure 6.1 The workflow diagram and need for earlier collaboration

need to change the process to improve?” and “When is the best time for a planner to join the project?” showed that they all agreed on the benefits of early collaboration if the planner joins the project at an earlier stage.

Another aspect of this research was the presentation of a 4D model of an actual project that the selected firm was undertaking, for the purpose of gathering more authentic feedback from interviewees. Demonstration using a project that the participants were involved with made it more believable that it could be achieved with the existing files and software.

Some interviewees found the simulation to be a practical tool for marketing that provided easier communication with clients, while participants from the construction team found it to be a powerful tool to streamline working with subcontractors and controlling site works. This finding emphasised the efficiency of the central model for different disciplines within the same project, as well as the value of early collaboration in development of the central model.

Another barrier to implementation of BIM mentioned in the literature review is technical support. The interview findings also confirmed this issue. For example, some interview participants had experienced some unsuccessful attempts to use hidden potentials of the 3D model for take offs and had finally given up; the provision of technical support and training could have helped them to apply new methods in their future projects.

Even though this case study satisfied the required context, including the partial availability of software, the research has identified the poor level of awareness and lack of willingness to make change as the main reasons for SMEs not adopting BIM.

In addition, other factors that cause SMEs to avoid adopting BIM are the cost, a lack of technical support, and the requirement to re-engineer processes to support collaboration among disciplines. The literature shows that the level of BIM adoption is growing. An increase in government support, particularly the offer of more technical support targeted at SMEs, would help to increase BIM adoption in this important sector and ensure that its benefits can be realised.

## 6.3 How Can SMEs Adopt BIM?

In order to establish how SMEs can adopt BIM, this research studied existing files and ran, analysed and documented a 4D simulation. Analysis was designed to identify any potential issues in the process, and to gain a common understanding of the requirements of collaborative 4D BIM within the context of an SME. It is anticipated that the results of the study could also be used as a foundation for adding future “dimensions”, including cost.

In order to prepare the 4D simulation, initially, the design aspects from each discipline needed to be amalgamated into a single central 3D model. However, it was found that not all disciplines were preparing their information in a 3D format, which impacted on the completeness of the central model. For this case study, the structural model was partly in 3D and partly in 2D, while the MEP information was mostly in 2D format. This resulted in a model that had some missing items. It is expected that this is fairly typical within this sector because results from the literature review indicated that only 4% of Australian firms currently implement fully collaborative BIM.

Despite this shortcoming, a unified model was created and linked to the construction program. The main issues at this stage arose from the different work breakdown structures of the design models and the construction program, which resulted in conflicting levels of detail between the two. Results of the literature search show that the differences in the work breakdown structures commonly adopted by the architectural and contractor industries are deeply embedded within their everyday work practices. However, there is significant room for improvement through more collaboration between the architectural and construction teams in the preparation of the project WBSs in the early stages of a project (Figure 6.2).

### 6.3.1 Add 4D Parameter to Revit File

The following section focuses on existing capabilities within the model that can be built upon to enable achievement of more effective collaboration between the designers and planners, without any major disruption, and some recommendations are proposed that may help to provide a better context for implementation of BIM in SME firms working on residential projects.

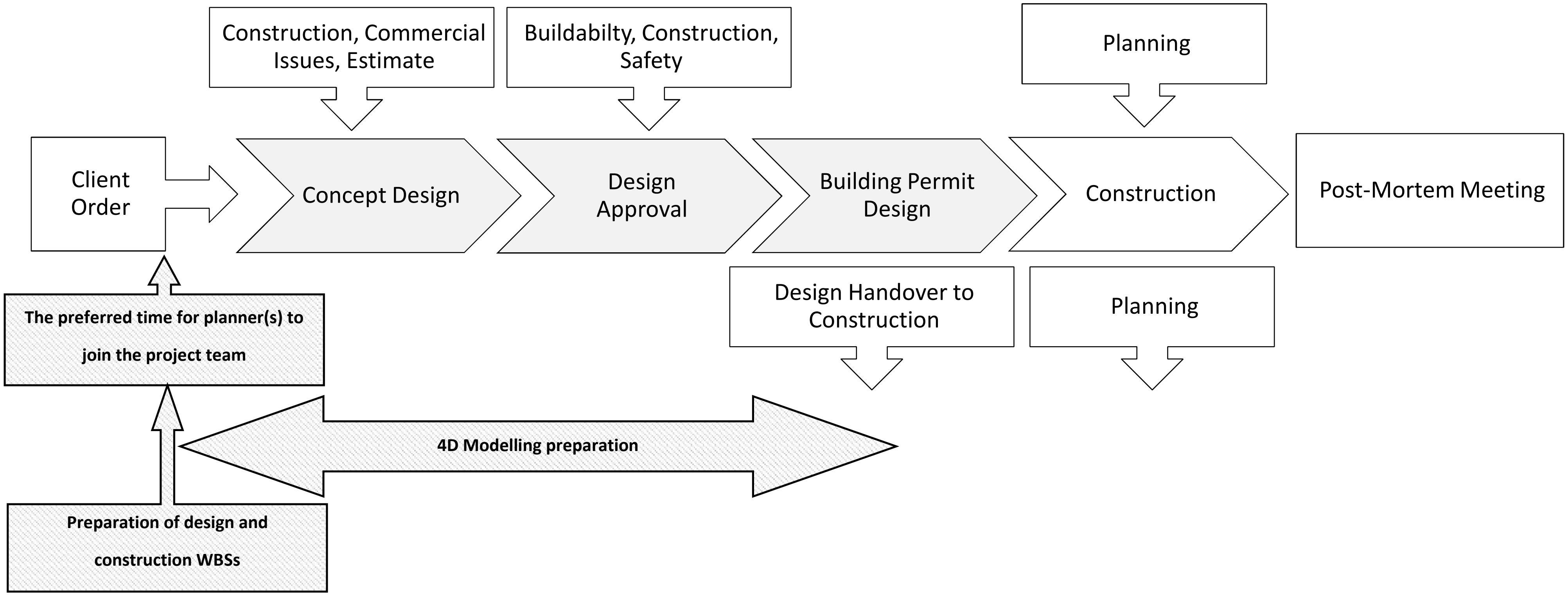



Figure 6.2 Evolved workflow to streamline BIM adoption by an SME

#### *6.3.1.1 4D Modelling Practice*

The Navisworks software has some embedded tools to streamline the linking process between schedule and model. These can be used to best effect if the structures of the 3D model and the schedule have been previously aligned. For example, the *Selection Set* and *Search Set* are tools that make the linkage process easier, but they are dependent on well-structured data with consistent naming conventions. All of the components from the Revit model can be viewed in the *Selection Tree* in Navisworks, along with the properties of each component. Navisworks is intended as a review tool and, therefore, is not suitable for editing a BIM. While minor changes can be made to semantic data within Navisworks, these changes will be overwritten every time the design model is updated.

It is possible to simply link individual components, or sets of components, to a task (or tasks) by "attaching" them through the *Timeliner*. Due to the different levels of detail in the 3D model, compared to the schedule, tasks in the project's timeline often refer to multiple components in the 3D model. It can be simpler to create "sets" of selected components before attaching them to the related task(s). As an example, Figure 6.3 shows a group of piles that have been selected through the *Selection Tree* and attached to the piling task in the *Timeliner.*

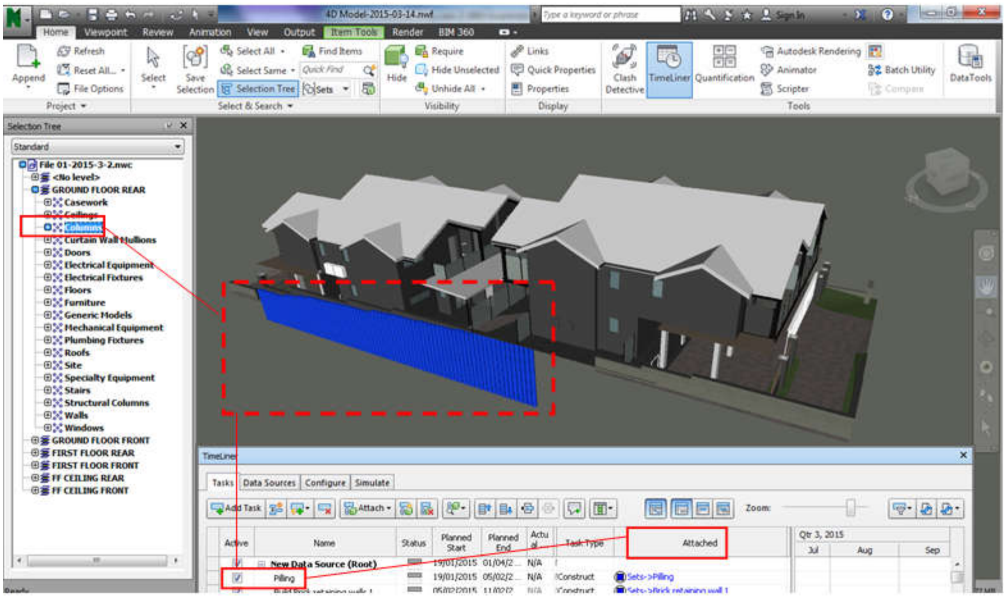


Figure 6.3 Linking 3D elements to tasks by attaching them

While this method of selection is simple, the selections are static. That is, they do not automatically update if the design changes. There is a more practical way to select groups of components that can accommodate changes in the 3D model by using the *Find Item* function in Navisworks to define a search, based on the category property values of components, and save the results as a *Search Set*. The main advantage of using *Search Set* in comparison to manual selection of sets is that the former can be dynamically updated if the model is updated. If a new component is added to the model, the search can be re-run, and it will find any new components that meet the search criteria, and then update the selection set (Figure 6.3).

Since all construction projects experience changes in the model or time schedule during the building process, the *Search Set* method is the preferred method for keeping the 4D model up to date.

Table 6.1 and Figure 6.5 present the properties of the case study's 3D model in Navisworks. Many of the categories are not helpful when searching for selection groups in line with the construction schedule. For example, a useful search result would be one that could identify all elements scheduled for construction at the same time but the design-oriented breakdown of the model cannot accommodate this without the addition of time-based information held within the schedule. However, there is potential for this information to be added to the design model if planners and

the design team collaborate at an early stage to agree upon the minimum requirements for alignment, which would significantly streamline 4D modelling.

| | |
|---|---|
| **Main Advantages of *Find Item* with *Search Set* Method** | Finds new items that match the search criteria |
| | Dynamically updates set(s) based on model updates |

Table 6.1 *Find Items* with *Search Set* method: Main advantages

In this case study, when executing the 4D modelling process, the search criteria for returning items associated with a particular task, executed through the *Find Item* function, worked for only some of the components. For example, when searching for "concrete slab of first floor" the data could not support the search. This was because it was based on the "level" and "family" categories and the remaining items were attached to the tasks manually (Figure 6.3).

The key to creating a sustainable 4D model in Navisworks is to ensure that all design data is edited in the 3D model (in this case, in Revit) and the construction tasks are edited in the schedule (in this case, in MS Project).

Given that *Search Set* results will ultimately be attached to the *Timeliner* tasks, adding new parameters to the Revit original file that are in agreement with the timing schedule may facilitate the use of the *Find Items* function for more efficient 4D modelling.

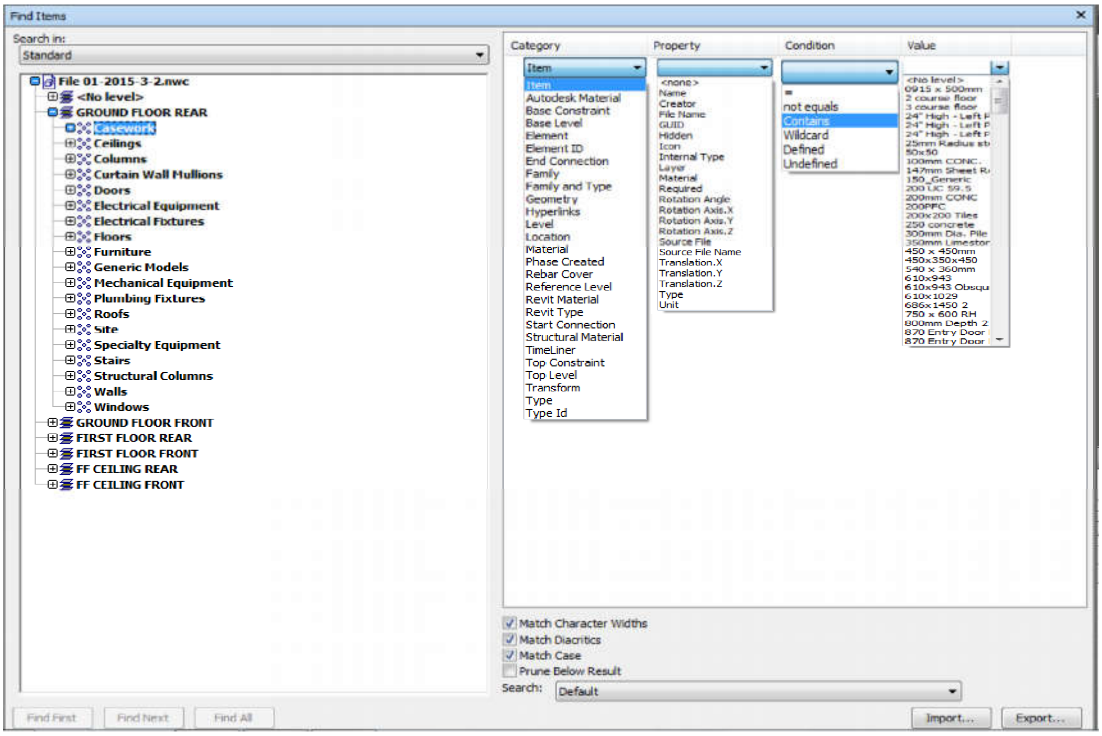



Figure 6.4 Capabilities of the *Find Items* function

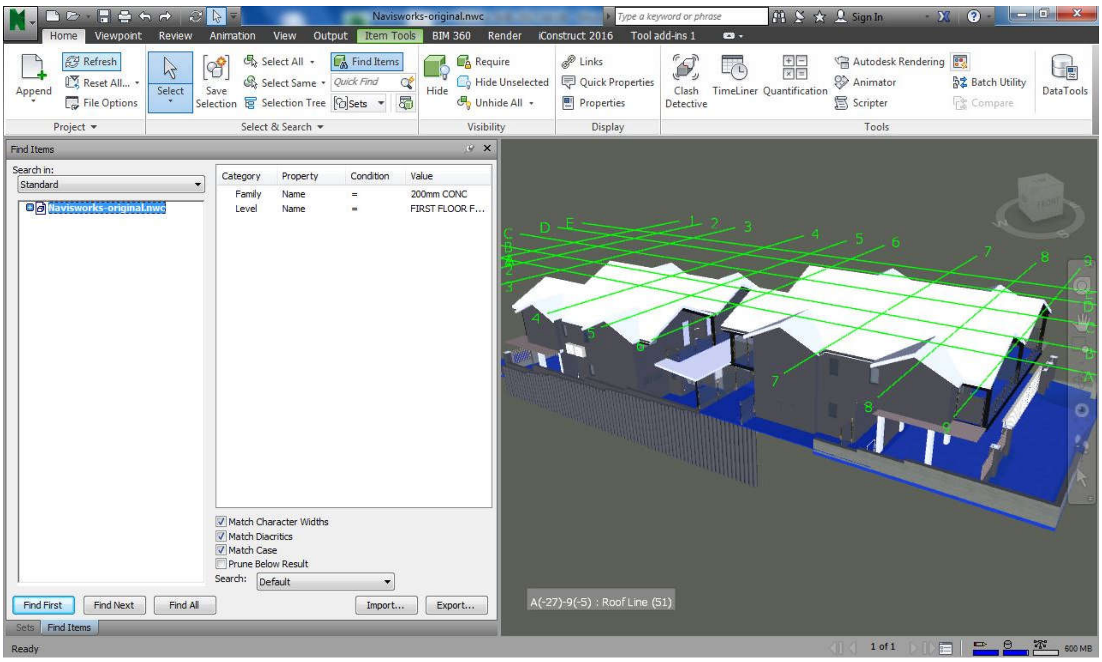



Figure 6.5 Find Items result for finding first floor concrete slab

Therefore, examination of existing files to create a BIM model reveals that the differences between design and construction WBSs impede the use of some 4D software functions.

Table 6.2 Applicable categories to the case study model and *Find Item* criteria

| Category | Applicable to the model | Property | Condition | Value |
|---|---|---|---|---|
| Item | ✓ | Name | = | Based on project values |
| Autodesk Material | × | Creator | Not equal | |
| Base Constraint | ✓ | File Name | Contains | |
| Base Level | ✓ | GUID | wildcard | |
| Element | ✓ | Hidden | Defined | |
| Element ID | × | Icon | Undefined | |
| End Connection | × | Internal Type | | |
| Family | ✓ | Layer | | |
| Family and Type | × | Material | | |
| Geometry | × | Required | | |
| Hyperlinks | × | Rotation Angle | | |
| Level | ✓ | Rotation Axis X | | |
| Location | × | Rotation Axis Y | | |
| Material | ✓ | Rotation Axis Z | | |
| Phase Created | × | Source File | | |
| Rebar Cover | × | Source File Name | | |
| Reference Level | × | Translation X | | |
| Revit Materials | ✓ | Translation Y | | |
| Revit Type | × | Translation Z | | |
| Start Connection | × | Type | | |
| Structural Materials | × | Unit | | |
| Timeliner | × | | | |
| Top Constraint | × | | | |
| Top Level | ✓ | | | |
| Transform | × | | | |
| Type | ✓ | | | |
| Type ID | × | | | |

In addition to problems relating to the linkage of items and tasks, there are also issues surrounding the modelling of temporary items. While it is clear that the modelling of many of the temporary items helps to provide a more complete picture of the construction process, it would also be useful to graphically differentiate them from permanent components within in a 4D model in order to clearly communicate with the site team. The Navisworks software facilitates this by allowing the user to select a task's presentation according to three types, namely: Construction, Demolition and Temporary. Each type has a colour code that can be changed by the user. By default, Construction tasks are presented in green, Demolition in red and Temporary in yellow. This function helps to clearly communicate the Permanent/Temporary systems within the design WBS.

If required, additional "temporary" types and colours can be added to the configuration. This means that, if desired, the WBS sub-systems for temporary items can each be presented individually. The presentation can be adjusted from *Model Appearance*, which by default is set to *Hide*, but can be changed based on the requirements of the project (Figure 6.7).

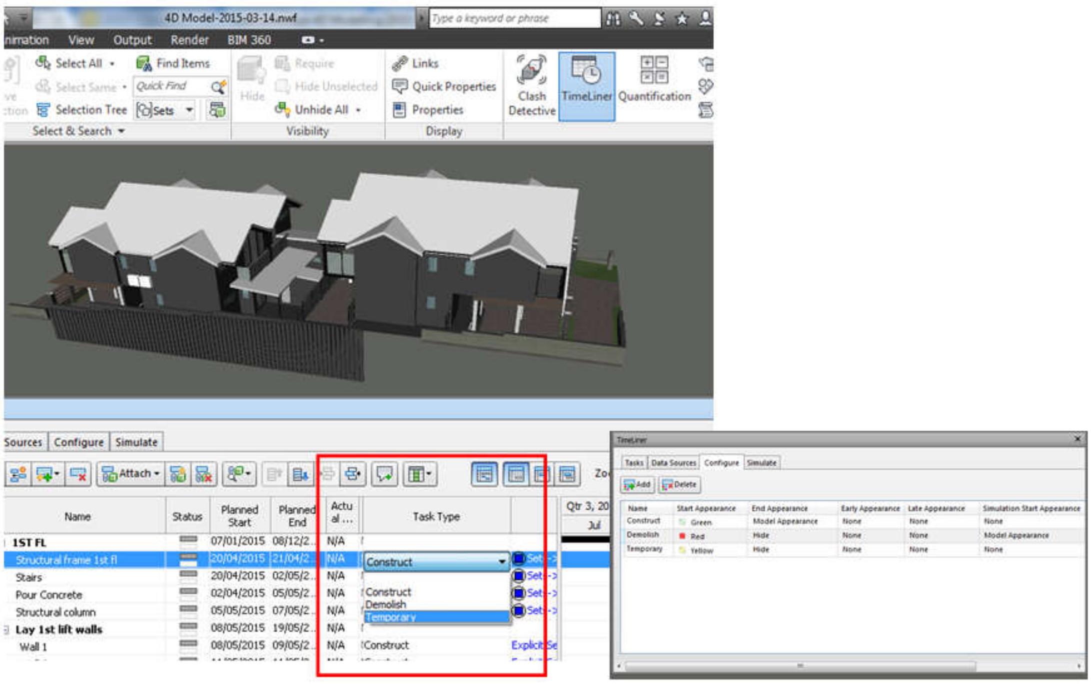


Figure 6.6 Task type

### *6.3.1.2 Streamlining the Linking Process*

The linking of elements within the model to tasks within the program is time consuming and requires maintenance if any changes are made to either the design or the program. However, Revit allows the addition of new parameters that can work in conjunction with the inbuilt functions of *Find Items* and *Search Set*, which makes the linkages between building elements and construction tasks more efficient and robust. The following section details the process for creating a new parameter and using it to automate the linking process.

Revit software uses *shared parameters* as a mechanism for consistent addition of information to elements across projects. Before creating a new *parameter*, a new *parameter group* is required.

Figure 6.8 presents the *Edit Shared Parameter* dialog box, which is accessible through the *Manage* menu. In the dialog box, a new group can be added. In this instance it has been named *4D Modelling* (Steps 1 to 4).

The next step is to create the new parameter within the *4D Modelling* parameter group. The new parameter has been named *4D Task ID* and assigned a parameter type *text*; see Figure 6.9, steps 5 to 7.

Once the *shared parameter* has been created, it can be added to any project. This process starts with the *Manage* tab (Step 8), then selection of *Project Parameter* (Step 9) and *Add* to add the new parameter (Step 10). In the *Parameter Properties* dialog box, the previously created parameter, *4D Tasks ID,* can be selected as a *shared parameter* (Steps 11 and12).

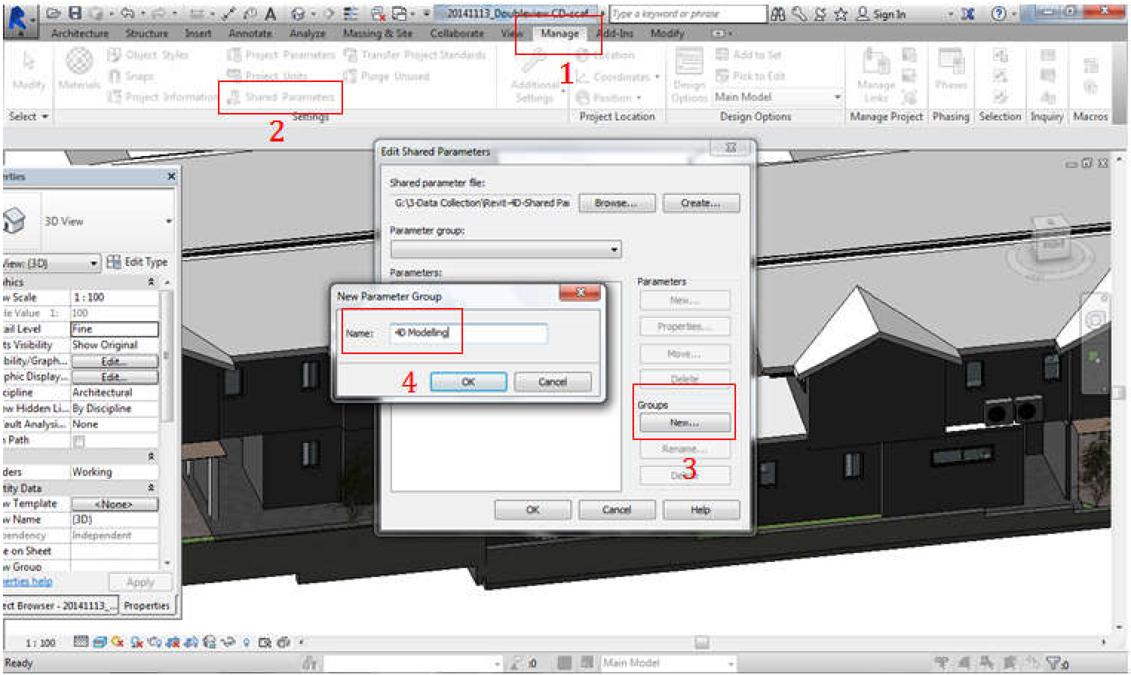



Figure 6.7 Creating new parameter group in Revit

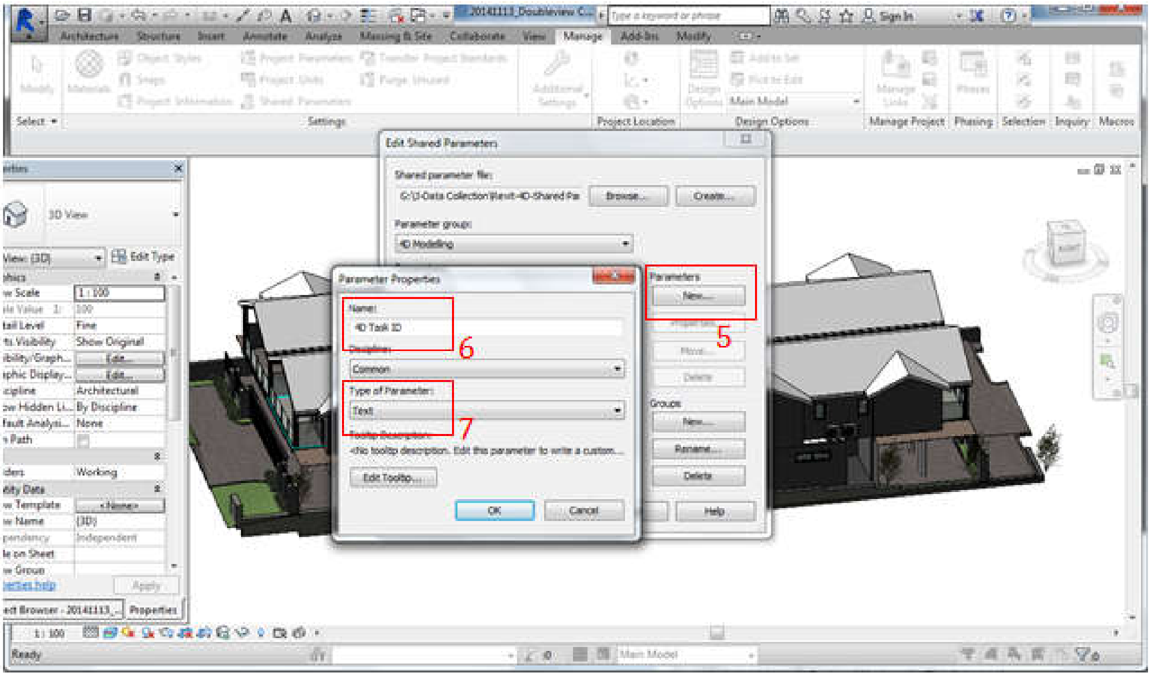



Figure 6.8 Creating new parameter within parameter group

As this new parameter was created for construction modelling and timeline management, it is appropriate to group it under the construction parameter group

(Step 13). This will ensure that it will appear in the correct section of the Revit properties dialog (Figure 6.10).

Finally, step 14 shows how to select the categories to which this parameter can be applied. As the *4D Tasks ID* is applicable to almost all of the categories, the *Check All* option is used to select all categories and those, such as Area, Room, Views, etc., which are not relevant, are subsequently unchecked.

Figure 6.11 illustrates the result of creating the new parameter in the Revit model. When an item is selected, *4D Task ID* appears in the properties pallet, under the construction group, and the value for the ID can be added by the user.

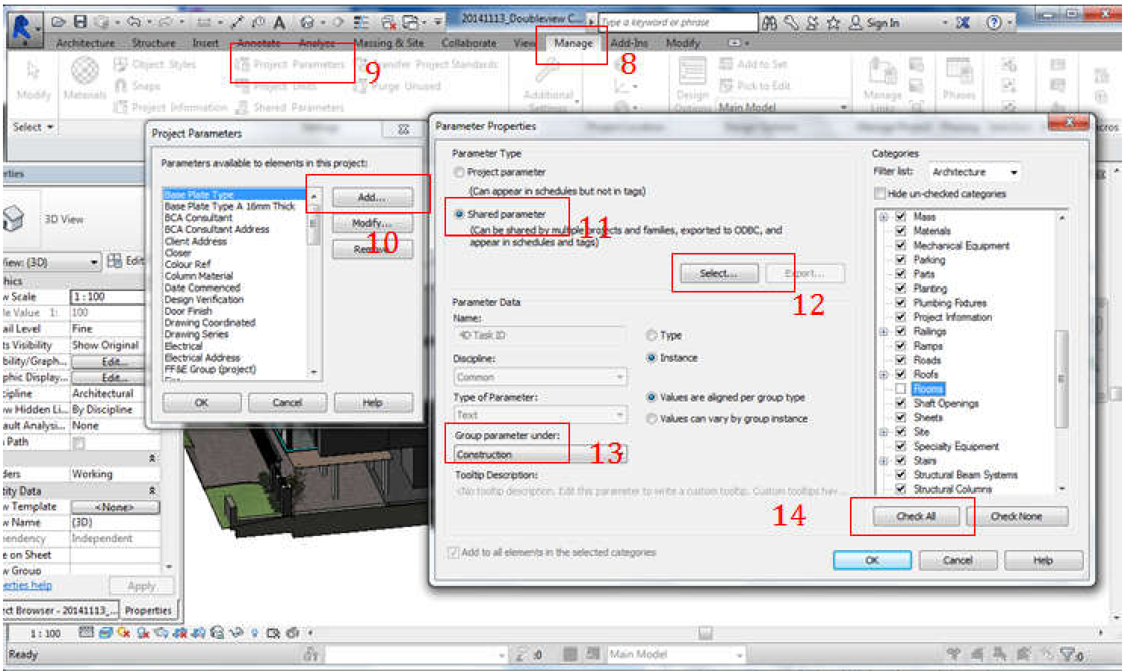



Figure 6.9 Adding new parameter to project

The addition of this parameter is the first step towards a construction-oriented model, with construction information embedded in the model during the design stage. This new parameter can be used as a mechanism to align the design WBS with the construction WBS, if the mapping between the two is agreed upon during the early stages of the project.

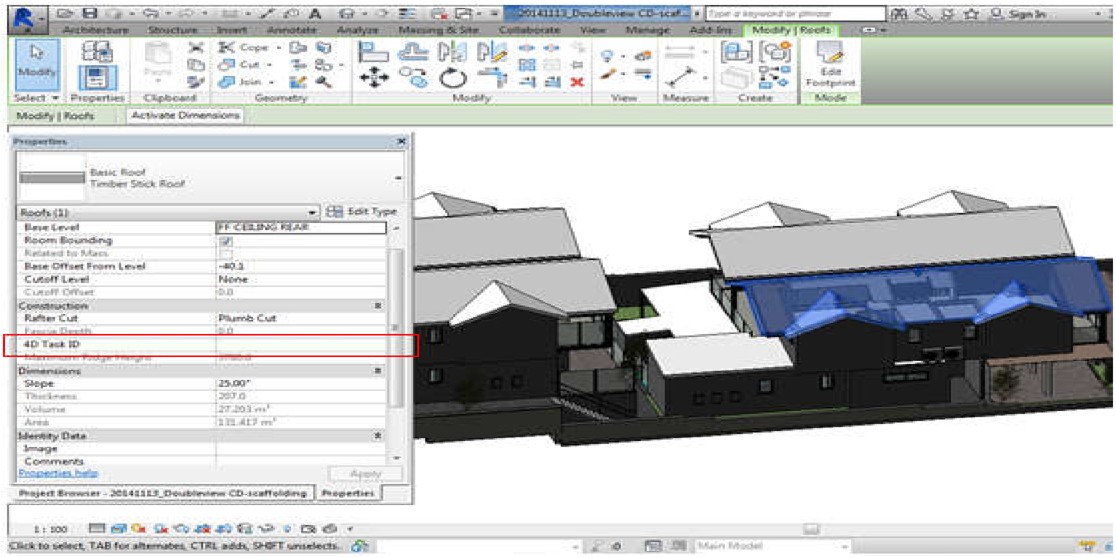



Figure 6.10 New parameter added to properties pallet

## 6.3.2 Task ID in Time Schedule

The Work Breakdown Structure (WBS) is a mechanism to break down a project into its different levels and phases, with each level further broken down to sub-levels as many times as required. The lower levels should be measurable and deliverable to enable project progress measurability. In this case study, Microsoft Project (MSP) was used to manage the breakdown of the construction into measurable tasks. In MSP, each task has a unique WBS ID that reveals the level of the task through a cascading hierarchy.

Figure 6.12 shows a sample of the WBS IDs of tasks in the case study project. In this example, ‘Pour Footings Block A’ has the WBS ID (1.2.3.4). This ID means it is task number four at the outline level three, which is called ‘Concrete Work Block A, Ground Floor’. ‘Concrete Work Block A, Ground Floor’ is a sub-level of ‘Site

Works', which is at outline level two of the project. The main project title is the highest level of the WBS, or outline level one.

Figure 6.13 shows the WBS ID hierarchy of a selected part of the whole project's WBS, with the different outline levels of the project, from the highest level to one highlighted individual measurable task.

The next step is to input the value for the WBS ID into the prepared parameter *4D Tasks ID* in the Revit model.

In order to prepare the above context for collaborative construction-oriented BIM, project teams need to work more closely together. If planners and designers can work together to agree on the mapping between the design and construction WBSs at the beginning of a project, then the designers could add the construction WBS IDs as parameters within all relevant categories of their model. This early collaboration would allow the development of a construction-oriented model that would meet all planners' requirements and allow integration of the project schedule (4D modelling).

The results of this study show that, even though the foundations for preparing a BIM model are in place, there are still some problems that need to be resolved to support collaboration on a BIM. Some internal processes need rethinking and streamlining to address differences, such as those between the design and construction WBSs. Other problems, such as those relating to the use of BIM by external project parties like the structural and MEP consultants, need patience to build up the required BIM skills and, if necessary, more technology-savvy tradespeople and consultants must be found to partner with.

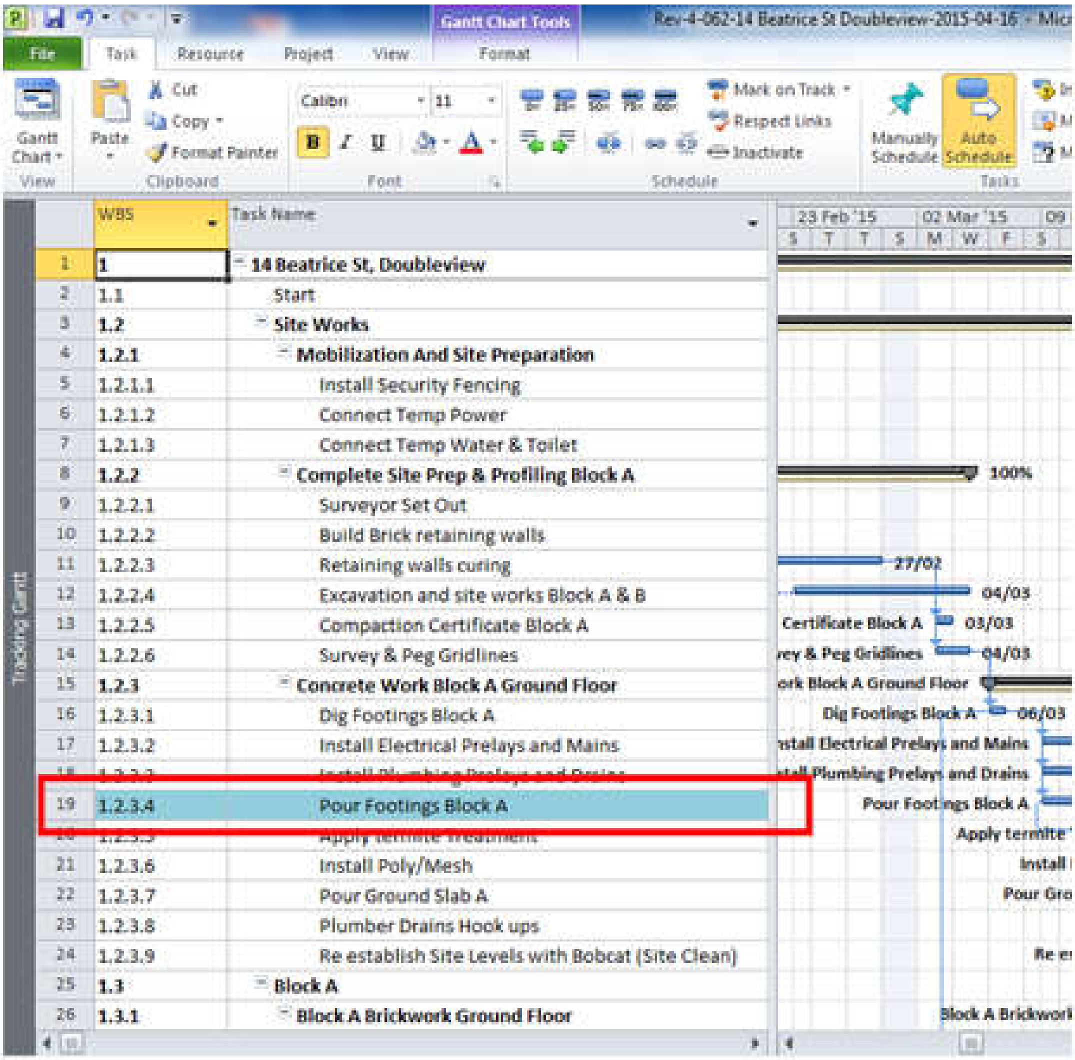


Figure 6.11 WBS ID of tasks

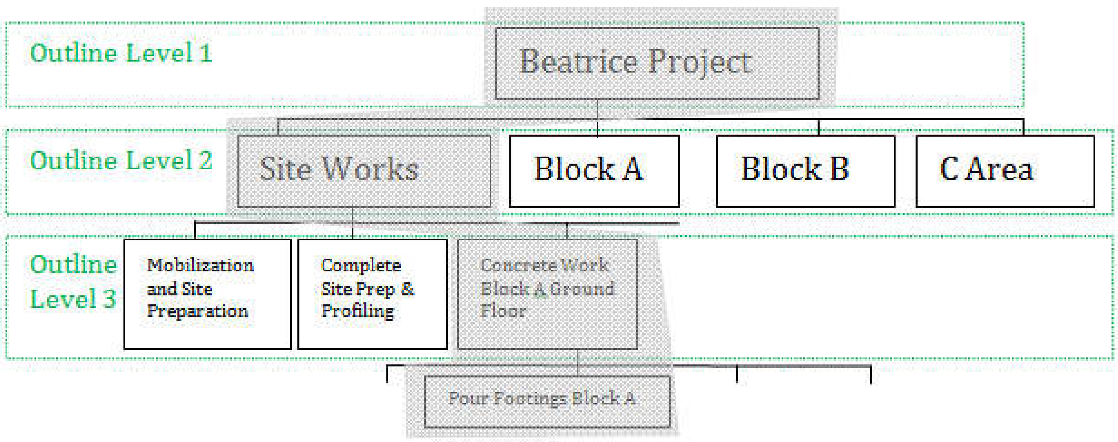



Figure 6.12 Part of the WBS that shows WBS ID: 1.2.3.4

# CHAPTER7: CONCLUSIONS

## 7.1 Literature Review

The review of existing knowledge and practices in BIM confirmed that, although the BIM implementation rate is increasing within the construction industry, the private sector has been slow to embrace this movement. Much of the focus of investigations to date have related to large-scale projects within the public sector, despite the importance of SMEs within the construction industry. Additionally, support for BIM adoption in the context of small to medium projects has focused on the design industry, with little penetration into the construction sector. With construction firms accounting for 95% of Australian SMEs, support for technology investment in this sector is needed in order to realise the benefits of a collaborative BIM environment.

Procurement methods are often cited as a perceived barrier to collaborative BIM. Within the SME sector, the de facto project delivery method for construction projects is the Design-Build method. The literature shows that this project delivery method has the required potential to engender collaborative BIM.

The success of a project delivered through the Design-Build method is often measured through timely completion. The addition of the time factor to a design model potentially expands BIM use to involve the construction team. The literature review findings show that planners and designers have different viewpoints as to how a project should be broken down (through a WBS). In order to enable collaborative BIM between design and construction there needs to be some alignment of these differing viewpoints. Once this alignment has been defined, time can be integrated into a design model to produce a 4D BIM that is suitable for collaboration during the construction phase.

## 7.2 Research Methodology and Design

Based on the findings in the literature review and the requirements for this research, the research methodology and design for this study was planned based on the two pillars of theoretical and practical research. The theoretical research was conducted via an in-depth review of the existing scientific resources; the practical research focused on a case study, through analysis of existing information models, as well as in-depth, semi-structured interviews.

According to the theories, the suggested strategy for answering "Why" and "How" research questions is use of the case study. Therefore, a single, in-depth case study project was selected as the approach of this study. Given that interview and observation are multiple data collection traditions in the case study approach, a semi-structured interview with the project's key members was selected for this research in addition to observation of the project's construction through weekly site visits. In order to enrich data collection, the triangulation research method was conducted. Hence, 4D documentary resources were selected as the third leg of the triangulation method. The 4D documentary resources included the examination of existing files to figure out potential issues, as well as to clarify the existing workflow among project team members in the chosen SME firm.

## 7.3 Interview

The in-depth, semi-structured interviews sought to identify "why" SMEs were not currently adopting BIM. The results affirmed that despite many of the components required for 4D modelling being available, including a 3D Revit model and the existing project time schedule, there were still some barriers to its implementation.

These included a lack of awareness and a lack of experience among existing staff, which slowed down the adoption process. Increasing knowledge of BIM, particularly among the owners and senior management staff, would increase the chance of successful BIM implementation in SME firms. An understanding of the benefits across a project's life-cycle is key for the senior managers because they will need to instigate a change in mindset to focus on deriving value over the entire project cycle rather than concentrating on the need to save time at the beginning of a project, which always results, at best, in digital rework within the project model or, at worst, rework on site during construction. While training is an effective mechanism for increasing awareness and building experience, the results from the interviews also indicated that the use of a practical "real" model was a very effective tool for communicating the potential benefits at all levels.

The findings from interviews reinforced that the current workflow, based on Design-Build, was compatible with a BIM-enabled method of working. Therefore, in this case study, the foundations for BIM were in place, ready for implementation. However, interviewees acknowledged that collaboration between the design and construction teams at an earlier stage would enhance the current workflow.

One of the key issues identified was the lack of integration and compatibility of shared file formats and an inadequate knowledge of software capabilities, resulting in project members resorting to the 'lowest common denominator' file format (in this case PDF). This was further compounded by poor coordination of information exchanges and insufficient familiarity of the external consultants and tradespeople with the new generation of software. In order for SMEs to fully embrace collaborative BIM, training needs to be extended to key sub-contractors, including the MEP and structural consultants.

## 7.4 4D Modelling and Observation

An examination of documentary sources, aimed at establishing "how" SMEs could best implement collaborative BIM, outlined three main problem nodes encountered through the 4D modelling process using the existing 3D model and time plan. These were:

1. Missing elements
2. Miss-matched levels of detail
3. Up-skilling of sub-contractors/consultants

In addressing all nodes, the early definition of a project's WBS is the key to successful BIM implementation across both design and construction. While this may vary across projects, depending on the individual requirements, the evidence presented suggests that more collaboration at earlier stages of the project, particularly between designers and planners, is essential to address the first problem node. This earlier collaboration would allow team members to agree on the required level of detail in the 3D model, in alignment with the breakdown level of the time schedule. In particular, modelling of key temporary components such as scaffolding, formwork and/or props would help to identify construction issues prior to work starting on site.

Even though the designers, when compared to other project parties, have a better level of BIM readiness, there are still areas of work where some basic actions could facilitate more efficient and effective modelling and, in so doing, would help to address problem node two. If designers, through collaboration with the construction team, could model project components with a construction mindset, the resulting model would be suitable for use throughout the design and construction phases. Construction-oriented modelling is a way to reduce the need for digital remodelling through integration of project information and it would provide the required context for 4D BIM implementation. It is worth noting that this would also help to prepare for future dimensions of project information, such as cost, to be added.

This collaboration needs to be bi-directional so that the planners, while working with the design team to clarify the construction sequence, would also have a better understanding of the project's progress through the resulting simulation, as well as a more accurate BIM tool for controlling project progress.

Problem node three identified that, in order for the model to be complete, all disciplines need to contribute to the shared model. However, in SME-scale projects the majority of the structural and MEP firms cannot easily meet the minimum requirement of a BIM model. This could be due to several different reasons, including the time required for up-skilling, the cost of training and software, and a lack of incentive to change. Given that the MEP component of this case study was outsourced, there was little opportunity to influence that change. Nonetheless, over time, as the new technology becomes more embedded within education and the entire industry, the investment required to make the change will decrease and the incentives will continue to grow. It is expected that, over time, the BIM technology and collaboration processes will mature and, even at this smaller scale, there will be MEP information in a 3D model. By the same token, modelling for construction purposes (or construction-oriented modelling) would help a firm to have a powerful concept model that could be blended with other disciplines more easily. This preliminary readiness will help to enhance the project model with some basic steps.

The observation section acted like a control of the 4D model in relation to the real world construction. The aim of this section was to monitor construction progress and the site reports, and to find out whether any of the reported items could be recognised through 4D modelling. This finding indicated that two main reported issues could have been realised through a simulation file if the temporary items and the site's existing features had been modelled. This finding accentuated that there were identical levels of detail among project teams. It also showed the efficiency of BIM for any size of project.

Importantly, the extension of BIM's use into the construction phase does not need to include a complete re-think but, particularly in companies such as this case study where BIM design models already exist, it can also be achieved incrementally.

## 7.5 Limitation of the Study

The research presented in this thesis is specific to SMEs operating under Design Build contracts and, therefore, it is not completely suitable for all residential sector construction projects.

Moreover, the research focused on a single, in-depth case study and current work practices embedded within. This included examination of workflows focused on a specific set of proprietary software, which, whilst know to be in wide use within the sector, are not universally adopted.

## 7.6 Future Research

In light of the limitations relating to a single in-depth case study it is recommended that the foundations laid within this work be extended to examine a broader context to include multiple cases across a range of DB residential contractors. Whilst there are some efforts underway to align discipline specific work breakdown structures with the object oriented needs of a BIM, there still remains much work to do to bring this work together into a pan-industry standard needed for effective collaboration. Finally, there is a specific need within the SME sector to investigate mechanisms for 'incentivising' SME sub-contractor BIM adoption.

# REFERENCES


AGC. 2006. "*AGC Contractor's Guide to BIM.*", Retrieved August 15, 2015, from: https://www.agc.org/

Amor, R., and R. Owen. 2011. "*Beyond BIM - It's Not the End of the Road.*" Retrieved October 5, 2015 from:

http://www.aecbytes.com/viewpoint/2011/issue_58.html

Arayici, Y., P. Cates, L. Koskela, and M Kagioglou. 2014. *"BIM Adoption and Implementation for Architectural Practices"* Manchester: University of Salford.

Arayici, Y, Coates, SP, Koskela, LJ, Kagioglou, M, Usher, C and OReilly, K.

Retrieved July 3, 2015, from:

http://usir.salford.ac.uk/13046/2/BIM_Adoption_and_Implementation_for_Architectural_Practices_Published_version.docx.pdf

Atkinson, R., 1999. *"Project management: cost, time and quality, two best guesses and a phenomenon, it's time to accept other success criteria."* International Journal of Project Management 17: 337–342.

Azhar, S., et al. 2012. *"Building information modelling (BIM): now and beyond."* Australasian Journal of Construction Economics and Building 12 (4) 15-28.

Babu, A. J. G., Suresh, Nalina. 1996. "*Project management with time, cost, and quality considerations.*" European Journal of Operational Research 88(2): 320-327. ISSN 0377-2217, 10.1016/0377 2217(94)00202-9.

Barlish, and Sullivan. 2012. "*How to measure the benefits of BIM — A case study approach.*" Automation in construction 24: 149-159.

*British Standard in Project Management 6079.* ISBN 0 58025594 8.

Beard, Jeffrey L.; Wundram Edward C.; Loulakis, Michael C. "*Design-Build: Planning Through Development.* An Introduction to Design-Build Project Delivery", Chapter (McGraw-Hill Professional, 2001), AccessEngineering

BIM Standard (2009) - AEC (UK) - Version 1.0 November 2009 First release, A practical & pragmatic BIM standard for the Architectural, Engineering and Construction industry in the UK.

Brady, T., Davies A., and Gann, D. 2005. "*Creating Value by delivering integrated Solutions*", International Journal of Project Management, pp. 360-365.

Brito, Douglas M., and Emerson A.M. Ferreira. 2015. "*Strategies for representation and analyses of 4D modelling applied to construction project management*" Procedia Economics and Finance: 8th Nordic Conference on Construction Economics and Organization 21: 374-382.

buildingSMART Australasia. 2012. *"Strategy: A strategy for the focussed adoption of building information modelling and related digital technologies and processes for the Australian built environment sector, report to the Department of Industry, Innovation, Science, Research and Tertiary Education, Sydney, June 2012*." National Building Information Modelling Initiative 1: pages (14 to 45).

buildingSMART Australasia. 2016. *"Meeting government policy objectives through the adoption of Building Information Modelling (BIM)*", Industry recommendation, November 2016.

Chau, K.W., M. Anson, and J.P. Zhang. 2004. "*Four-Dimensional Visualization of Construction Scheduling and Site Utilization."* Journal of Construction Engineering and Management, ASCE 130(4): 598-606.

Colin Robson. 2004. *Real world research: a resource for social scientists and Practitioner-researchers.* 2nd ed. Victoria: Blackwell Publishing. ISBN0-631-21304-X.

Czmocha, Ireneusz, and Adam P. Ċkalaa. 2014. *Traditional Design versus BIM Based Design.* Warszawa, Poland: Elsevier Ltd. This is an open access article under the CC BY-NC-ND license.

Dainty, Andrew, Roine Leiringer, Scott Fernie, and Chis Harty. 2015. "*Don't Believe the (BIM) Hype: The Unexpected Corollaries of the UK 'BIM Revolution."* Paper presented at the Engineering Project Organization Conference, The University of Edinburgh, Scotland, UK, June 24-26.

Dakhil,A , Underwood, J, (2016). *"BIM benefits-maturity relationship awareness among UK construction clients"From:* https://www.researchgate.net/publication/308375997_BIM_benefits-maturity_relationship_awareness_among_UK_construction_clients

Deke, Smith, 2007. "*AIA. An Introduction to Building Information Modelling (BIM)."* Journal of building information modelling - An official publication of the National BIM standard (NBIMS) and the National Institute of Building Science (NIBS). http://www.wbdg.org/pdfs/jbim_fall07.pdf

Devi, T. Rajani, and Reddy, V. Shobha. 2012. "*Work Breakdown Structure of the Projec.*" *International Journal of Engineering Research and Applications (IJERA)* 2(2): 683-686. ISSN: 2248-9622 www.ijera.com.

Eastman, C., P. Teicholz, R. Sacks, and K. Liston. 2011. *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors.* 2nd ed. NY: John Wiley and Sons.

Eastman, C., and M. Henrion. 1977. "*GLIDE: A Language for Design Information systems.*" ACM SIGGRAPH Computer Graphics 11(2): 24-33.

Engineers Australia. 2014. *Driving Building Information Modelling (BIM) uptake.* https://www.engineersaustralia.org.au/portal/news/driving-building-information-modelling-bim-uptake

Engineers Australia Queensland Division, 2005. *Getting it Right the First Time: A plan to reverse declining standards in project design documentation with the building and construction industry, Industry wide taskforce.*

Erika, E., 2012. *Implementing Successful Building Information Modelling.* Norwood: Artech House. ISBN: 9781608071401.

Fellows, R., and A. Liu. 1997. *Research Methods for Construction.* Oxford: Blackwell Science Ltd.

Flyvbjerg, Bent. 2006. "*Five Misunderstandings About Case-Study Research*." Qualitative Inquiry 12(2): 219-245.

French, S., and A Khanzode. 2006. "*3D and 4D Modelling for Design and Construction Coordination: Issues and Lessons Learned*." http://itcon.org/2007/26/ EDITOR: B-C Björk.

Ghaffarianhoseini, A , Rehman, A, Naismith, N, Tookey, J, et al. 2016. "*Developing a BIM Executive Framework for SME Construction Companies in the UK."* Paper presented at the *4th BIM International Conference, Sao Paulo and Lisbon, September.*

Ghaffarianhoseini, Ali, John Tookey, Ghaffarianhoseini Amirhosein, Nicola Naismitha, Salman Azhard, Olia Efimovaa, and Kaamran Raahemifarb. 2017. "*Building Information Modelling (BIM) uptake: Clear benefits, understanding its* *implementation, risks and challenges." Renewable and Sustainable Energy Reviews* 75: 1046-1053.

Gledson, Barry, Daniel Henry, and Paula Bleanch. 2012. "*Does size matter? Experiences and perspectives of BIM implementation from large and SME construction contractors."* Paper presented at the *1st UK Academic Conference on Building Information Management (BIM) 2012, Northumbria University, Newcastle Upon Tyne, 5-7 September.*

Goodridge, P., J. Haskel, and G. Wallis. 2014. *UK Innovation Index.* NESTA. Retrieved July 25, 2015, from: http://www.nesta.org.uk/sites/default/files/1407_innovation_index_2014.pdf

Guba, E. G., and Y. S. Lincoln. 1994. "Competing Paradigms in Qualitative Research." In *Handbook of Qualitative Research*, edited by N. K. Denzin, and Y. S. Lincoln, 105-117. London: Sage.

*Handbook of research on building information modelling:* http://www.igi-global.com.dbgw.lis.curtin.edu.au/gateway/chapter/full-text-html/39492

HM Government. 2015. *Digital Britain Level 3 BIM - Strategic Plan. Crown Copyright.* Retrieved July 8, 2015, from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/410096/bis-15-155- digital-built-britain-level-3-strategy.pdf

Holzer, Dominik. 2015. "BIM for procurement - procuring for BIM." In Living and Learning: Research for a Better Built Environment: 49th International Conference of the Architectural Science Association 2015, edited by R. H. Crawford, and A. Stephan, 237–246. Melbourne: The Architectural Science Association and The University of Melbourne.

Hosseini, M. R., S. Banihashemi, N. Chileshe, M. O. Namzadi, C. Udeaja, R. Rameezdeen, and T. McCuen. 2016. "*BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model*." *Construction Economics and Building* 16(3): 71-86. DOI: http://dx.doi.org/10.5130/AJCEB.v16i3.5159

Howard, Rob and Bo-Christer Björk. 2008. *"Building Information Modelling – Experts′ Views on Standardisation and Industry Deployment."* Advanced Engineering Informatics 22(2): 271-280.

HM Government. 2012. *Industrial strategy: government and industry in partnership, Building Information Modelling.* From: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/34710/12-1327-building-information-modelling.pdf

JBIMS. 2007. "*Building Information Management*." Journal of building information modelling - An official publication of the National BIM Standard (NBIMS) and the National Institute of Building Science (NIBS).

Koo, B., and Fisher, M. 2000. *"Feasibility study of 4D CAD in commercial construction."* ASCE Journal of Construction Engineering and Management 126(4): 251-260.

Kubba, Sam. 2012. *Handbook of green building design and construction*: LEED®, BREEAM®, and Green Globes®. United Kingdom-based: Elsevier Inc. ISBN 978-0-12-385128-4 © Butterworth-Heinemann 2012.

Laiserin, Jeery. 2010. *THE LAISERINLETTERTM (www.laiserin.com). ISSUE No. 26 — SPECIAL EDITION, MARCH 2010.*From: http://www.laiserin.com/features/issue26/feature01.pdf

L. Jiang, and R. M. Leicht. 2016. *"Supporting automated constructability checking for formwork construction: an ontology."* ITcon: Special Issue CIB W78 2015 Special track on Compliance Checking 21: 456-478.

Latiffi Aryani Ahmad, Brahim Juliana, Fathi Mohamad Syazli. 2013. *The Development of Building Information Modelling (BIM) Definition.* Malaysia From: https://s3.amazonaws.com/academia.edu.documents/34927795/The_Development_of_Building_Information_Modeling_BIM_Definition.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1510814630&Signature=NNYvDlILGAwCDDozuvYzKwk5aHs%3D&response-content-disposition=inline%3B%20filename%3DThe_Development_of_Building_Information.pdf .

Levy, Sidney M. 2010. *Construction Process Planning and Management.* Oxford UK, Burlington USA: Elsevier Inc.

Liebich, T., Y. Adachi, J. Forester, J. Hyvarinen, S. Richter, T. Chipman, M. Weise, and J. Wix. 2010. *Industry Foundation Classes IFC2.* 4th ed. From: http://www.buildingsmart-tech.org/specifications,©2008-2017of buildingSMART International Ltd. BuildingSMART.

Light, David. 2011. *BIM Implementation – HOK.* Newcastle, UK: buildingSMART. https://www.thenbs.com/knowledge/bim-implementation-hok-buildingsmart

Love, Peter E. D., Matthews Jane, Simpson Ian, Hill Andrew, and Olatunji, Oluwole A. 2013. *A benefits realization management building information modeling framework for asset owners.* Automation in construction, Volume 37, pages 1-10. 2013 Elsevier B.V.

Love, Peter E.D., Zhou, Jingyang, Matthews, Jane, Sing, Chun-Pong, and Carey, Brad. 2015. *"A systems information model for managing electrical, control, and* *instrumentation assets*." *Built Environment Project and Asset Management.* Vol. 5 Iss3pp.278–289.Permanent link to this document: http://dx.doi.org/10.1108/BEPAM-03-2014-0019

Love, Peter E.D.,2002. *"Influence of Project Type and Procurement Method on Rework Costs in Building Construction projects"* Journal of Construction Engineering and Management / Volume 128 Issue 1- February 2002

Loveday, Jake & Kouider, Tahar & Scott, Jonathan. 2016. "*The Big BIM battle; BIM adoption in the UK for large and small companies."* Healthy Buildings: Innovation, Design & Technology, ICAT 2016: Conference Proceedings of the 6th International Congress of Architectural Technology, University of Alicante 12-14 May 2016. San Vicente del Raspeig: Universidad de Alicante, 2016. ISBN 978-84-16724-10-9, pp. 53-66.

Lu, W., D. Zhang, and S. Rowlinson. 2013. "*BIM collaboration: a conceptual model and its characteristics."* In Procs 29th Annual ARCOM Conference, 2-4 September 2013, Reading, UK, edited by S.D. Smith, and D.D. Ahiaga-Dagbui, 25-34. Reading: Association of Researchers in Construction Management.

Mackenzie, R. A. 1990. *The time trap.* New York, NY: AMACOM.

McGraw Hill Construction. 2014. *Research & Analytics/ Industry Insights & Alliances,From:* http://www.autodesk.com/temp/pdf/McGraw_Hill_Business_Value_of_BIM_ANZ.pdf

McGraw Hill Construction. 2008. *Building Information Modelling (BIM), Transforming Design and Construction to Achieve Greater Industry Productivity.*

McGraw, B. A., and R. Leonoudakis. 2009. *Project Time Management: The Foundation for Effective Resource Management.* from:

http://www.rbryanpeterson.com/files/Project_Time_Management_v2_2 Feb 2009-1.pdf [Accessed on 15/04/2013].

Moscardi, Luca. 2016. *"Innovate design and construction process: BIM Collaboration."* National BIM report 2012.

http://www.thenbs.com/topics/bim/articles/nbsNationalBimSurvey_2012.asp

*National BIM report 2016.*

https://www.thenbs.com/knowledge/national-bim-report-2016

(NATSPEC) 2013 *The Australian National Building Specification system-* http://bim.natspec.org/index.php/resources/glossary

*NBIMS (2007), National Building Information Modelling Standard, National Institute of Building Sciences, NBIMS-US™ V2 eBook* https://www.nibs.org/store/ViewProduct.aspx?nonssl=1&id=2038899

*NBIMS (2018), NIBS, "What is BIM*?" https://www.nationalbimstandard.org/faqs

Norman, E. S., S. H. A. Bortherton, and R. T. Fried. 2008. *Work Breakdown Structures: The Foundation for Project Management Excellence.* 1st ed. Canada: John Wiley & Sons. 1–25.

Poirier, E., S. Staub-French, and D. Forgues. 2015a. *"Embedded contexts of innovation: BIM adoption and implementation for a specialty contracting SME." Construction Innovation* 15(1): 42-65. doi: http://dx.doi.org/10.1108/CI-01-2014-0013

Project Management Institute (PMI), 2006. *Practice Standard for Work Breakdown Structures.* 2nd ed. USA: ISBN 1933890134.

Project Management Institute (PMI), 2008. *A Guide to Project Management Body of Knowledge.* 4th ed. USA: Project Management Institute Standards Committee, ISBN13: 9781933890517.

Project Management Institute (PMI), 2008. *The practical guide to project planning: Project Planning Using the PMBOK Guide 3rd Edition.* Place: Taylor & Francis Group, LLC.

Robert C. Mutchler, FAIA, and Christopher R. Widener, AIA. 2000. "Construction Management." *The Architect's Handbook of Professional Practice.* 13th ed.

Race, Steve. 2012. *BIM Demystified - An architect's guide to Building Information Modelling/ Management (BIM).* 2nd ed. UK: RIBA Publishing.

*Research Methodology in Doctoral Research: Understanding the Meaning of Conducting Qualitative Research*. Available from: https://www.researchgate.net/publication/275956584_Research_Methodology_in_Doctoral_Research_Understanding_the_Meaning_of_Conducting_Qualitative_Research [accessed Oct 08 2017].

Scott, S., and S. Assadi. 1999. "A survey of the site records kept by construction supervisors." *Construction Management & Economics* 17(3): 375-382.

Sidwell, A.C. 1984. "The time performance of construction projects." *Architectural Science Review* 27(4): 85-91.

Small Business Development Corporation WA. 2016. *Government of Western Australia, Facts and Statics.* https://www.smallbusiness.wa.gov.au/about/small-business-sector/facts-and-statistics

Stauffer, Griffin K, *LT, CEC, USN,* 2006. *Design-Build vs Design-Bid-Build: A Procurement Method Selection Framework.* Construction, Engineering and Management, Purdue University West Lafayette, India.

Succar, B. 2009. "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in Construction* 18(3): 357-375.

Sutrisna, M. 2009. "Research Methodology in Doctoral Research: Understanding the Meaning of Conducting Qualitative Research, Working Paper." In P*roceedings of the Association of Researchers in Construction Management (ARCOM) Doctoral Workshop, Liverpool, UK, 12 May,* edited by A. Ross. ISBN 978-0-9562622-0-8.

Sutrisna, M., and P.S. Barrett. 2007. "Applying rich picture diagrams to model case studies of construction project." *Engineering Construction and Architectural Management* 14(2): 164-179.

Sutrisna, M., and C. Abbott. 2007. "Presenting case studies of construction projects to the construction industry audience." Paper presented at the *4th International SCRI Symposium, University of Salford, Salford, UK, 26-27 March,* edited by C. Abbott, G. Aouad, M. Kagioglou, and L. Ruddock, 395-407.

Underwood, Jason, Zlatanova, Sisi and Isikdag, Umit, 2013. "*International Journal of 3-D Information Modelling (IJ3DM)"*: 30-44. ISSN: 2156-1710|EISSN: 2156-1702|DOI: 10.4018/IJ3DIM. From: www.igi-global.com/article/functional-suitability-of-bim-tools-in-pre-construction-construction-and-post-construction-phases-of-a-building-project/89442

Vanlande et al. 2008. Renaud Vanlande, Christophe Nicolle, Christophe Cruz "*IFC and Building Lifecycle Management" From:*
https://pdfs.semanticscholar.org/4464/0ddb59efc6e2448be8df717505200388dfd7.pdf

Yin, Robert K. 2003. *Case Study Research: Design and Methods - Applied Social Research Methods Series – Volume 5 – researchers.* 2nd ed. Thousand Oaks-London-New Delhi: SAGE Publications.

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