IMPROVING THE EFFICIENCY OF STRUCTURAL ENGINEERING DESIGN IN THE EASTERN CAPE THROUGH THE IMPLEMENTATION OF BUILDING INFORMATION MODELLING (BIM)

A research dissertation submitted to the faculty of Engineering and the Built Environment in fulfilment of the requirements for the Degree of

MASTER OF ENGINEERING

IN

CIVIL ENGINEERING

AT THE

DURBAN UNIVERSITY OF TECHNOLOGY

Prepared by

Mr David Jason Hiscock

AUGUST 2017

IMPROVING THE EFFICIENCY OF STRUCTURAL ENGINEERING DESIGN IN THE EASTERN CAPE THROUGH THE IMPLEMENTATION OF BUILDING INFORMATION MODELLING (BIM)

A research dissertation submitted to the faculty of Engineering and the Built Environment in fulfilment of the requirements for the Degree of Master of Engineering at the Durban University of Technology.

Prepared by: Mr David Jason Hiscock
Student Number: 21748912

22/10/2018
Date

Mr David Jason Hiscock
Pr TechniEng, M.Eng (Civil Engineering) Candidate
BTechEng (Cum Laude), ND Civil Eng (Cum Laude), MSAICE

24/10/2018
Date

Supervisor
Mr Bonga PraiseGod Khuzwayo
Pr TechEng, D.Eng Candidate
M.Eng, BSc (Hons), BTechEng, ND Civil Eng, MSAICE, MIPET

22/10/2018
Date

Co-Supervisor
Prof Deborah Whelan
PhD

24/10/2018
Date

Co-Supervisor
Mrs Elke Helene Hefer
PhD (Candidate), MSc (Cum Laude), BSc (QS)

ABSTRACT

Technology is evolving at a rapid pace, enabling traditional methods of working in a variety of professional fields to be performed more efficiently. This is no different for the Architectural, Engineering, and Construction (AEC) industry. Building Information Modelling (BIM) is a significant innovation, enabled by the advancement in technology, which is currently transforming the AEC industry. BIM technology allows for the creation of an intelligent 3D model consisting of information-linked objects, which assist AEC professionals to more efficiently visualise, plan, design, construct, and manage a project throughout its entire life-cycle.

This dissertation focuses on the implementation of BIM in the structural engineering field, particularly in the Eastern Cape province of South Africa. Currently, structural engineering practitioners in the Eastern Cape face the threat of being 'left behind' in terms of BIM technology, and therefore are losing out on reaping the benefits associated with BIM implementation. Furthermore, BIM is no longer a 'nice beneficial technology to have', but is fast becoming a global requirement within the AEC industry.

The main aim of this study is to investigate the necessity for BIM implementation into the structural engineering organisations within the Eastern Cape. The hypothesis behind the research is that the implementation of BIM technology will improve the efficiency of the structural engineering design process currently being used within the province. A secondary hypothesis is that BIM will soon become standard practice for the AEC industry.

The study identifies the significant advantages of using BIM technology for structural engineers, such as improved visualisation, efficient collaboration between design team members, reduction in design clashes and the production of documentation, and an overall increase in productivity. These advantage areas all culminate to form the measurement of improved design efficiency. Furthermore, the study identifies that a number of countries have various mandates in place for the implementation of BIM, for projects of a certain type, size or value.

Research tools such as questionnaires and interviews are used to identify the current methods of design by the structural engineers, concluding that the majority of structural engineers continue to employ more traditional methods of design. The study compares these traditional methods with using BIM technology for similar design tasks, and shows that the implementation of BIM technology will in fact, be able to significantly improve the efficiency of the structural engineering design processes currently being used within the province. These efficiency improvements are crucial for companies who want to remain competitive in today's fast-paced industry.

This dissertation concludes with the recommendation that the organisations should adopt a proactive approach to BIM implementation in order to benefit from the advantages associated with BIM technology.

The findings from this study will help provide important insight into understanding BIM trends, and further assist structural engineering professionals in the Eastern Cape, in implementing BIM technology in the near future.

DECLARATION

I, David Jason Hiscock (Student Number: 21748912), hereby declare that this dissertation, except where otherwise indicated and referenced, is my own work and has not been submitted in part or in whole at any other University or Institution. All sources used within this dissertation are acknowledged in text and included within the reference list.

This dissertation has been submitted to the Durban University of Technology in fulfilment of the requirements for the Degree of Master of Engineering (M.Eng) in Civil Engineering.

22/10/2018

Mr David Jason Hiscock
M.Eng (Civil Engineering) Candidate
Student Number: 21748912
Pr TechniEng, BTechEng (Cum Laude), ND Civil Eng (Cum Laude), MSAICE

Date

DEDICATION

This dissertation is dedicated to my truly amazing wife, Tarryn, for her continued support, encouragement, and strength during my research. I could not have done it without you.

ACKNOWLEDGEMENTS

I would firstly like to thank the Durban University of Technology (DUT) for providing me with the educational platform and financial support to be able to obtain a Master of Engineering degree in the field which I am so passionate about.

To my main supervisor, Mr Bonga PraiseGod Khuzwayo, for his continued support, valuable advice, and the time that he sacrificed from his own doctoral studies to guide me through this journey. I am truly grateful for your contribution.

To my co-supervisors for their continued support and encouragement, Professor Deborah Whelan, and Mrs Elke Helene Hefer, I am grateful for your contributions to my research.

To Mr Thomas William Mckune for his unmatched willingness to assist. It was Mr Mckune that led me to DUT and made me believe that I was capable to complete this journey. Thank you for believing in me and your continued encouragement.

To my brother, Mr Mark Gareth Hiscock, for proof reading my research and providing valuable input. Furthermore, for your guidance when I was unsure of how to best present my research. I am truly grateful for your contribution.

To everyone else that contributed to my research (questionnaire and interview participants). Thank you.

Lastly, to my wife, Tarryn, for the time you had sacrificed so that I may complete my dissertation. I thank you for your patience, strength, and unwavering support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS

A/E	:	Architectural/Engineering
AEC	:	Architectural, Engineering, and Construction
AGC	:	Associated General Contractors
BCA	:	Building and Construction Authority
BIM	:	Building Information Modelling
BOQ	:	Bill of Quantities
CAD	:	Computer Aided Design
CIFE	:	Centre for Integrated Facilities Engineering
CITA	:	Construction Information Technology Alliance
DEng	:	Doctor of Engineering
DUT	:	Durban University of Technology
EC	:	Eastern Cape
EL	:	East London
ECSA	:	Engineering Council of South Africa
EPA	:	Engineering Profession Act
GSA	:	General Services Administration
HKHA	:	Hong Kong Housing Authority
ICT	:	Information and Computer Technology
IFC	:	Industry Foundation Classes
IP	:	Intellectual Property

JIT	:	Just In Time
LEED	:	Leadership in Energy and Environmental Design
MEP	:	Mechanical, Electrical and Plumbing
MEng	:	Master of Engineering
NBI	:	National Building Information Modelling Initiative
NBIMS	:	National Building Information Modelling Standard
NBS	:	National Building Specification
O&M	:	Operation and Maintenance
M&E	:	Mechanical and Electrical
PDF	:	Portable Document Format
PE	:	Port Elizabeth
PhD	:	Doctor of Philosophy
RAM	:	Random Access Memory
SA	:	South Africa
SAICE	:	South African Institute of Civil Engineering
UAE	:	United Arab Emirates
UK	:	United Kingdom
US	:	United States
USACE	:	United States Army Corps of Engineers
USD	:	United States Dollar
2D	:	Two-Dimensional (Visual)
3D	:	Three-Dimensional (Visual)

4D	:	Four-Dimensional (Scheduling)
5D	:	Five-Dimensional (Estimating)
6D	:	Six-Dimensional (Sustainability)
7D	:	Seven-Dimensional (Facility Management Applications)

CHAPTER 1

INTRODUCTION TO THE RESEARCH

1. CHAPTER 1: INTRODUCTION TO THE RESEARCH

1.1 CHAPTER INTRODUCTION

This chapter provides an overview of the research and introduces the concept of Building Information Modelling (BIM). Following this, the research aims, objectives, and questions are presented along with an introduction to the research methodology adopted to answer the research questions. The study area and limitations of the research are also established in this chapter. The chapter then concludes with an outline of the structure of the dissertation and the chapter summation.

1.2 RESEARCH BACKGROUND

"In the business of building design, a structural engineer is often expected to be strategically proactive. But even as BIM is touted as the future of the industry, many structural engineers remain hesitant to take the lead and use BIM software tools" (Willard, 2009).

This statement by Willard regarding the implementation of BIM into the structural engineering industry sets the context for this research dissertation.

The structural engineering industry is ever changing and becoming increasingly more competitive. It is critical that the modern day structural engineer stays proactive in adapting to the times in order to stay competitive and keep up to date with modern technology (Hunt, 2013).

BIM is one of the most promising developments in recent years and presents exciting possibilities for the future of the Architectural, Engineering, and Construction (AEC) industry (Panaitescu, 2014). During these early days of BIM implementation, possibilities for research presents itself on a number of aspects related to the industry enhancing BIM phenomenon. Hence the interest which gave rise to this research dissertation.

The BIM implementation process is following a similar path to the implementation of the past industry enhancing phenomenon of Computer Aided Design (CAD), which has drastically transformed the AEC industry over the past 50 years (McCuen et al, 2012).

The slow implementation of CAD by engineering organisations was due to a number of aspects similar to those which hinder BIM implementation in structural engineering organisations today. Over time the implementation of CAD and its associated benefits have been effectively introduced into the AEC industry (Khemani, 2008). It is believed that BIM is the evolution of CAD within the AEC industry and that BIM will introduce a similar magnitude of benefits experienced by the implementation of CAD in the past (Migilinskas et al, 2013).

The benefits of BIM for the AEC industry are evident in the literature reviewed and will be unpacked throughout this research dissertation. Jan-Peter Ter Maaten made a statement based on his research that, *"the question no longer is whether BIM should be adopted, but in what way it should be done"* (Ter Maaten, 2015).

In recent years, the adoption of BIM has increased globally at a rapid pace (Holzer, 2015) and is even being mandated by government in a number of countries. However, the implementation of BIM within South Africa (SA) has been relatively slow in comparison with the rest of the world (White, 2015), especially in the less technologically advanced provinces like the Eastern Cape.

The professional structural engineers within the Eastern Cape, fall under the regulation of the Engineering Council of South Africa (ECSA). ECSA is a statutory body established in terms of the Engineering Profession Act (EPA), 46 of 2000 (ECSA, 2016). A key aspect of ECSA's definition of professionalism for the engineering practitioner states that a professional should strive *"to improve all work, using the most up-to-date techniques and procedures"* (ECSA, 2016).

Globally, there has been an increased uptake of BIM technology (Holzer, 2015) and the implementation of BIM is rapidly increasing each year (CAD Services India, 2015). The literature reviewed on BIM implementation points to the conclusion that the most up-to-date techniques and procedures (which relates back to ECSA professionalism definition) currently facing the structural engineering industry is BIM technology.

The structural engineering professionals within the Eastern Cape need to adapt to BIM technology in order to remain up-to-date with modern technologies and remain competitive within the AEC industry.

The slow implementation of BIM technology in the structural engineering organisations within the Eastern Cape, may be due to a number of factors.

One of these factors which limits BIM implementation is the unknown benefits of the technology (Barlish, 2011). Organisations are hesitant to implement BIM without fully understanding its capabilities and benefits. Another limiting factor includes the lack of knowledge as how to effectively implement BIM into an engineering organisation (Burger, 2014).

This research dissertation will aim to provide clarity as to the above mentioned factors and investigate the necessity for BIM implementation into the structural engineering organisations within the Eastern Cape. Furthermore, this dissertation aims to encourage BIM implementation within the Eastern Cape and to ensure that the structural engineering professionals within the province use *"the most up-to-date techniques and procedures"* (ECSA, 2016).

1.3 INTRODUCTION TO BIM

In order to get an initial idea of the BIM phenomenon, this section provides an introductory definition of BIM. Autodesk, which is an American multinational software corporation that makes software for the AEC industry, simply defines BIM as: *"an intelligent 3D model-based process that equips architecture, engineering, and construction professionals with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure"* (Autodesk, 2016).

There are a vast number of definitions of BIM available, however, the definition provided by Autodesk specifies two key words, namely *"more efficiently"*. These two words used to describe the proceeding activities "*plan, design, construct, and manage buildings and infrastructure*", is exactly what a structural engineer is striving to achieve.

Figure 1-1 on the following page graphically illustrates the different stages of a project life cycle with which BIM is interconnected.

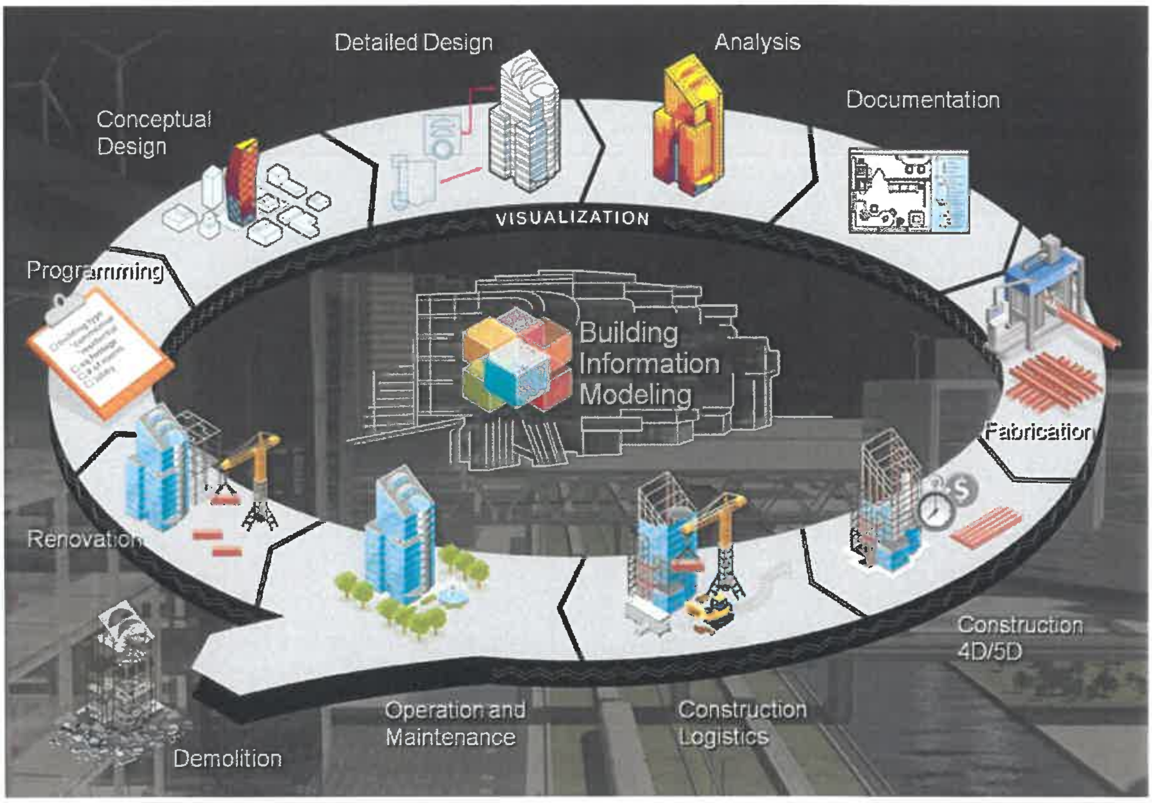


Figure 1-1: BIM Project Life Cycle Diagram (Austin, 2011)

1.4 PROBLEM STATEMENT

BIM offers significant advantages for the AEC industry, however, the implementation of BIM within South Africa has been relatively slow in comparison with the rest of the world (White, 2015), especially in the smaller provinces like the Eastern Cape. Structural engineering organisations in the Eastern Cape face the threat of being left behind in terms of BIM technology and losing out on reaping the benefits associated with BIM. Furthermore, BIM implementation is no longer a 'nice beneficial technology to have' but fast becoming a global requirement within the AEC industry.

The global trend towards mandatory BIM implementation on projects of a certain size or value indicates that larger projects within the Eastern Cape, will start requiring BIM usage within the near future. The structural engineering organisations within the province will then start losing larger projects to more technologically advanced companies within South Africa and/or foreign companies which are already well versed in using BIM technology.

1.5 HYPOTHESIS TO BE INVESTIGATED

The hypothesis which gave rise to this research dissertation, is that the implementation of BIM technology will improve the efficiency of the structural engineering design process (1) currently being used by the structural engineering organisations within the Eastern Cape, and secondly that BIM will soon become standard practice for the AEC industry.

1.6 AIMS OF THE RESEARCH

The aim of this research is to provide clarity on the above mentioned hypothesis, therefore, the overarching aim of the research is to:

Investigate the necessity for BIM implementation into the structural engineering organisations within the Eastern Cape.

Subsequent to the overarching aim of this dissertation, the research will aim to contribute to the structural engineering industry of the Eastern Cape by *"filling the gaps in literature"* (English, 2012) on BIM implementation in the province.

BIM research has increased around the world over the past couple of years. However, there is currently limited research conducted on BIM implementation and/or literature related to the benefits of BIM for the structural engineering organisations within the Eastern Cape (EC) province.
This dissertation also aims to provide guidelines on an appropriate implementation strategy for introducing BIM into a typical structural engineering organisation within the province.

In summary and in addition to the overarching aim of the research, the following aims are summarised below:

- Contribute to the body of knowledge on BIM implementation in the EC.
- Provide recommendations on BIM implementation in the EC.
- Encourage BIM implementation within the EC.

---

(1) The structural engineering design process include, planning, conceptual design, modelling, calculations, analysis, drafting, detailing, documentation and final design.

1.7 RESEARCH OBJECTIVES AND QUESTIONS

1.7.1 Research Objectives

The research objectives have been formulated to assist in achieving clarity on the overarching aim of the research. The objectives of this dissertation are as follows:

1) Identify the current structural engineering design process being used by a typical consulting engineering organisation in the EC.
2) Identify the advantages and disadvantages associated with BIM implementation and relate them to the overarching aim of the research.
3) Determine the international and national (SA) implementation trends of BIM.
4) Provide recommendations for BIM implementation into a typical structural engineering organisation within the EC.

1.7.2 Research Questions

The research questions have been formulated to assist in providing answers to the above objectives of the research. The research questions are as follows:

1) What are the current structural engineering design methods being used in the EC?
2) What is the current state of BIM implementation and what are the barriers hindering BIM implementation in the EC?
3) What are the problems and challenges associated with BIM implementation and how can they be minimised?
4) What are the capabilities and potential benefits associated with BIM implementation?
5) What are the international implementation trends of BIM?
6) What are the national (SA) implementation trends of BIM?
7) What is the most used BIM compatible software programme used for structural engineering in SA?
8) What BIM training courses are available within SA?

1.7.3 Relationship between Research Aim, Objectives and Questions

Table 1-1 below identifies the relationship between the overarching aim of the research, the research objectives, and the research questions:

Table 1-1: Research Aim, Objectives and Questions Relationship

Research Aim	Research Objectives	Research Questions
Investigate the necessity for BIM implementation into the structural engineering organisations within the EC.	1. Identify the current structural engineering design process being used by a typical consulting engineering organisation in the EC.	Q1. What are the current structural engineering design methods being used in the EC?
		Q2. What is the current state of BIM implementation and what are the barriers hindering BIM implementation in the EC?
	2. Identify the advantages and disadvantages associated with BIM implementation and relate them to the overarching aim of the research.	Q3. What are the problems and challenges associated with BIM implementation and how can they be minimised?
		Q4. What are the capabilities and potential benefits associated with BIM implementation?
	3. Determine the international and national (SA) implementation trends of BIM.	Q5. What are the international implementation trends of BIM?
		Q6. What are the national (SA) implementation trends of BIM?
	4. Provide recommendations for BIM implementation into a typical structural engineering organisation within the EC.	Q7. What is the most used BIM compatible software programme used for structural engineering in SA?
		Q8. What BIM training courses are available within SA?

1.8 METHODOLOGY ADOPTED FOR THE RESEARCH

This dissertation will adopt both quantitative and qualitative research methods to best provide answers to the objectives. Therefore, the mixed methods research approach is the preferred design for this study. This approach was chosen due to the fact that mixed methods research *"focuses on collecting, analysing and mixing both quantitative and qualitative data in a single study"* which in turn provides *"a better understanding of research problems than either approach alone"*

(Creswell & Plano Clark, 2007). The sub-sections below further expand on the methodological approach used for each objective.

Objective 1:

Quantitative research in the form of questionnaires will be used to collect the basis of the data for the study, in respect to identifying the current structural engineering design methods used, the current state of BIM implementation and barriers hindering BIM implementation in a typical structural engineering organisation in the Eastern Cape.

- Answers to question 1 and 2 of the study will be determined by the results of the questionnaires.

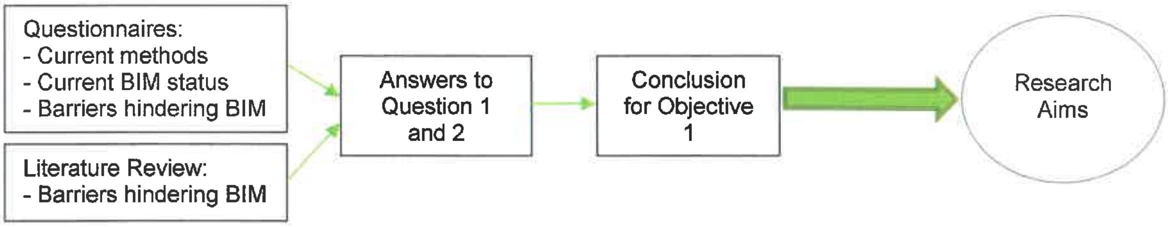


Figure 1-2: Flowchart for Research Objective 1

Objective 2:

Qualitative research in the form of an illustrative case study which will involve the investigation of a recent project that used aspects of BIM technology during the design process. Advantages and disadvantages of the process will be documented.

Separate from the case study, a literature review on the advantages and disadvantages of BIM implementation will be conducted.

- Answers to question 3 and 4 of the study will be drawn from the case study and the literature reviewed.

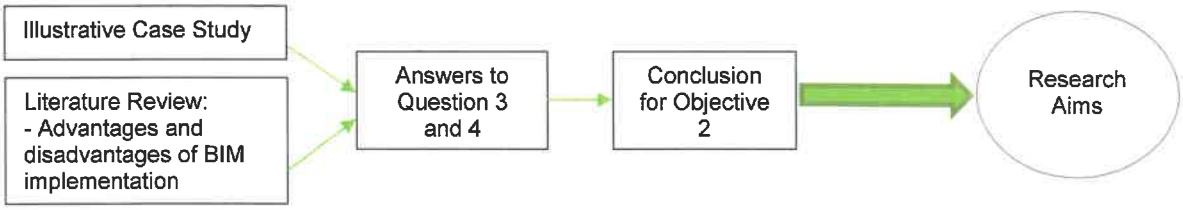


Figure 1-3: Flowchart for Research Objective 2

Objective 3:

International and national BIM implementation trends will be concluded from the literature review.

- Answers to question 5 and 6 of the study will be concluded from the literature reviewed.

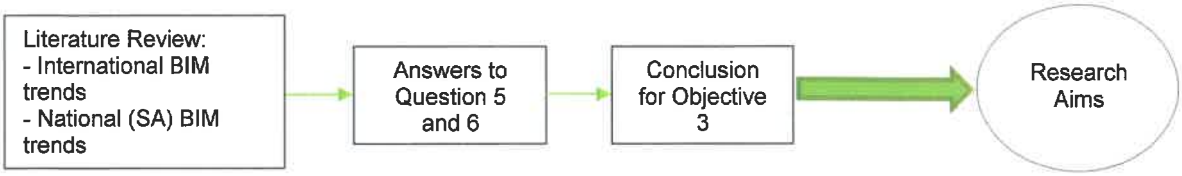


Figure 1-4: Flowchart for Research Objective 3

Objective 4:

Recommendations will be provided from a combination of data obtained from the research questionnaires, and a desktop study on available BIM software, and available training courses within South Africa.

- Answers to question 7 and 8 of the study will be drawn from the questionnaires and the desktop study.

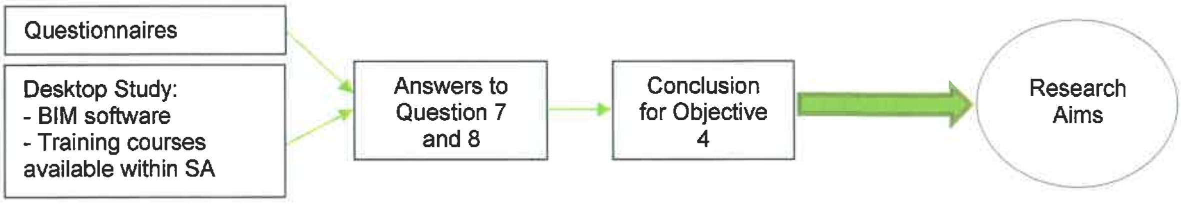


Figure 1-5: Flowchart for Research Objective 4

1.9 STUDY AREA

The research focuses on the structural engineering industry of the Eastern Cape province of South Africa. The two major cities within the Eastern Cape, are East London (EL) and Port Elizabeth (PE). Typical structural engineering organisations within the Eastern Cape, which have an office based in EL and PE will be investigated to assist in providing answers to the relevant research questions.

1.10 LIMITATIONS OF THE RESEARCH

There is a limited amount of information on the structural engineering design process used within the Eastern Cape.

Furthermore, there is limited research and literature pertaining to BIM implementation within the province. Due to the lack of information and literature available, the majority of the initial information will be obtained through data collection from questionnaires.
Data collection from questionnaires will pose limitations for the research due to the willingness of the structural engineers in the province to participate and complete the questionnaires.

The case study conducted by the researcher involves investigating only certain aspects of the comparison between using current structural engineering design methods compared to using BIM methods for the same structure. This is due to the fact that the researcher was learning the practical application of BIM technology at the stage at which the case study was conducted.
The research may have been improved if the researcher had more experience on the practical use of BIM at the time of writing this dissertation. However, taking this limitation of the study into account, literature will be reviewed on the advantages and disadvantages of BIM implementation to further substantiate and add to the findings from the project case study.

1.11 STRUCTURE OF THE DISSERTATION

The dissertation is structured into seven chapters. The major aspects of each of the seven chapters of the dissertation are summarised as follows:

Chapter 1: Introduction to the Research
The introduction provides an overview of the research and presents the research aims, objectives and questions.

Chapter 2: Literature Review
The literature review will focus on expanding on the concept of BIM. Literature will be reviewed on the advantages and disadvantages of BIM implementation and current BIM implementations trends both nationally (SA) and internationally.

Chapter 3: Research Methodology
This chapter will present the research methodological process that was used to provide answers to the research objectives and questions.

Chapter 4: Project Case Study

A case study on a recent project that used aspects of BIM technology during the design process will be investigated in this chapter. Advantages and disadvantages of the process will be documented.

Chapter 5: Results and Discussion

The results from the research questionnaire will be presented within this chapter. Results will be discussed and summated into a logical structure.

Chapter 6: Conclusions

This chapter will provide conclusions to the overarching aim of the research based on the results and findings identified in the previous chapters.

Chapter 7: Recommendations and Further Research

Recommendations stemming from the research will be provided in this chapter. Further potential research will also be presented in this chapter.

Figure 1-6 below graphically represents the structure of the dissertation:

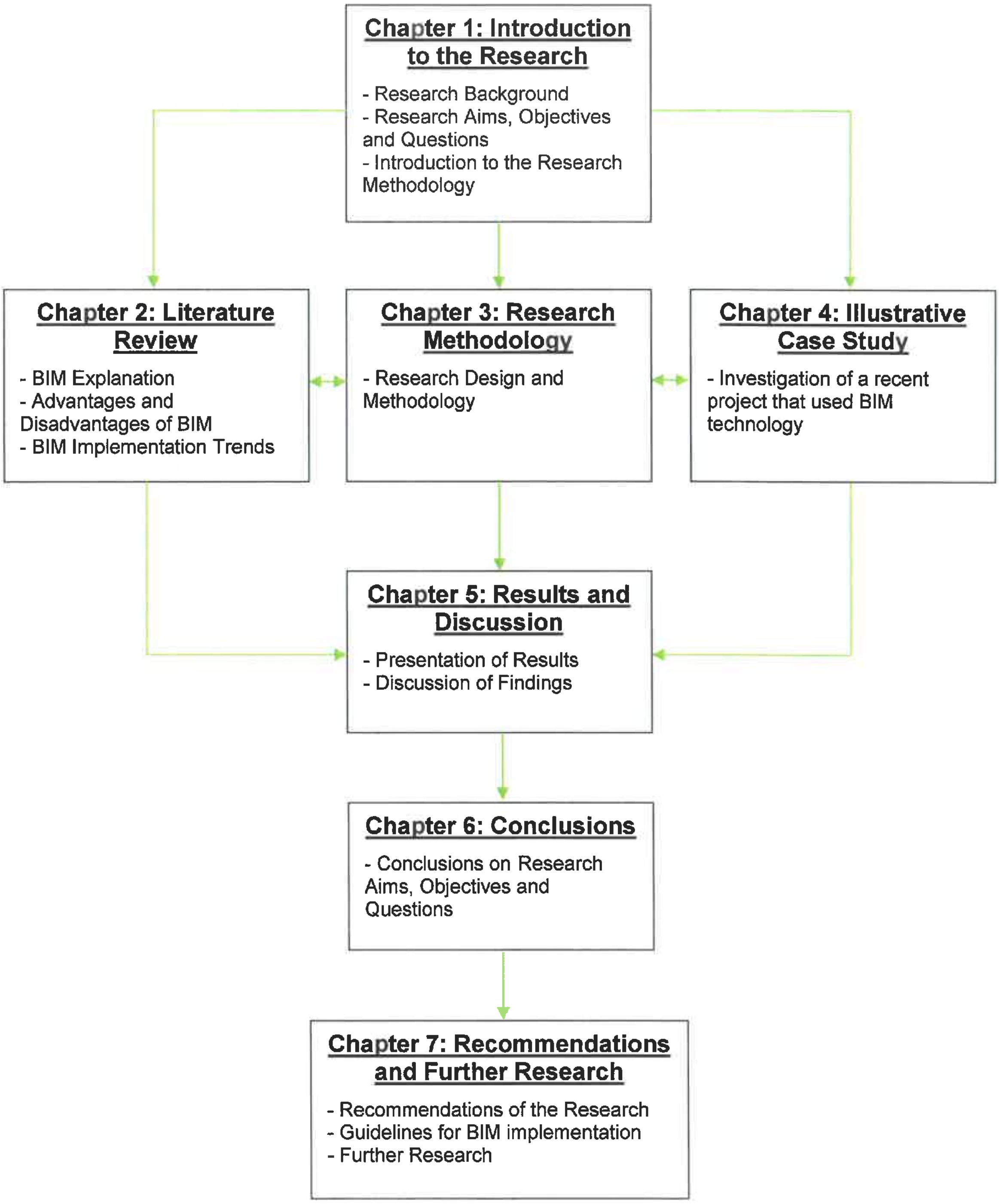


Figure 1-6: Structure of the Dissertation

1.12 CHAPTER SUMMARY

BIM technology is enabling exciting developments in the AEC industry around the world and the advantages of BIM have been recognised by various governmental departments. This has resulted in BIM implementation becoming mandatory in a number of international countries for projects of a certain size and/or value. South Africa and more specific to this dissertation, the Eastern Cape's structural engineering organisations, need to start considering BIM implementation in order to remain up to date with current technologies.

This chapter has set out the background of the research. The hypothesis of the research and the problem statement have also been presented which justifies the rationale for this research dissertation. The aims of the research, objectives and questions along with an introduction of the research methodology have been presented in this chapter.

The dissertation proceeds to the literature review chapter. The next chapter provides a more in-depth explanation on the concept of BIM and reviews the relevant literature related to the research objectives.

CHAPTER 2

LITERATURE REVIEW

2. Chapter 2: Literature Review

2.1 CHAPTER INTRODUCTION

Having provided an overview of the research and an introduction to the concept of BIM in chapter 1, chapter 2 focuses on the review of literature relevant to the research aims, objectives and questions - as set out in chapter 1. This chapter begins with a more comprehensive explanation of BIM. Following this, literature is reviewed on the advantages and disadvantages of BIM implementation, as well as current BIM implementation trends both internationally and nationally. The chapter concludes with a review of case studies and the chapter summation.

2.2 WHAT IS BIM?

BIM is an innovative method for the design, construction and management of structures throughout their full life cycle. The initial process begins with the creation of a virtual 3D model in software. However, BIM is more than just a 3D model and cannot be viewed as a latest version of CAD (Cooksey, 2011). CAD simply provides a 2D graphical representation of a structure, whereas, BIM provides a number of additional parameters (Sacks & Barak, 2010).

The virtual 3D model is assembled from intelligent objects with physical properties linked to each object. *"So while a door represented in a 2D CAD drawing is just a collection of lines, in BIM it is an intelligent object containing information on its size, cost, manufacturer, schedule and more"* (Haron, 2013).The figure below graphically illustrates the difference between 2D CAD, 3D CAD and 3D BIM:

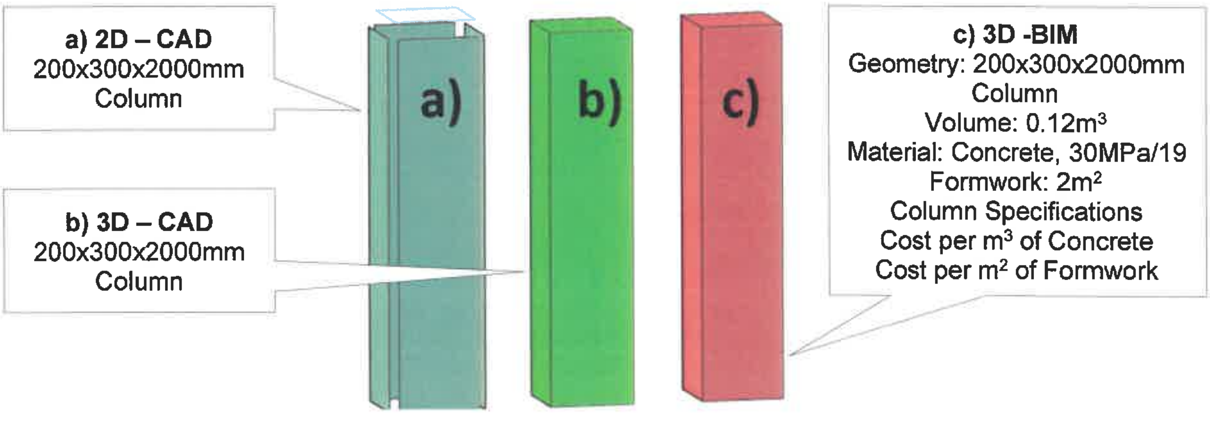


Figure 2-1: Comparison of a 2D (CAD), 3D (CAD) and a 3D (BIM) object (Fleming, 2016, p.21)

The philosophy of BIM is that it is not merely an isolated software package but a means of true representation, collaboration, and integration of a building's information (Johnson, 2012) which enables the project team to visualise, simulate and analyse an integrated design before it goes out to construction (Panaitescu, 2014). Thus it provides the designers the opportunity to rectify any shortcomings at an early stage in the project. This is a significant advantage to the AEC industry and will be discussed in more detail throughout this chapter.

2.2.1 BIM Definitions

The reviewed literature has identified a number of different definitions of BIM. This section provides some of the most referenced definitions encountered, and concludes with a definition developed for this dissertation.

The National Building Information Model Standard (NBIMS) Project Committee defines BIM as:

> *"Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".*
>
> (NBIMS-US, 2016)

BuildingSMART provides the following definition:

> *"Building Information Modelling: Is a business process for generating and leveraging building data to design, construct and operate the building during its lifecycle. BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms".*
>
> (BuildingSMART 2012a)

Ole Bengt Berard used the following definition of BIM within his PhD thesis:

> *"Building Information Modelling or BIM is the creation and use of information-bearing, object-oriented, geometrical models of a building utilised in design, planning, and execution of construction work".*
>
> (Berard, 2012)

For the purpose of this dissertation, the following definition of BIM has been developed:

BIM is the process of managing an intelligent 3D model, which consists of information linked objects, that assist AEC professionals to more efficiently visualise, plan, design, construct, and manage a project throughout its entire life-cycle.

2.2.2 BIM Dimensions

BIM is broken down into different dimensions (3D, 4D, 5D, 6D and 7D). These dimensions help better illustrate the vast difference between regular 2D CAD and BIM.

The table below provides a description of the different dimensions of BIM. An example of each dimension is also provided to further emphasise BIM's capabilities:

Table 2-1: Different Dimensions of BIM (Waldeck Consulting, 2013)

BIM Dimensions	Description	Examples and Capabilities
3 Dimensional (3D)	Visualisation	- 3D Models - Animations and Renderings - Walkthroughs - Safety & Logistics Models - BIM Model Driven Prefabrication

4 Dimensional (4D)	Scheduling	- Project Phasing Simulations
		- Lean Scheduling
		    - Just In Time (JIT)
		    - Detailed Simulation Installation
		- Visual Validation for Payment Approval

5 Dimensional (5D)	Estimating	- Real Time Modelling and Cost Planning
		- Quantity Extraction to Support Detailed Cost Estimates
		- Trade Verifications
		    - Structural Steel
		    - Mechanical, Electrical and Plumbing
		- Valve Engineering (Quantity Extractions)
		- Prefabrication Solutions
		    - Equipment Rooms
		    - MEP Systems
		    - Architectural and Structural Elements

6 Dimensional (6D)	Sustainability	- Conceptual Energy Analysis - Detailed Energy Analysis - Sustainable Element Tracking - LEED Tracking
7 Dimensional (7D)	Facility Management Applications	- Life Cycle BIM Strategies - BIM As-Builts - BIM Embedded O&M Manuals - BIM Maintenance Plans and Technical Support

2.3 ADVANTAGES OF BIM IMPLEMENTATION

In order for a structural engineering organisation to consider adjusting from their current design methods to using BIM technology, the organisation will require knowledge of the potential advantages of BIM implementation. This section reviews literature on the advantages of BIM implementation for structural engineering organisations. The findings will assist in providing solutions for objective 2 of this research dissertation.

A case study, conducted by the Stanford University Centre for Integrated Facilities Engineering (CIFE), studied 32 major projects that utilised BIM and found the following advantages (Azhar et al, 2012):

- Up to 40% elimination of unbudgeted change
- Cost estimation accuracy within 3%
- Up to 80% reduction in time taken to generate a cost estimate
- A savings of up to 10% of the contract value through clash detections
- Up to 7% reduction in project time

The results from the case study provide an initial overview of the significant advantages of BIM implementation.

The following sub-sections below have been developed to guide the literature review in investigating five important aspects of the structural engineering design process, and to identify the advantages of BIM implementation related to each aspect. The subsections were developed through recurring themes identified in past research papers on the benefits of BIM in structural engineering (Ball, 2014; Hunt, 2013; Yin and Damian 2008).

The five main aspects to be investigated are as follows:

- Visualisation
- Simulation
- Collaboration
- Documentation
- Productivity

2.3.1 Visualisation

The process of designing with BIM technology begins with the creation of a digital 3D model of a building or structure. The 3D model consists of Architectural / Engineering (A/E) objects such as, foundations, walls, slabs, beams, columns, etc. The A/E objects substitute regular drawing lines into a working 3D virtual model (Parvan, 2012).

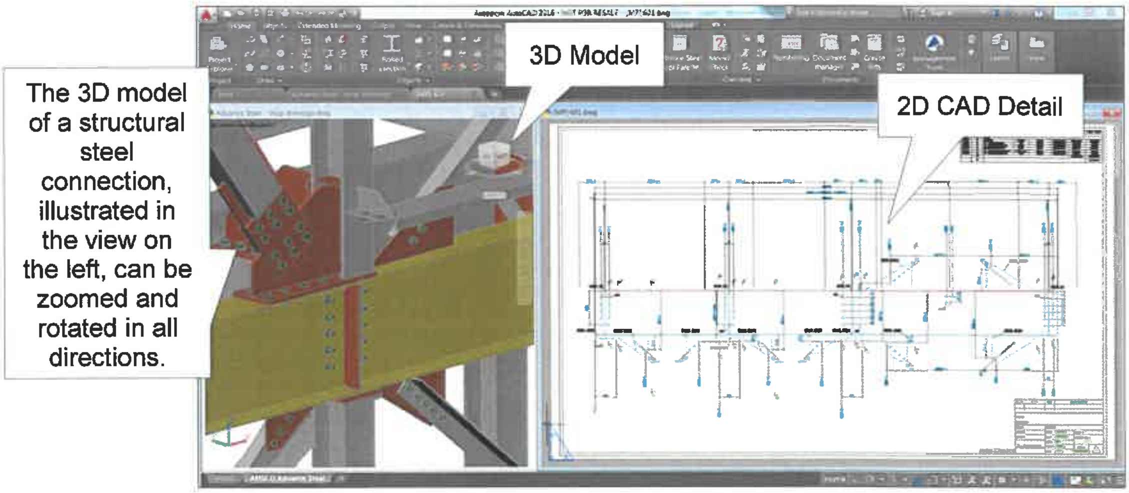
The 3D model can be panned, zoomed, and rotated in all directions, which enables a structural engineer to better visualise the building or structure before it is constructed (VICOSoftware, 2016). This visual representation greatly assists with preventing errors, solving problems, and improving designs (Hunt, 2013).

The visualisation advantages of the 3D model can be seen graphically in the examples below:

1. Structural Steel

Connection detail, involving a number of structural steel members interconnecting at one point, is generally challenging to visualise using 2D design software. 3D BIM enables the structural engineer to visualise the connection, providing a greater understanding of how to best undertake and optimise the design.

The figure below illustrates the visualisation advantages of a 3D model of a structural steel connection.

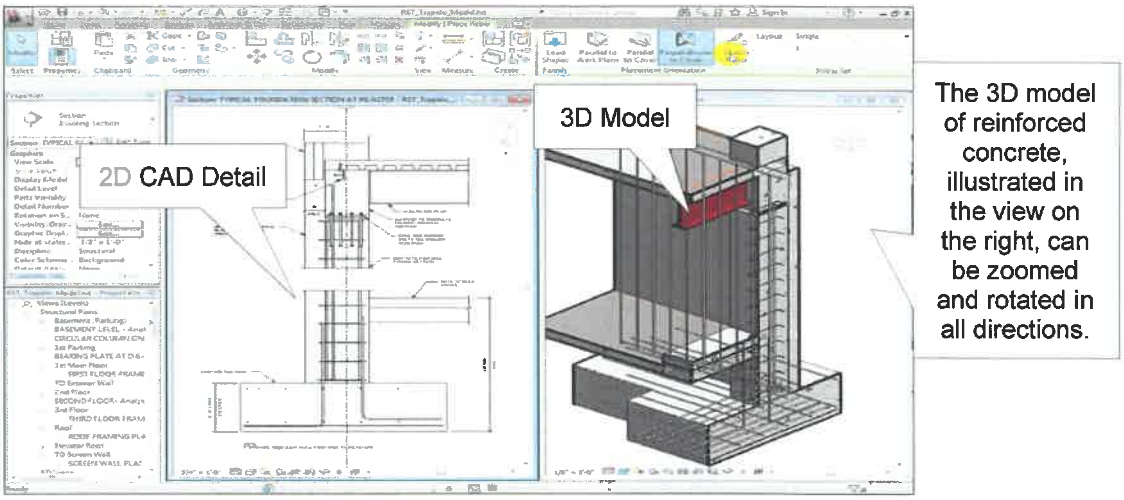


The 3D model of a structural steel connection, illustrated in the view on the left, can be zoomed and rotated in all directions.

Figure 2-2: 3D BIM Visualisation (Erickson C, Autodesk. 2015)

2. Reinforced Concrete

The reinforced concrete design process presents similar visualisation challenges, to those mentioned above, with respect to visualising the arrangement of reinforcing bars in concrete. 3D BIM once again provides the structural engineer with the opportunity to better visualise, and improve on, the design digitally. The figure below illustrates the visualisation advantages of 3D BIM detailing of structural reinforced concrete.



The 3D model of reinforced concrete, illustrated in the view on the right, can be zoomed and rotated in all directions.

Figure 2-3: 3D BIM Visualisation (Image Courtesy of Autodesk Revit Structure)

The 3D model can be used to clearly present ideas with the project team (project manager, architect, structural engineer, quantity surveyor, mechanical engineer, electrical engineer, etc.), providing greater project insight and an enhanced understanding of each team member's designs (Hunt, 2013).

The end result of a 3D model is a composite visualisation of the building or structure that incorporates the entire project teams' design into one 3D model. The composite model provides the advantage of visualising what the building or structure is going to look like when it is completed. This 3D model assists in presenting the design to the client, and provides the client with the opportunity to make changes before construction is completed (Ball, 2014).

The figure on the following page graphically illustrates a 3D model divided into two sections, namely the architectural aspects on the left, and, more particular to this dissertation, the structural engineering components (foundations, columns, beams, slabs and staircases) on the right.

Figure 2-4: 3D BIM Visualisation of a Composite Model (Image Courtesy of Autodesk)

2.3.2 Simulation

BIM technology allows for the simulation and digital construction of a building or structure before it is physically constructed. The ability to virtually simulate and construct a design provides structural engineers with the opportunity to assess and optimise designs (Berard, 2012).

BIM simulation technology provides a structural engineer with the advantage of being able to simulate a 3D model as a complete structure. Thus the structural engineer has the opportunity to analyse and view the results of the forces acting on a structure as a whole. The figure on the following page graphically illustrates a building that has been simulated using BIM technology.

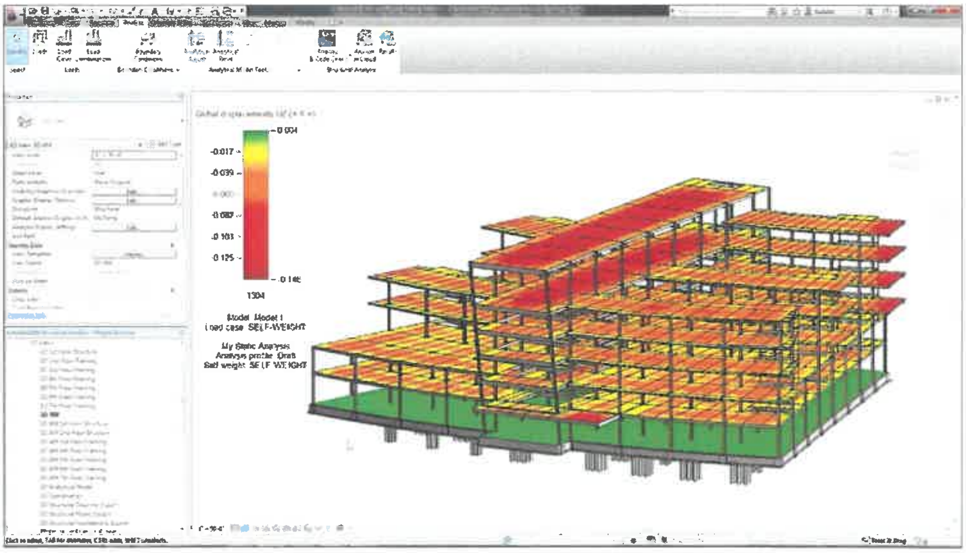


Figure 2-5: BIM Structural Simulation of a Building (Autodesk, 2016)

BIM simulation technology also allows for clash detection during the simulation process. The clash detection simulation software checks for inconsistencies in the design (Panaitescu, 2014), and will graphically identify if there are any design clashes, or design problems, before a design is finalised.

By identifying clashes digitally during the design stage, costly on-site clashes during the construction stage are reduced (Ball, 2014). As specified above, the case study conducted by Stanford University found that savings of up to 10% of the contract value were achieved through BIM clash detections (Azhar et al, 2012). The figure below graphically illustrates a design clash, in which horizontal ducting is clashing with a steel section.

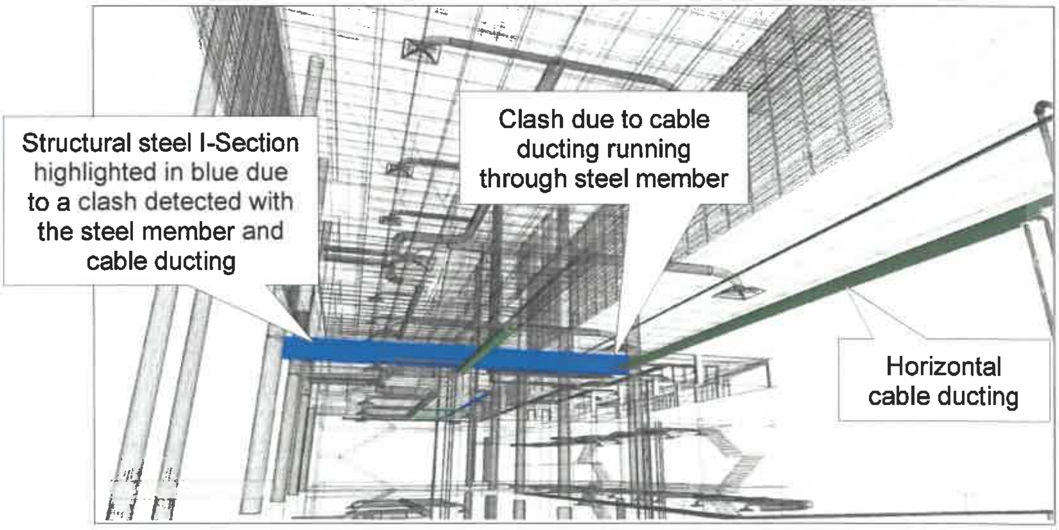


Figure 2-6: BIM Clash Identification (International BIM Services, 2016)

2.3.3 Collaboration

A building project within the AEC industry usually consists of a large design team. The design team is typically made up of a number of different professionals. Collaboration of designs and information is often time consuming on AEC projects, due to the large team of professionals. Structural engineers can often find themselves spending more time collaborating with the design team, than conducting the actual structural design and analysis (Schinler & Nelson, 2008).

BIM provides significant efficiencies in creating, managing, and exchanging of information between the project design team (ArcDox, 2016). BIM is a collaborative model of a building, or structure, which incorporates a multitude of different professional inputs and designs into a single, composite model. As a result, collaboration is improved as each professional's design is simulated as a composite model, ensuring that each design is compatible with the next.
Therefore, the model reduces the time required for the collaboration of information, allowing the structural engineers more time to focus on their design (Hunt, 2013).

The improved collaboration between the design team made possible by BIM technology, also reduces the chance of unbudgeted changes during the construction stage of a project.
The aforementioned case study found up to 40% elimination of unbudgeted changes (Azhar et al, 2012). The figure below graphically illustrates the various professionals of the design team who collaborate information, and add to the composite model.

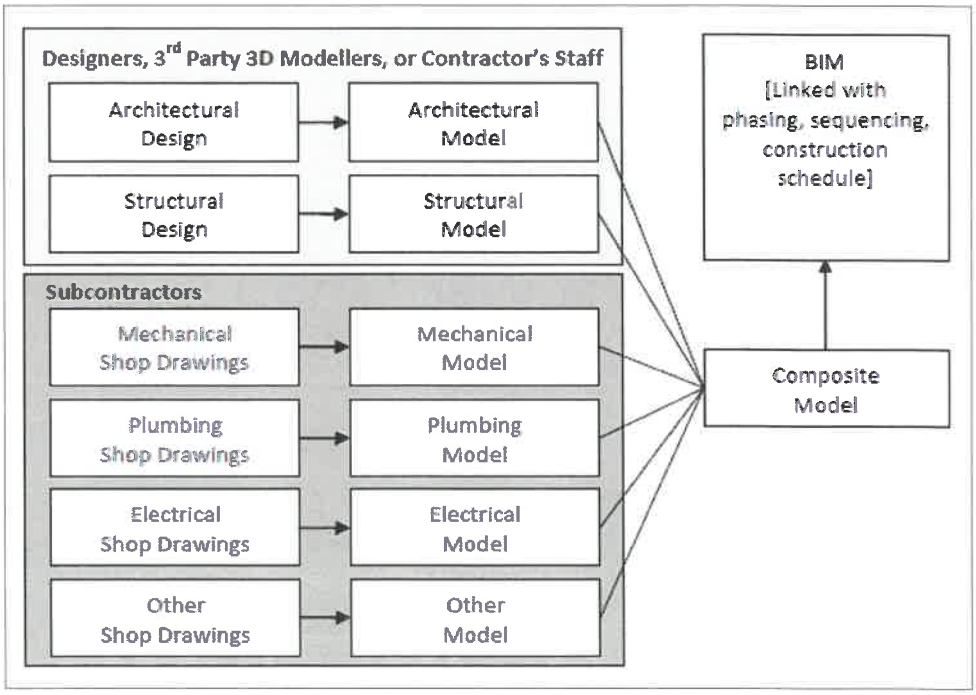


Figure 2-7: Collaboration of Information into a Single BIM Model (AGC, 2006, p5)

2.3.4 Documentation

Once the design of a structure is completed, the structural engineer begins preparing the documentation, which is used for the physical construction of the project. The documentation pertaining to the design usually includes the following:

- 2D drawings
- Specifications
- Schedules
- Production details

BIM technology has significantly streamlined the time-consuming process of preparing documentation within the AEC industry. The intelligent objects (foundations, walls, slabs, beams, columns, etc) that make up the 3D model, each contain a vast amount of information (Haron, 2013), from which 2D drawings, specifications, schedules, and production details, can be automatically generated. Furthermore, if the BIM model is adjusted by the structural engineer, the documentation is automatically updated to incorporate the adjustment (ArcDox, 2016).
The figure below graphically illustrates the output information that can be automatically derived from a BIM model.

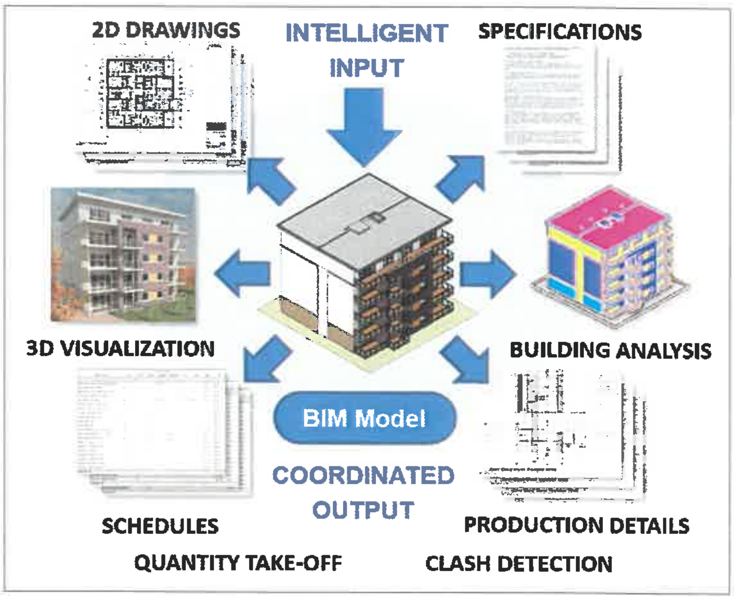


Figure 2-8: BIM Coordinated Output (ArcDox, 2016)

The preparation of documentation is not only sped up by using BIM technology, but the accuracy of the documentation is also improved. This can be seen from the findings of the case study conducted by Stanford University, which found cost estimation accuracy within 3% using BIM technology (Azhar et al, 2012).

2.3.5 Productivity

A significant advantage for the AEC industry enabled by BIM technology is that it improves productivity (Sacks & Barak, 2007; Hunt, 2013; Goldswain, 2016). Examples as to how BIM technology improves productivity within the AEC industry, are provided below:

- The improved visualisation of a 3D model assists the structural engineer in formulating solutions to complex situations in less time, therefore reducing the design duration (Fleming, 2016).
- Increased consistency and productivity of designs, due to improved simulation capabilities of BIM technology (Panaitescu, 2014).
- Improved collaboration enabled by BIM technology, reduces the time required to share information and incorporate designs between the design team (ArcDox, 2016).
- Reduced time required for checking for inconsistencies in the design and design clashes (Panaitescu, 2014).
- The automatic generation of 2D drawings, specifications, schedules, and production details, significantly improves productivity (Hunt, 2013).
- If an object is altered, added, or deleted within a BIM model, all output information is updated automatically, which avoids duplication of effort associated with the traditional methods of working (ArcDox, 2016).
- The case study conducted by Stanford University, found up to 80% reduction in time taken to generate a cost estimate, and up to 7% reduction in project time using BIM technology (Azhar et al, 2012).
- The financial feasibility of designs can be assessed in a shorter time, due to the reduction in time taken to generate a cost estimate. This results in financially feasible designs in less time.

2.3.6 Summary of the Advantages of BIM Implementation

In conclusion, there are clear advantages related to the implementation of BIM technology; such as the improved visualisation, improved collaboration between the design team, reduction in design clashes, reduced time to produce documentation, and an overall increase in productivity.

The table below provides a summary of the advantages of BIM implementation.

Table 2-2: Summary Table of the Advantages of BIM Implementation

No	Aspect	Summary of Advantages
1	Visualisation	- Improved 3D visualisation - Improved presentation of designs to clients - Easier to visualise integrated connections and complex sections - Visual representation of simulation results - Visual representation of design clashes
2	Simulation	- Simulation of a building or structure as a whole - Clash detection simulation - Increased consistency in designs - Reduced analysis time
3	Collaboration	- Improved information sharing - Improved design co-ordination and integration - Reduction in redundant work - Reduction of unbudgeted changes
4	Documentation	- Automatic generation of documentation: • 2D drawings • Specifications • Schedules • Production details - Improved accuracy of documentation - Documentation is automatically updated as the design is updated and/or adjusted
5	Productivity	- Increased speed of designs - Reduction in time for checking for design clashes - Less time required for collaboration - Less time required for the production of documentation - The financial feasibility of a design is assessed in less time

2.4 DISADVANTAGES OF BIM IMPLEMENTATION

While there are numerous advantages of BIM, it also has its drawbacks. This section of the chapter will explore the potential disadvantages and challenges of BIM implementation for structural engineering organisations. The findings will assist in providing solutions for objective 2 of this research dissertation.

The sub-sections below have been developed to guide the literature review in investigating the five most common categories of the disadvantages and challenges of BIM implementation. These five main categories to be investigated are as follows:

- Human Factors
- Software Factors
- Legal Concerns
- Lack of BIM Expertise
- Cost of BIM Implementation

2.4.1 Human Factors

It is clear from the literature reviewed in the previous section that BIM presents a number of industry enhancing advantages for the AEC industry. However BIM still requires a human component to implement the software based technology (Goldswain, 2016).

The human component introduces challenges for the implementation of BIM. There is a social and habitual resistance to change as structural engineers are content with using traditional methods of design, and are generally resistant to changing from their traditional methods of design to using BIM technology (Yan & Damian, 2008). The successful implementation of BIM requires the willingness of structural engineers and the project team to adjust from their current methods of design to using BIM technology.

Despite the vast number of benefits of BIM technology and the global trend towards mandatory BIM implementation, there is still resistance to change within the AEC industry (Tabesh, 2014).

2.4.2 Software Factors

A challenge encountered by many structural engineers that implement BIM software is that a larger 3D BIM model becomes sluggish (Fleming, 2016). This is due to the vast amount of information incorporated within a larger 3D BIM model. The model consumes a considerable amount of RAM, hence resulting in the sluggish effect of the software. BIM software requires computers with higher specifications to operate efficiently.

Compatibility of software introduces challenges when implementing BIM technology on a project. This is due to the wide range of BIM software packages available, namely: Autodesk Revit Structures, Telka Structural Designer, Robot Structural Analysis Professional, etc. Different software packages have different data formats which are sometimes incompatible with the next, making the exchange of information between the project team difficult (Goldswain, 2016).

2.4.3 Legal Concerns

There are uncertainties within the AEC industry when it comes to the sharing of a BIM model between the project team (Eadie et al, 2012). The collaboration and exchange of information, between the project team presents certain legal concerns in relation to the copyright of Intellectual Property (IP) due to the sharing of a single model (Goldswain, 2016).

There are also concerns regarding the ownership of the BIM model and its information. Nevertheless, there are guidelines being developed to contractually address the legal concerns when it comes to BIM implementation on projects (Eastman et al, 2012).

2.4.4 Lack of BIM Expertise

BIM software packages require a level of expertise and understanding in order to fully reap the advantages associated with BIM technology. This requires a structural engineering organisation to allocate valuable time and human resources to attend training on BIM software (Yan & Damian, 2008).

Due to the lack of expertise within an organisation during the implementation stages of BIM technology, an organisation may require the assistance from costly external BIM experts to solve problems that may arise (Revit Modelling, 2015).

2.4.5 Cost of BIM Implementation

A number of the disadvantages mentioned above have a direct link to the initial costs involved with the implementation of BIM. An organisation implementing BIM will be required to purchase BIM software. The organisation will need to identify the most suitable BIM software package, and then determine the number of licences they will require based on the number of users (Fleming, 2016). The choice of software package, and number of licences required, will determine the costs involved for the BIM software.

The structural engineers implementing BIM will be required to attend training courses in order to use BIM software - this is one of the most pivotal challenges when it comes to implementing BIM technology (Crotty, 2011). The training courses, and time required for the professionals to attend the training courses, will add to the initial cost of implementing BIM.

The added computer hardware requirements of BIM software may also require an organisation to upgrade a number of computers to run the software effectively.

The initial purchase of BIM software, licences, upgrading of computers and training, presents structural engineering organisations with the challenge of high costs for implementing BIM technology.

2.4.6 Summary of the disadvantages of BIM Implementation

In conclusion, there are disadvantages related with the implementation of BIM technology, such as the human factors, software factors, legal concerns, lack of BIM expertise and implementation costs. The table below provides a summary of the disadvantages of BIM implementation.

Table 2-3: Summary Table of the Disadvantages of BIM Implementation

No	Aspect	Summary of Disadvantages
1	Human Factors	- Reluctant to change from traditional methods of design to using BIM technology
2	Software Factors	- Larger 3D BIM models are sluggish on standards computers - Compatibility of different software packages

3	Legal Concerns	- IP copyright concerns - Vague understanding of the ownership of the BIM model
4	Lack of BIM Expertise	- Requires human resource time for training courses - External experts during implementation stages
5	Cost of BIM Implementation	- Cost of BIM software - Cost of BIM software licences - Upgrading of computers - Cost of training courses

2.5 INTERNATIONAL BIM IMPLEMENTATION TRENDS

In this section of the literature review, the international BIM implementation trends will be analysed, and a summary will be provided on the current state of BIM implementation within 32 countries around the world. The review will further focus on the countries that have already placed some form of mandatory requirements on BIM implementation, such as Australia, Denmark, Finland, Hong Kong, Sweden, Singapore, United Arab Emirates, United Kingdom, and the United States. The findings from this section will assist in providing solutions for objective 3 of this research dissertation.

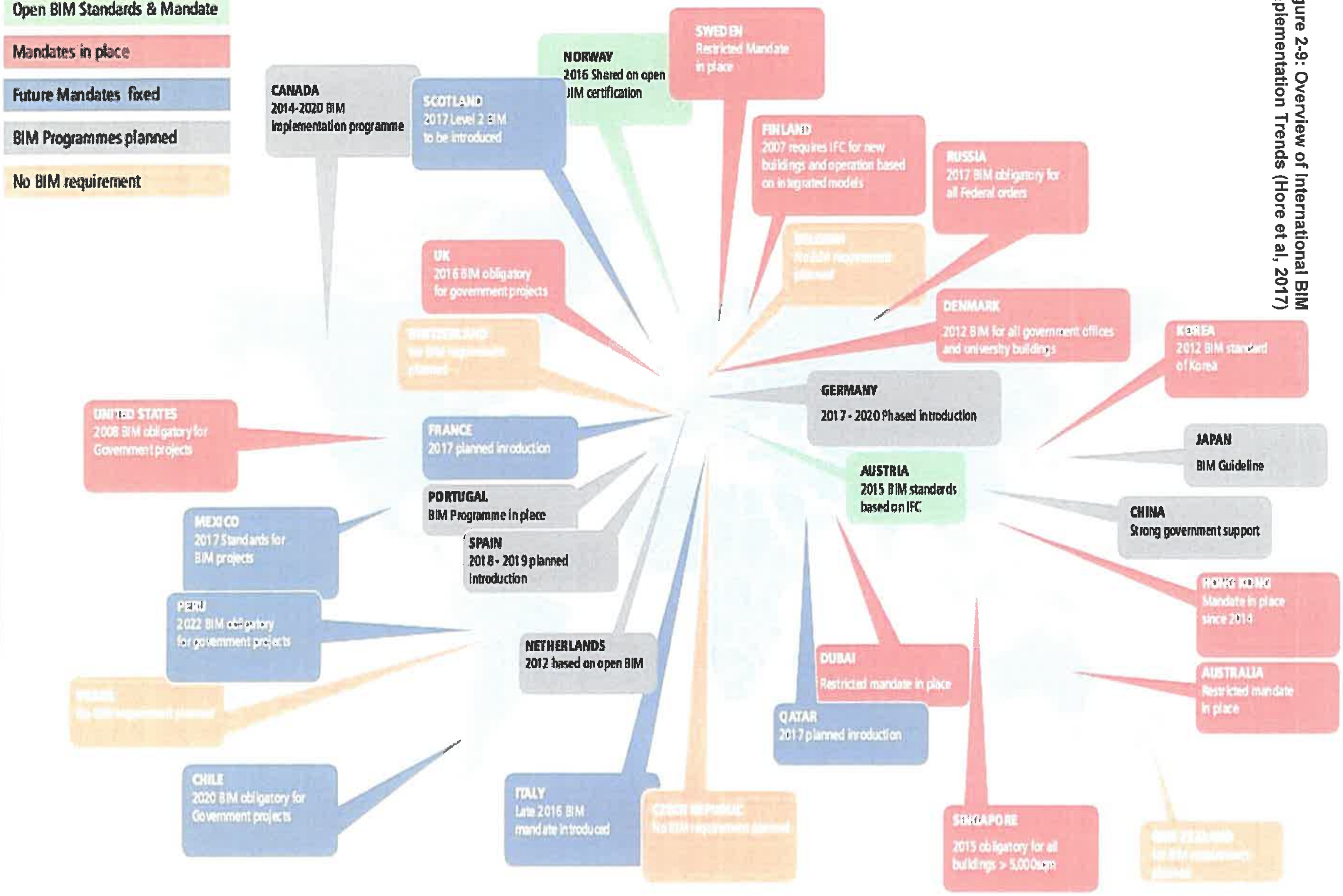
The implementation of BIM in the AEC industry is accelerating at rapid rate around the world (Hore et al, 2017). Recent research conducted on the size, trends and forecasts of the global BIM market, reported that it is expected to reach around the $8 billion mark by 2020 - this is at an annual growth rate of 13% per annum from 2015 to 2020 (Daedal, 2016).
In a report released by McGraw Hill in 2014, it was found that globally, over 30% of the contractors within the AEC industry had implemented BIM on their projects (McGraw Hill, 2014a).
A survey conducted by the National Building Specification (NBS) in the United Kingdom, found that the implementation of BIM had increased from 13% in 2011 to 54% in 2016 within their AEC industry (Hore et al, 2017).

It is clear from the above paragraph, that there is a shift in the AEC industry towards BIM technology. Countries around the world are recognising the advantages that BIM implementation is introducing into the AEC industry. This has resulted in the increase of mandatory BIM implementation being introduced in some countries, or at least being highly recommended in others (Baier, 2016).

The figure on the following page was developed by Construction Information Technology Alliance (CITA), for their report on the Global BIM Study 2017 (Hore et al, 2017). It provides a graphic representation of the overview of international BIM implementation trends. The figure demonstrates the considerable increase in BIM implementation around the world. The place-marks on Figure 2-9 are colour coded as follows:

- Green – Open BIM Standards & Mandate
- Red – Mandates in place
- Blue – Future Mandates fixed
- Grey – BIM Programmes planned
- Orange – No BIM requirement

Figure 2-9: Overview of International BIM Implementation Trends (Hore et al, 2017)



2.5.1 Australia

The implementation of BIM in Australia has increased significantly in recent years. 2014 reports conducted by McGraw Hill, indicated that 61% of design professionals in the country had implemented BIM, and that it was predicted to rise to 77% by 2016 (McGraw Hill, 2014b).

The National BIM Initiative (NBI) in Australia is believed to be a significant contributor to the increase in BIM implementation in the country over the years (BuildingSmart, 2012b). The NBI report comprises of 2 volumes:

1. Volume 1: Strategy (what needs to be done)
2. Volume 2: Implementation Plan (how it should be done)

The New South Wales Health Department and the Australian Department of Defence have mandated BIM implementation on all projects of over $30 million.

2.5.2 Denmark

Denmark is notably, one of the earliest countries to have mandated BIM implementation. In 2007, regulations for mandatory BIM implementation were applied to all central government projects with a value of over €677,000 (Baier, 2016).

In 2011, the Danish Parliament decided to extend on the mandate set in 2007, by mandating BIM implementation to all local and regional projects with a value over €2.7 million.

2.5.3 Dubai (United Arab Emirate, UAE)

BIM implementation was first mandated in Dubai by the Dubai Municipality in November 2013. The municipality's regulations called for mandatory BIM implementation on buildings over 40 floors tall, or buildings with an area greater than 27 871m^2. This included all government projects, hospitals, universities and schools (Hore et al, 2017).

In July 2015, the Dubai Municipality issued an updated circular (207), titled, *"Regarding the expansion of applying BIM on buildings and facilities in the Emirate of Dubai"*.
The new circular expanded the mandatory implementation of BIM for project owners, consulting firms, contractors and governmental departments. This circular made the implementation of BIM mandatory on buildings that are above 20 floors for all governmental projects (Bhatia, 2015).

2.5.4 Finland

In 2002, the Confederation of Finnish Construction Industries, 'set the ball in motion' by announcing their decision that BIM technology would be the future direction of the AEC industry in the country (CIOB, 2015).

The state-owned company, Senate Properties, were early implementers of BIM technology on their projects, and in 2007 they announced that BIM would be mandatory for all projects over the value of €1.0 million. Along with the mandate in 2007, Senate Properties also published BIM guidelines highlighting specific requirements for projects (Baier, 2016).

2.5.5 Hong Kong

One of the main reasons for the decision to mandate BIM implementation in Hong Kong, was to ensure that their AEC industry, and all the professionals within the industry, keep up to date with developing countries in order to compete for projects outside of Hong Kong (Hore et al, 2017).

The Hong Kong Housing Authority (HKHA) first started implementing BIM on social housing construction projects back in 2006. In 2014, the HKHA mandated full BIM implementation on all projects (Baier, 2016).

2.5.6 Sweden

Sweden has a number of initiatives and programmes in place in order to promote BIM implementation within the country. The BIM Alliance Sweden is a non-profit organisation, which is a key driver of BIM implementation in the country. In 2013, the BIM Alliance Sweden, in collaboration with various other industry drivers, published the 'BIM - Standardiseringsbehov' guidelines, which assisted in promoting and increasing BIM implementation in Sweden (Eckholm et al., 2015).

The Swedish Transportation Administration, which is the biggest project owner in the country, mandated BIM technology for all new investment projects in 2015 (Hore et al, 2017).

2.5.7 Singapore

The Singapore government embarked on improving their AEC industry through BIM technology. They introduced a $6 million BIM implementation fund in 2010, which was used to incentivise early BIM users within the country. The finances were to be used to cover the costs of training, software and hardware (Khemlani, 2012).

The Building and Construction Authority (BCA) mandated the implementation of BIM within their construction industry in 2015 (Hore et al, 2017).

2.5.8 United Kingdom (UK)

The UK government announced its intention to mandate BIM implementation (with all project and asset information, documentation and data being electronic) on all its projects by 2016 (Johnson, 2012). This mandate required a minimum of level 2 BIM standard usage which came into effect in April 2016.

A number of educational courses to accredit organisations to a BIM level 2 standard, have been developed within the country. This is to aid in the support of training and educating professionals within the UK AEC industry, in order to fulfil the requirements of the mandate set in 2016.

2.5.9 United States (US)

The US is one of the leaders in BIM implementation, and has experienced one of the highest increases in BIM usage around the world. This can been seen from the McGraw Hill report conducted in 2013, which indicated the increase from 28%, of construction professionals using BIM in 2007, to 71%, in 2012. This amounts to a 43% increase in just 5 years (McGraw Hill, 2013).

There are multiple mandates in place throughout the US, some of which include the General Services Administration (GSA), and the US Army Corps of Engineers (USACE), who require BIM deliverables on all major projects within the country (Hore et al, 2017).

2.5.10 Conclusion on International BIM Implementation Trends

The literature reviewed above regarding international BIM developments, provides insight as to the global increase and shift towards BIM implementation within the AEC industry.

A number of countries have various mandates in place for the implementation of BIM, for projects of a certain type, size or value. The decision by so many countries to apply mandatory BIM implementation requirements, is said to be due to the increased efficiency and simultaneous financial savings, which are associated as advantages of implementing BIM technology (BuidlingSMART, 2010; Cabinet Office, 2011; Poon, 2013; Baier, 2016).

The Global BIM Study report conducted by CITA identified twelve countries which have mandatory BIM implementation regulations in place in 2017, with a further nine countries that have mandatory regulations planned within the near future (Hore et al, 2017).

Considering the current international trends of BIM implementation, it is highly possible that in the future, South Africa will start requiring BIM implementation on projects. It is important to understand the international developments of BIM and its increased usage around the world, in order to ensure that SA's AEC industry, and all the professionals within the industry, stay up to date with modern technologies.

The table below provides a summary of the international trends of BIM implementation. The column on the far right (BIM Mandatary Implementation Status) highlights countries which have some form of mandatory regulations in place for BIM implementation.

Table 2-4: Summary of International BIM Implementation Trends (based on Baier, 2016; Hore et al, 2017)

No	Country	Details	BIM Mandatory Implementation Status
1	Australia	Restricted mandate in place	Mandatory
2	Austria	Likely to be in place by 2018	In progress (2018)
3	Belgium	No regulation to date	None
4	Brazil	No BIM implementation planned	None
5	Canada	No regulation to date	None

No	Country	Details	BIM Mandatory Implementation Status
6	Chile	BIM mandated for 2020	In progress (2020)
7	China	BIM mandate part of 5year plan (2014 start)	In progress (2014 – 2019)
8	Czech Republic	No BIM implementation planned	None
9	Denmark	Mandatory since 2007	Mandatory
10	Dubai	Mandatory since 2013	Mandatory
11	Finland	2007 requires IFC for new buildings and operation on integrated models	Mandatory
12	France	BIM Mandated for 2017	In progress (2017)
13	Germany	BIM mandated for 2020	In progress (2020)
14	Hong Kong	Mandate in place since 2014	Mandatory
15	Italy	No mandate	None
16	Japan	No mandate	None
17	Korea	2012 BIM standard of Korea	Mandatory
18	Mexico	BIM Mandated for 2017	In progress (2017)
19	Netherlands	2012 based on open BIM	None
20	New Zealand	No BIM implementation planned	None
21	Norway	Mandate since 2016	Mandatory
22	Peru	BIM mandated for 2022	In progress (2022)
23	Portugal	No BIM implementation planned	None
24	Qatar	No regulation to date	None
25	Russia	2017 BIM obligatory for all Federal orders	Mandatory
26	Scotland	BIM Mandated for 2017	In progress (2017)
27	Singapore	Mandate since 2015	Mandatory
28	Spain	BIM mandated for 2018	In progress (2018)

No	Country	Details	BIM Mandatory Implementation Status
29	Sweden	Restricted mandate in place	Mandatory
30	Switzerland	No BIM implementation planned	None
31	United Kingdom	BIM Mandated since 2016	Mandatory
32	United States of America	2008 BIM mandatory for Government projects	Mandatory

2.6 NATIONAL (SA) BIM IMPLEMENTATION TRENDS

The international trends of BIM implementation have been presented in the previous section. This section investigates the BIM implementation trends in South Africa. The findings from this section will assist in providing solutions for objective 3 of this research dissertation.

The implementation of BIM in South Africa has been relatively slow in comparison with the rest of the world (White, 2015). It is mainly being implemented on larger more technical projects in South Africa. Most projects are still using traditional 2D CAD as a standard (Rooney, 2015). However, recent findings from a survey conducted on the BIM uptake trends in South Africa, found that BIM implementation had increased from 2009 to 2013 (Froise and Shakantu, 2014). The figure below was created by Froise and Shakantu based on their research survey data. The figure graphically illustrates the increase of BIM implementation in South Africa compared with other countries.

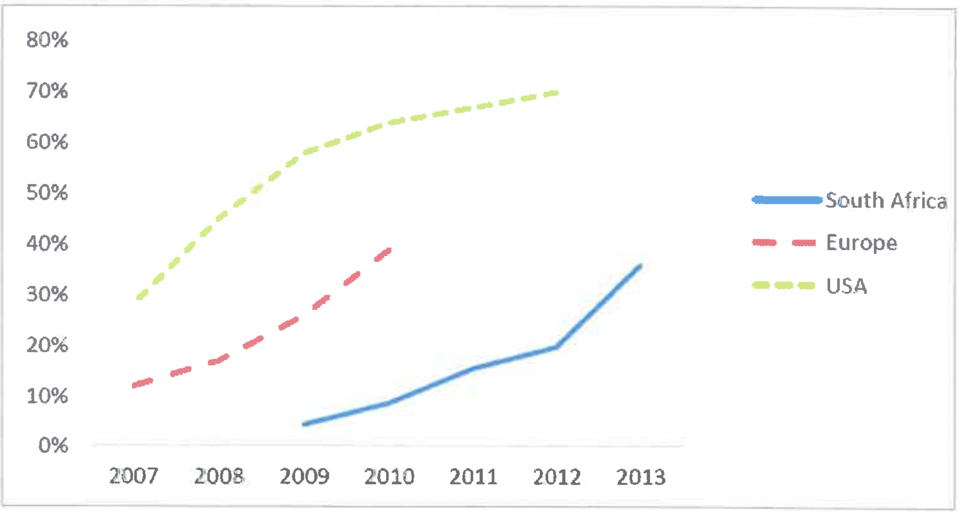


Figure 2-10: BIM Implementation Trend Line (Froise and Shakantu, 2014)

This study identified four main barriers which hinder BIM use in South Africa (Froise and Shakantu, 2014). These are:

- Lack of awareness by large clients
- Lack of awareness by the government
- Lack of awareness by industry bodies
- A procurement process that discourages collaborative processes

Despite the increase in BIM implementation in recent years, South Africa is still lagging behind the rest of the world. BIM implementation is not mandatory in South Africa. However, questions surrounding mandatory BIM implementation being able to speed up BIM usage in South Africa, have already started circulating within South Africa's AEC industry (Harris, 2016).

2.7 BIM CASE STUDY REVIEW

This section of the literature review investigates international case studies in which BIM technology played a significant role.

2.7.1 Abu Dhabi International Airport

The Abu Dhabi International Airport project consisted of a new terminal which is capable of housing 65 aircrafts, 136 screening lanes and 22 kilometres of conveyor belts. The figure below is a graphical 3D BIM representation of the Airport.

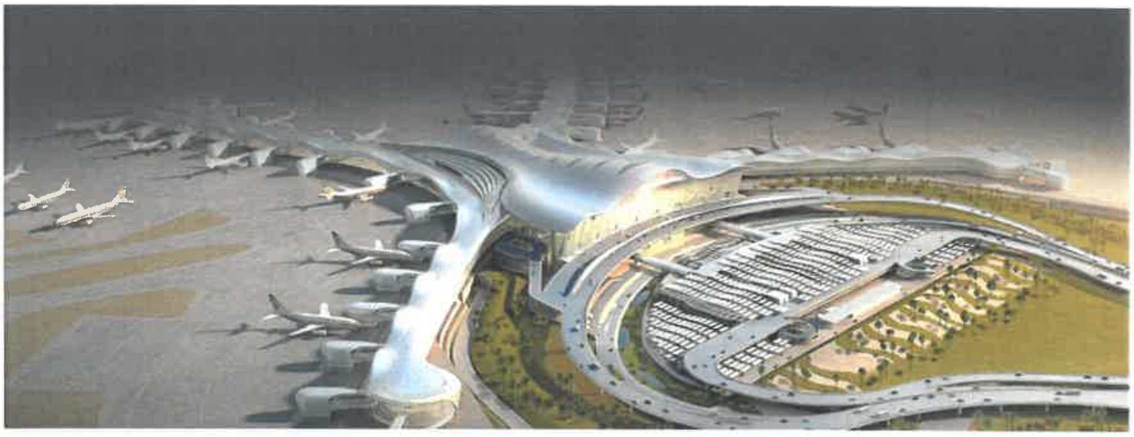


Figure 2-11: 3D BIM Representation of the Abu Dhabi International Airport

The project design team used BIM technology to improve collaboration and ultimately, to save costs and time on the project.

BIM enabled the design team to implement the following tasks with ease (Civilax, 2017):

- Forecasting construction schedules;
- Cross checking designs and detecting clashes;
- Confirming and managing resource allocation;
- Analysing data files produced by other consultants in the team; and
- Monitor costs and risks via dashboards.

BIM technology enabled the design team to detect structural clashes and other problems early in the design stage, which prevented costly on-site construction clashes and abortive work.
The implementation of BIM technology on the Abu Dhabi International Airport project saved over $1.0 million (USD), and an estimated 51 000 working hours (Civilax, 2017).

2.7.2 Hilton Aquarium

The data for the Hilton Aquarium case study, was provided by the Holder Construction Company, Atlanta, Georgia. The case study highlighted a number of cost and time savings, due to the implementation of BIM. BIM technology was implemented for the design coordination, clash detection, and work sequencing. The findings from the case study are as follows (Azhar et al, 2012; Panaitescu, 2014):

- BIM implementation cost to project: $90 000.00 - 0.2% of the total project budget
- BIM cost savings: $600 000.00 - mainly due to the elimination of clashes
- BIM time and schedule savings: 1 143 working hours

2.7.3 Gensler's Shanghai Tower

The Gensler's Shanghai Tower is the tallest building in China, and second tallest building in the world. The building's geometry slightly rotates on each floor, creating a spiral effect of the Tower. The spiral effect was not only designed for aesthetic purposes, but also to resist lateral loads acting on the building. This design increased the lateral resistance by 24%. There are over 7000 variations of geometries, and 20 000 dual-skinned curtain walls, which make up the structure (Civilax, 2017).

The complexities of the building's geometry made the use of 2D models and other traditional methods of structural design extremely difficult. The implementation of BIM on this project provided the structural engineers with the opportunity to better visualise the entire structure's complex geometry as a 3D model. Furthermore, the BIM model also enabled the structural engineers to analyse the building as a whole, taking into account how wind and seismic loads will affect the spiral geometry of the building (Civilax, 2017). The figure below is a graphical 3D BIM representation of the building.

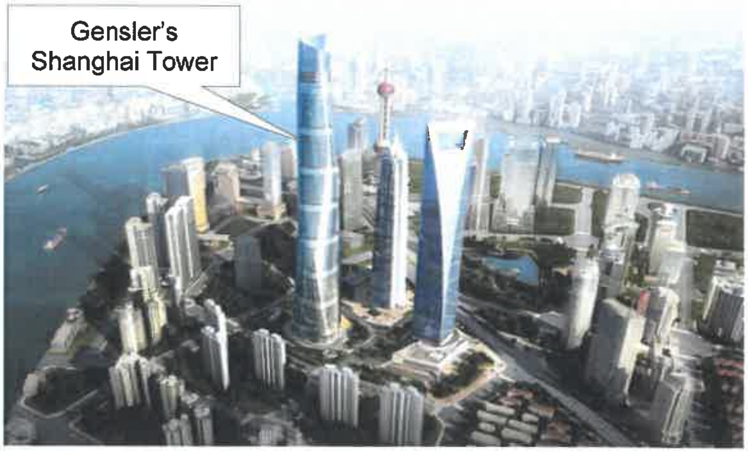


Figure 2-12: 3D BIM Representation of the Gensler's Shanghai Tower

2.8 FUTURE OF BIM

A significant future standard which is forthcoming in the AEC industry, is the 3D printing of designs. With the developments of 3D printing combined with BIM technology, 3D printed models are the future of presenting designs to clients.

The figures below graphically illustrate a 3D printed model of the design for the Stockholmsarenan Stadium in Sweden, produced in combination with 3D printing and BIM technology (Sculpteo, 2017).

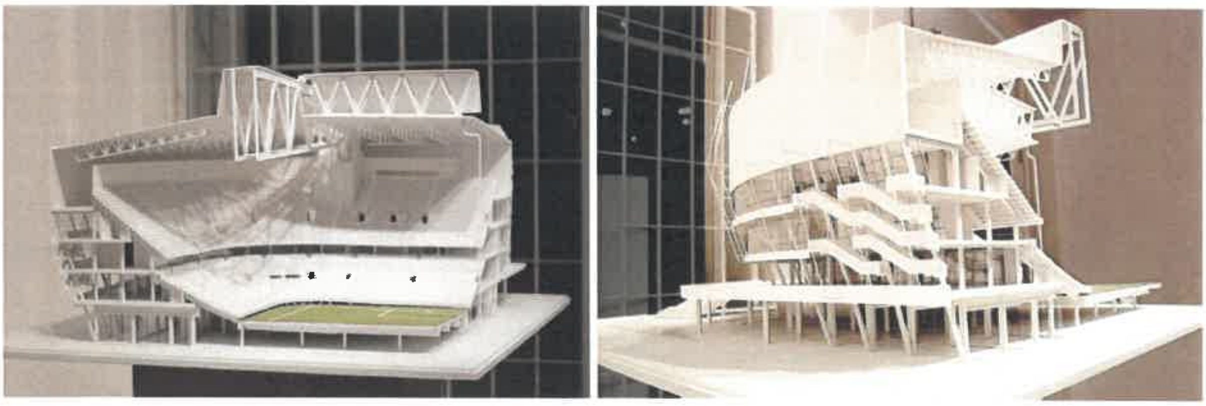


Figure 2-13: 3D Printed Model Produced from BIM (Sculpteo, 2017)

3D laser scanning is another future development for BIM. The AEC industry is focusing on using 3D laser scanning technology to produce accurate surveys of a proposed building site's existing terrain. The 3D survey can then be imported into a 3D BIM model (Fleming, 2016).

The long term future of BIM is focused on further developments in software, collaboration, facility management, and cloud based information storage, in order to further improve on the advantages of BIM (Panaitescu, 2014).

The future of BIM is also focused on the human, and social acceptance towards BIM implementation. The UK based, National BIM Survey (NBS) indicated that 94% of the participants from the AEC industry expected that they will be using BIM by 2016 (NBS, 2013). Based on the findings from the NBS survey, it is expected that there will be a mind shift in the AEC industry towards BIM technology, and that BIM will be adopted in more engineering organisations in the future.

The literature, reviewed in this section, has shown that BIM implementation is increasing at a rapid rate (McGraw Hill, 2013; Panaitescu, 2014; Holzer, 2015), and is becoming a mainstream practice within the AEC industry (Eastman et al, 2011). It is expected that the future of BIM will see more countries mandating BIM implementation on projects, and that eventually, BIM will become standard practice within the AEC industry.

Drawing from the above information, it is important to consider the future of BIM within the AEC industry. Investigating the future of BIM has identified further efficiency improvements and the implementation of mandatory use of BIM on projects in the future.

2.9 CHAPTER SUMMARY

BIM is reshaping the AEC industry, and providing the early users of BIM with a number of advantages. Based on the literature reviewed within this chapter, it is envisioned that BIM will become an industry standard in the future, and organisations may find themselves scrambling to learn BIM technology, once it becomes a mandatory requirement by clients.

This chapter has provided a comprehensive explanation of BIM. Following this, literature has been reviewed on the advantages and disadvantages of BIM implementation. The chapter then presented the current BIM implementations trends, both nationally and internationally. The chapter concluded with the review of case studies that implemented BIM, and the future of BIM for the AEC industry. The results from this chapter will assist in providing solutions for objectives 1, 2, and 3, of this dissertation.

The dissertation proceeds to the research methodology chapter which will present the research process and methodology used to provide answers to the research objectives, and questions.

CHAPTER 3

RESEARCH METHODOLOGY

3. CHAPTER 3: RESEARCH METHODOLOGY

3.1 CHAPTER INTRODUCTION

The purpose of this chapter is to provide the research design and methodological approach which was adopted to address the research objectives and questions of this dissertation. This chapter first presents the processes that were followed in the collection of the data and the analysis of the data thereafter. Following this, the validity and reliability of the research will be presented. Potential biases and ethical considerations will also be highlighted in this chapter. The chapter then concludes with the chapter summation.

3.2 RESEARCH DESIGN

The research design adopted for this dissertation involved a combination of methods. It, therefore makes use of the mixed methods research approach. A mixed method research approach is the combination of both quantitative and qualitative methods into a single study (Wiersma & Jurs, 2009).

The mixed method approach provides a number of advantages, as Punch highlights (Punch, 1998):

- The combination of methods allows one method to validate the other.
- Quantitative findings can be substantiated by qualitative research, which can provide a deeper understanding of the context and background to the quantitative findings.
- Quantitative research can bring structural aspects, while qualitative research can add process elements.
- Quantitative research can uncover relationships between aspects, while the qualitative research can help understand the relationship between aspects.

This dissertation requires both structured facts, and the ability to understand how those facts impact BIM implementation within context. Due to its ability to meet both of these requirements, the mixed methods approach was the preferred method for this dissertation.

3.3 RESEARCH METHOD

The research methodology adopted for this dissertation involved the combination of various data collection techniques, in order to best provide solutions for the research objectives and questions.

The approach investigated both theoretical and practical aspects related to the research objectives. The theoretical component examined published academic journals, papers and dissertations. The practical component used a combination of questionnaires, interviews, and a case study.

The various methodologies which were adopted for this dissertation are listed below, along with a research methodology diagram:

1. **Literature Review**
2. **Quantitative Research**
   - Questionnaires
   - Structured Interviews
3. **Qualitative Research**
   - Illustrative Case Study
   - Interviews
4. **Desktop Study**

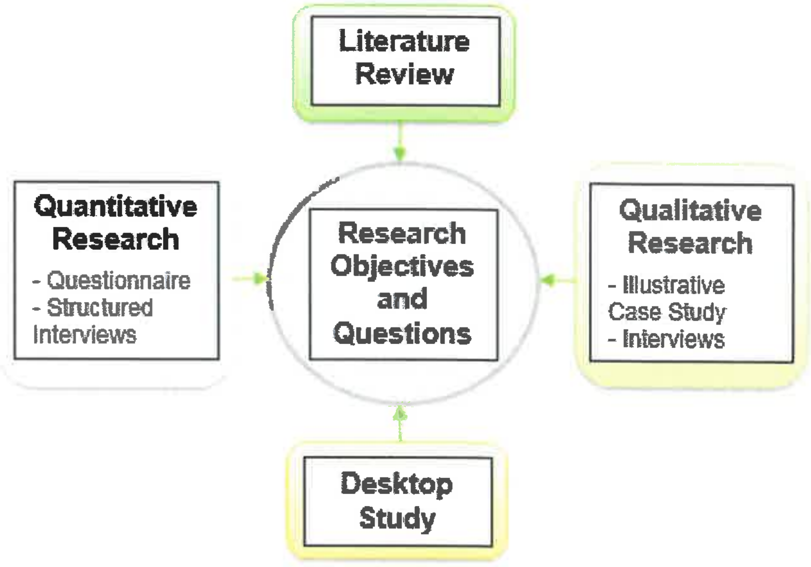


Figure 3-1: Research Methodology Diagram

The table below provides an overview of the data collection methods, and how each method is linked to the research objectives and questions.

Table 3-1: Research Methodology Link with Research Objectives and Questions

Research Method	Objective 1		Objective 2		Objective 3		Objective 4	
	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8
Literature Review		X	X	X	X	X		
Questionnaires	X	X	X	X			X	

Research Method	Objective 1		Objective 2		Objective 3		Objective 4	
	Question 1	**Question 2**	**Question 3**	**Question 4**	**Question 5**	**Question 6**	**Question 7**	**Question 8**
Illustrative Case Study	X		X	X				
Interviews (Structured and Unstructured)		X	X	X				
Desktop Study							X	X

3.4 DATA COLLECTION

As previously indicated, the mixed methods approach adopted for this dissertation allowed for the use of a number of different data collection methods. Quantitative data collection in the form of questionnaires and structured interviews, was adopted, while qualitative data collection methods in the form of interviews and a case study, were used. The sections below further elaborate on the different data collection methods that were used.

3.5 QUANTITATIVE RESEARCH

The quantitative research method focuses on the collection and analysis of numerical data (Bryman & Bell, 2014). This approach was used to numerically quantify and analyse findings from the questionnaires and structured interviews.

This data was used to identify the current structural engineering design methods, the current state of BIM usage, and the barriers hindering BIM implementation, within structural engineering organisations of the Eastern Cape.

Structured interviews were also developed in order to quantify the advantages and/or disadvantages experienced by the architects and structural engineers involved in a recent project which used BIM technology (refer to chapter 4: illustrative case study on the project).

3.5.1 Questionnaire

The questionnaire was designed to include a combination of structured multiple choice questions, rating scales, and open-ended questions. The questionnaire was designed to be as simple as possible for the participant, in the aid of improving the response rate.

The structured multiple choice questions and rating scales facilitated the completion of the questionnaire in minimal time. Open-ended questions, and comment sections were included to provide the participant with the opportunity to add their own input and honest opinions (Cohen et al, 2005).

Questionnaires were hand delivered or emailed to structural engineers within the Eastern Cape. Contact details were sourced from the researcher's industry peers, telephone directories, internet directories and databases from the South African Institute of Civil Engineering's (SAICE) local branch.

The questionnaire was segmented into 4 main sections, which are as follows:

- **Section 1:** Gathered information, in order to obtain a brief overview of the participant. This section consisted of four sub-questions.
- **Section 2:** Investigated the current structural engineering design methods being used in the EC. This section consisted of six sub-questions.
- **Section 3:** Investigated the current state of BIM implementation, and the barriers hindering BIM implementation in the EC. This section consisted of eleven sub-questions.
- **Section 4:** Gathered general information on the most used drafting and structural design software being used by participants. This section consisted of two sub-questions.

The research questionnaire developed for this dissertation has been attached as Appendix C.

3.5.2 Structured Interview

A structured interview guide was developed in order to investigate the advantages and/or disadvantages experienced by the architects and structural engineers involved in the project case study. The structured interview guide used both quantitative methods to assist in numerically quantifying responses. A comment section was added to capture qualitative aspects from the participants. This section focuses on the quantitative portion of the interview.

The structured interview made use of rating scales to numerically quantify the participant's responses.

The rating scales were designed using Likert scales (e.g. rating in order of significance from 1 to 5), which provided participants with the opportunity to express an extent of agreement or disagreement (Johns, 2010). The table below illustrates the Likert scale that was used to quantify participant's responses.

Table 3-2: Likert Scale used for the Structured Interviews

Strongly Disagree (1)	Disagree (2)	Unsure (3)	Agree (4)	Strongly Agree (5)

The structured interviews were used to identify the participants experience using BIM technology on the project. The interview was structured into five (5) main sections, namely:

1. Visualisation
2. Simulation
3. Collaboration
4. Documentation
5. Productivity

The structured interviews were conducted face-to-face or via telephonic calls. The interview guide developed for the case study has been attached as Appendix E.

3.6 QUALITATIVE RESEARCH

The qualitative research method focuses more on words and pictures, as opposed to quantifying numbers, which is the focus of the quantitative research method (English, 2012). The qualitative approach was used to further substantiate the quantitative findings from the questionnaires and structured interviews. The qualitative research methods used for this dissertation included an illustrative case study and interviews.

3.6.1 Illustrative Case Study

The case study method was adopted to investigate BIM technology in its real-world context (Yin, 2014). The case study focused on a recent project, within the Eastern Cape, that implemented BIM technology during the design stage of the project.

The case study was divided into five main sub-sections. The figure on the right graphically illustrates the five main sub-sections of the case study, and how BIM is interconnected to each aspect.

These sub-sections were developed to further explore themes that were uncovered during the literature review on the advantages of BIM implementation.

While the literature review investigated the theoretical aspects of BIM, the case study investigated the practical application of BIM technology on the project.

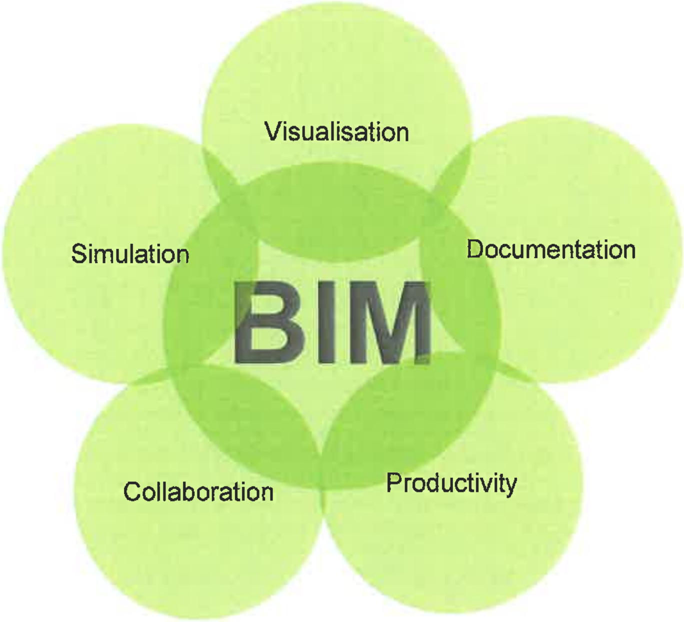


Figure 3-2: Relationship between BIM and the 5 Sub-Sections of the Case Study

BIM is predominately a visual based technology. Therefore, the use of visualisations to illustrate aspects of BIM technology is the best way to explain the concept of BIM to an unfamiliar reader.

An illustrative case study was the preferred type of case study for this dissertation, as this method focuses on visual representations and small sections of different aspects of a topic in order to explain the topic to an unfamiliar reader, while sustaining the reader's interest (Mann, 2006).

3.6.2 Interviews

The illustrative case study included data from interviews to further elaborate on the five main sub-sections of the case study. As specified in the structured interview section above, the interview was designed to use both quantitative and qualitative methods. This section focuses on the qualitative portion of the interview.

The qualitative portion of the interview assisted the researcher in probing the participant to further elaborate on their answers (Welman et al, 2005). Therefore, the qualitative section of the interview was used to encourage participants to provide their own opinions and perceptions of BIM technology on the project.

3.7 SAMPLING

This dissertation focuses on the structural engineering industry of the Eastern Cape province of South Africa. Taking these specific parameters into account, purposive sampling was employed in order to acquire the relevant people to provide the most accurate responses to the questionnaires (Cohen et al, 2005).

The criteria used to determine the participants was as follows:

1. Area of expertise - the participant had to specialise in the field of structural engineering.
2. Geographical location - the participant had to be working within the Eastern Cape.

Information regarding the relevant people that suited the purposive sampling criteria was sourced from the researcher's industry peers, telephone directories, internet directories and databases from the SAICE's local branch.

The sampling for the structured interviews also used purposive sampling. The architects and structural engineers that used BIM technology on the case study project, were selected for the interviews.

3.8 DATA ANALYSIS

The data collected from both the quantitative and qualitative research methods was analysed using different sets of procedures. This section is divided into three sub-sections, namely:

- Analysis of Quantitative Data
- Analysis of Qualitative Data
- Computer Assisted Data Analysis

3.8.1 Analysis of Quantitative Data

The data, collected from the quantitative research method was analysed using the following procedures (English, 2012):

1. **Data Scales:** The ordinal data system was used to analyse the data collected, whereby each answer was assigned a unique number in order to quantify the findings.
2. **Data Preparation:** Data was collated and scrutinised for any inconsistencies, and then prepared for analysis.
3. **Descriptive Statistics:** Data was then organised, tabulated, and summarised in the form of graphs, charts, and diagrams.
4. **Data Summary:** The data analysis concluded with the writing up of results and the discussion of the findings.

3.8.2 Analysis of Qualitative Data

This dissertation used the Miles and Huberman framework for the analysis of the qualitative data. The three phases in their framework are, as follows (Miles & Huberman, 1994; Punch 1998; English, 2012):

1. **Data Reduction:** Data from the interviews and case study was first collated then simplified. Following this, the data was organised into recurring themes and patterns.
2. **Data Display:** The organised data was then compressed and assembled into graphs, charts and diagrams.

3. **Drawings and Verifying Conclusions:** The data was then interpreted, and conclusions were drawn. The data analysis concluded with the writing up of the results, and the discussion of the findings.

3.8.3 Computer Assisted Data Analysis

The data was captured electronically using computer software such as Microsoft Excel. The computer software was used to facilitate the storing, arranging, sorting, and production of graphics; in the aid of analysing the data, and, ultimately, producing clear results.

3.9 VALIDITY AND RELIABILITY OF THE RESEARCH

The use of purposive sampling ensured that the participants selected for the questionnaires and interviews, were working within the Eastern Cape, and are specialists in the field of structural engineering. The purposive sampling method aided in providing valid data from knowledgeable industry professionals.

Furthermore, in order to get a true representation of the structural engineering industry of the EC as opposed to only a minority, questionnaires were issued to as many structural engineers within the EC as possible.

The response rate is also an important aspect to consider. A higher response rate is important in order to avoid only receiving a minority view. English suggests that a response rate of 60% or more is regarded as very acceptable, while 50% is regarded as acceptable, and anything less than 50% becomes problematic and bias (English, 2012).

A response rate of **74%** (25 responses out of 34 questionnaires issued) was achieved for the questionnaires, and **100%** (6 interviews conducted out of 6 intended interviewees) was achieved for the interviews. Therefore, the data collected from the questionnaires and interviews was deemed as being very acceptable.

In order to establish the reliability of the data collected from the structured interviews, the Cronbach Alpha Consistency test was used. The closer the Cronbach Alpha score was to 1, the higher the consistency, and, ultimately, the reliability of the data collected (Daud et al, 2010).

Table 3-3: Cronbach Alpha Consistency Chart

Cronbach's Alpha	Consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

The overall consistency score (calculation attached as Appendix G of this dissertation) of the structured interviews using the Cronbach Alpha test, was calculated as α = **0.842**. As per the above table, this score indicates that the consistency of the data collected from the structured interviews is deemed as being **'good'**.

The researcher also employed triangulation methods to further ensure the validity and reliability of the collected data. The literature review, questionnaires, interviews, and the illustrative case study, were all used to collect data in order to triangulate the results.

Furthermore, after collecting and reviewing the data from questionnaires, the researcher identified any inconsistencies and followed up with the participant for further clarity on their answers.

In conclusion, the data that was collected was deemed to be sufficient in both quality and quantity in order to draw valid and reliable conclusions to the research objectives of this dissertation.

3.10 ROLE OF THE RESEARCHER

The role of the researcher in the collection and analysis of the data was as follows:

- Distribution of the research questionnaires, and following up on any inconsistencies identified in the responses.
- Organise appointments, and undertake interviews using the aid of the interview guide developed for this study.
- Capture the data that was collected on computer software.

- Assemble data into graphs, charts and diagrams using computer software.

Due to the researcher's direct involvement with the collection and analysis of data, it is important to consider the possibility for biases.

3.11 BIASES

The researcher is in favour of the implementation of BIM into the structural engineering industry of the Eastern Cape. The researcher acknowledges that there may be an element of bias towards BIM implementation. Therefore, in order to mitigate the bias that may arise, the researcher relied specifically on results from the data collected to draw conclusions.

3.12 ETHICAL CONSIDERATIONS

The researcher ensured that the processes, which were implemented throughout this dissertation, took cognisance of the ethical codes of conduct, and standards, laid down by the Durban University of Technology (refer DUT ethical checklist attached as Appendix F).

The researcher obtained organisational clearance in order to approach the organisation's employees to participate in answering questionnaires and interviews (refer Appendix A).

Each questionnaire and interview guide was accompanied by a covering letter (refer Appendix B & D), which provided the participant with up-front information to either complete the questionnaire, or partake in the interview.

The information on the covering letters included the following (Kumar, 2005; Hay, 2013):

a) Introduction of the researcher;
b) Identify the qualification and University the researcher represents;
c) Description of the aim of the study;
d) General instructions and information;
e) Assurance that answers which participants provide shall remain anonymous and will be used for academic research purposes only;

f) Contact details provided in the event of questions; and,

g) Thanking the participant in advance for their participation.

The table below lists the appendices containing the ethical consideration documents which were used during this dissertation:

Table 3-4: Ethical Consideration Documents

No	Appendix	Ethical Consideration Detail
1	A	Typical Organisational Clearance Letter
2	B	Research Questionnaire Covering Letter
3	D	Case Study Interview Covering Letter
4	F	Ethical Checklist

The ethical process, which was followed for the collection of data, is graphically illustrated in the process diagram below:

Figure 3-3: Ethical Data Collection Process Followed

3.13 CHAPTER SUMMARY

The research methodology adopted for this dissertation has been carefully considered by the researcher, in order to best provide results and conclusions to the research questions, objectives, and, ultimately, the overarching aim of the research.

This chapter has provided the research design and methodological approach, which was used for this dissertation. Following this, the processes which were followed in the collection of data and the analysis of the data thereafter, were presented. The chapter then presented reasons why the collected data was deemed to be valid and reliable. The role of the researcher, potential biases and ethical consideration were also presented in the chapter.

The dissertation proceeds to the illustrative case study chapter. This chapter will present information both textual and visual, on a recent project within the Eastern Cape which used BIM technology during the design stage of the project.

CHAPTER 4

ILLUSTRATIVE CASE STUDY

4. CHAPTER 4: ILLUSTRATIVE CASE STUDY

4.1 CHAPTER INTRODUCTION

This chapter focuses on a recent project in the Eastern Cape, which implemented BIM technology during its design stage. The chapter first presents an overview of the case study, and then the project itself. Following this, the chapter then focuses on five important aspects of the design process, and identifies the practical advantages experienced while using BIM technology, in relation to each aspect. Disadvantages experienced while implementing BIM on the project are also highlighted in this chapter. The chapter then concludes with the chapter summation.

4.2 CASE STUDY AND PROJECT OVERVIEW

This illustrative case study was designed to investigate the advantages and disadvantages of BIM implementation experienced by the designers of the project.

Whilst the literature review chapter investigated the theoretical aspects of BIM, this case study investigates the practical application of BIM technology on the project.

The case study is divided into five main sub-sections in order to identify the advantages of BIM implementation in relation to the various aspects of the design process. The five main aspects to be investigated are, as follows:

1. Visualisation
2. Simulation
3. Collaboration
4. Documentation
5. Productivity

This section also presents the disadvantages experienced while using BIM technology on the project. The disadvantages are presented in sub-section 6 as follows:

6. Disadvantages / drawbacks

The case study uses illustrations to graphically demonstrate what the designers were able to see during the design process. Additional illustrations and examples have been added as Appendix J.

In addition to the use of illustrations, this case study also used interviews as a form of data collection to investigate the architects and structural engineers experiences of using BIM technology for the design. The interviews were structured in accordance with the sub-sections of this chapter. The findings from this illustrative case study will assist in providing solutions for objective 2 of this dissertation.

4.2.1 BIM Software used for the Project

The architects and structural engineers both used Autodesk Revit (BIM enabled design software) for the design of the project. Autodesk Revit accommodates for different disciplines, so that the various professionals of a structural project may work on the same design with ease.

The figure below graphically illustrates that switching between architectural and engineering aspects of a design is simplified by merely selecting the appropriate tab on Autodesk Revit.

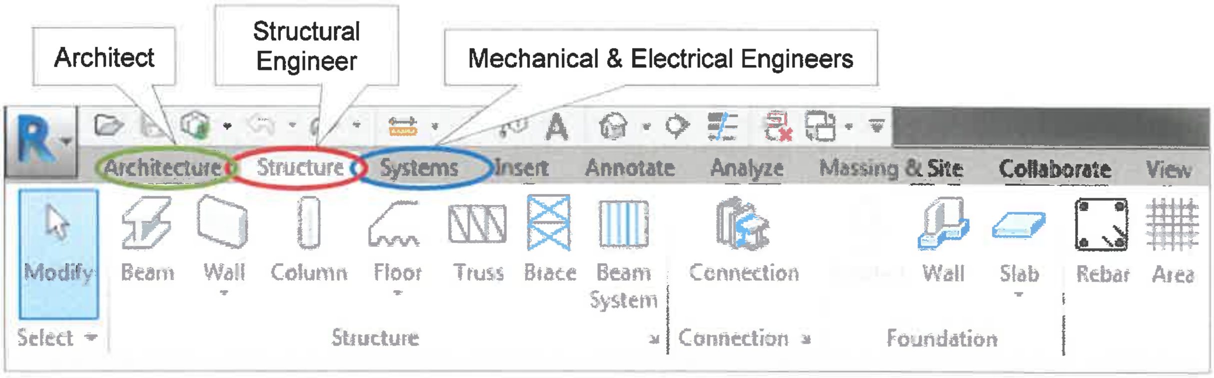


Figure 4-1: Autodesk Revit Design Toolbar

4.2.2 Project Overview

The project investigated for this illustrative case study was a 50 000m² land development project, of which 28 000m² consisted of various structures. The structural portion consisted of a factory, administration, cafeteria, and changeroom buildings, amongst others. The project was a real-life project within the Eastern Cape and fitted the criteria to be used as a case study for this dissertation. The figures on the following page provide a 3D graphical representation of the project.

Figure 4-2: 3D BIM Image of the Project (Front View)

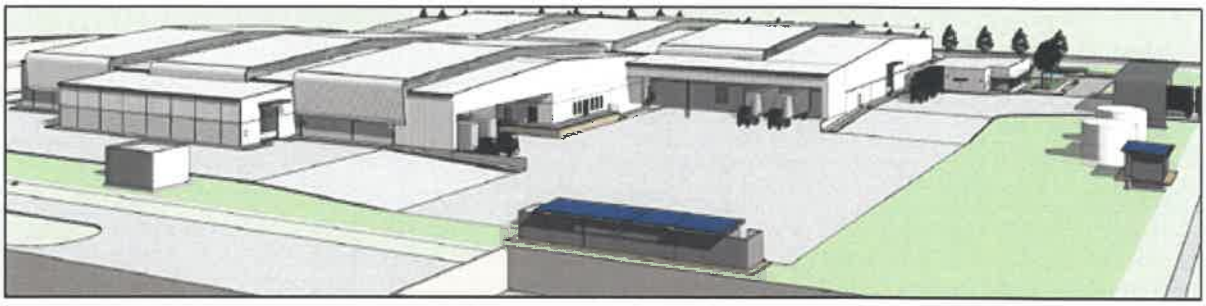


Figure 4-3: 3D BIM Image of the Project (Rear View)

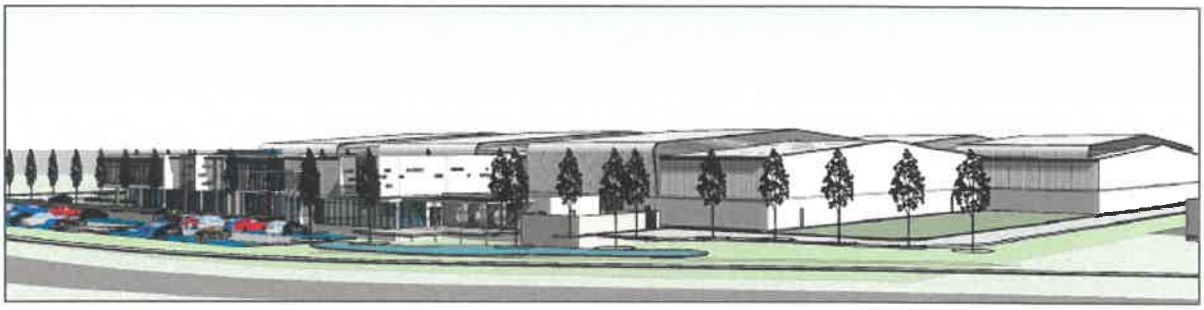


Figure 4-4: 3D BIM Image of the Project (Side View)

This project is relevant as a case study for this dissertation due to its geographical location and the use of BIM technology during its design stage.

4.2.3 Role of the Researcher

The researcher's role on the illustrative case study and the project was as follows:

1. **Illustrative Case Study**
    - Development of the case study.
    - Organise appointments and undertake interviews, using the aid of the interview guide, developed for this study.

- Capture the collected data on computer software.
- Assemble data into graphs, charts, and diagrams using computer software.

2. **Project Role**
   - Employee of the organisation - employed for the Civil and Structural engineering design of the project.
   - Project leader - for the Civil and Structural portion of the project.
   - Structural engineering designer.

In order to mitigate the bias of the researcher resulting from the researcher's significant role, conclusions are drawn from practical examples, illustrations, and interview results.

4.2.4 Overview of the Interview Structure

The interview was divided into five main sub-sections as specified above. Each sub-section was further divided into two portions.

The first portion involved a quantitative question which requested the participants to rate their BIM experience with regards to particular aspects of the project.

This was followed by a qualitative portion which discussed the participant's rating provided in the first portion of that particular sub-section.

The image on the right graphically illustrates the process that was followed during the interviews, for each main sub-section.

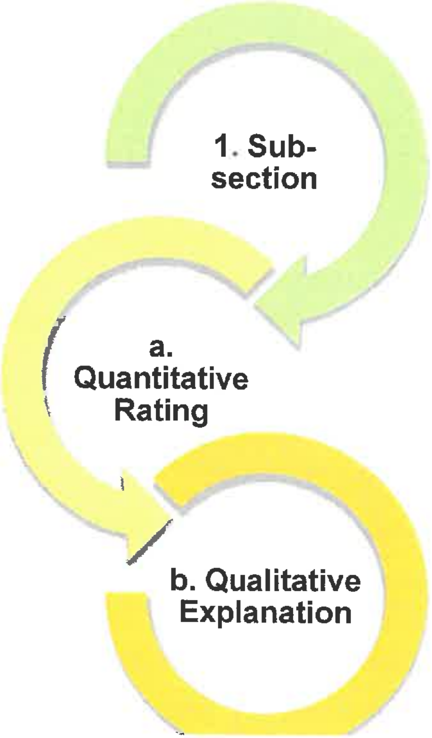


Figure 4-5: Overview of Interview Structure

4.2.5 Participants of the Interview

The interviews focused on the members of the design team that implemented BIM technology on the project. It was identified early in the design stage that the architects and structural engineers, would be using BIM for the design of the project.

Purposive sampling was employed in the selection of interviewees, in order to obtain the most relevant information for this case study. The following design team members were identified as potential candidates for the interview:

- Three design team members from the architectural portion; and,
- Three design team members from the structural engineering portion of the design team.

A total of six design team members were identified as potential participants for the interviews.

4.2.6 Interview Response Rate

All six of the design team members identified through purposive sampling, agreed to participate in the interviews - this resulted in a 100% response rate for this case study.

4.3 VISUALISATION

The implementation of BIM technology on this project provided a number of visualisation advantages. The initial process involved the development of a 3D BIM representation of the envisaged structures. The graphical representation enabled the project team and the client to visualise the project at conception stage.

During the design stage, the ability to visualise the structure in 3D provided the structural engineers with a greater understanding of complex problem areas - this was due to the fact that the structural engineers were able to visualise the problem from a variety of angles, enabled by the 3D model. This, therefore assisted the structural engineers in developing solutions to complex problems in reduced time.

Figure 4-6 represents the 3D architectural model, and Figure 4-7 represents the structural steel model of the manufacturing building, in Autodesk Revit. These models can be zoomed and rotated in all directions, providing designers the opportunity to visualise the design from a number of different perspectives. BIM implementation allowed the structural engineers to visualise their design in accordance to the architect's design. Additional illustrations, and examples, have been added as Appendix J.

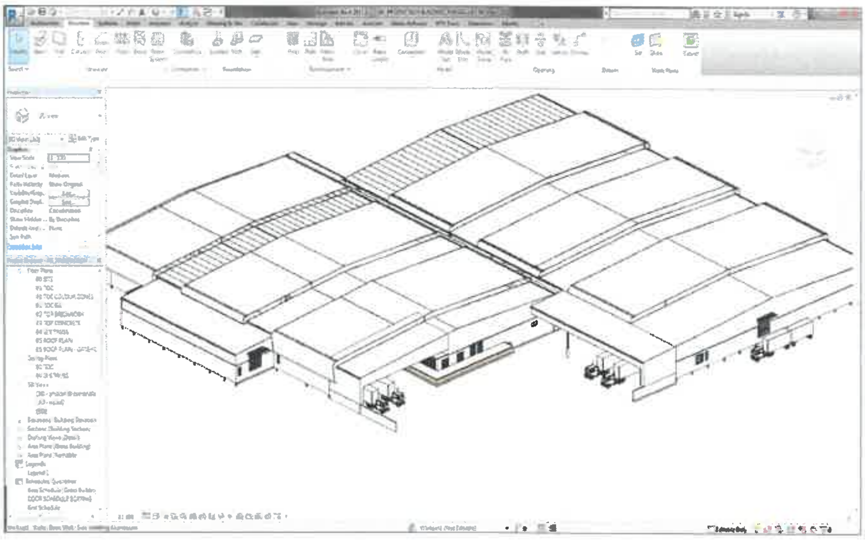


Figure 4-6: 3D BIM Image of the Manufacturing Building (Architectural Model)

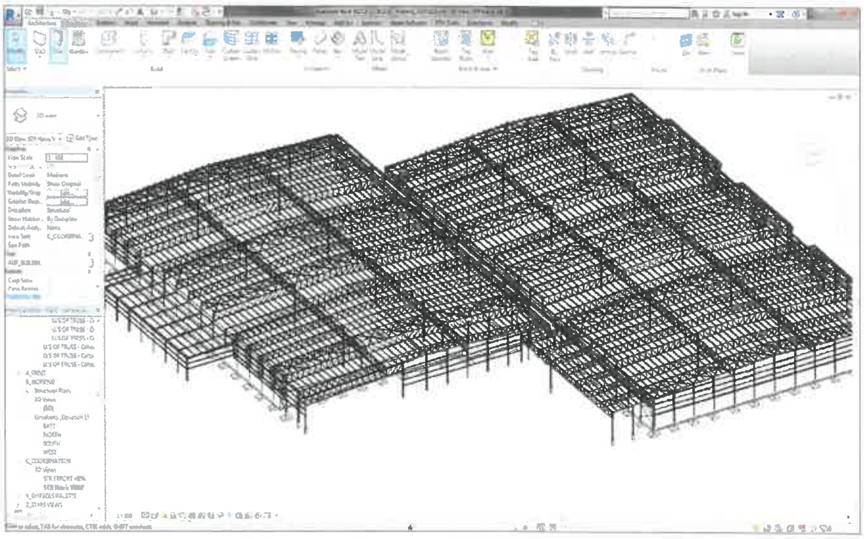


Figure 4-7: 3D BIM Image of the Manufacturing Building (Structural Steel Model)

4.3.1 Visualisation Interview Results

Portion A: Quantitative Rating

The participants were first asked to provide an overall opinion related to the visualisation aspects of the design, whilst using BIM technology on the project. This was done by requesting the participants to rate the following statement:

- *The use of Autodesk Revit improved visualisation aspects on this project.*

The figure below, indicates that all of the respondents **(100%) strongly agreed** that BIM technology improved visualisation aspects on this project.

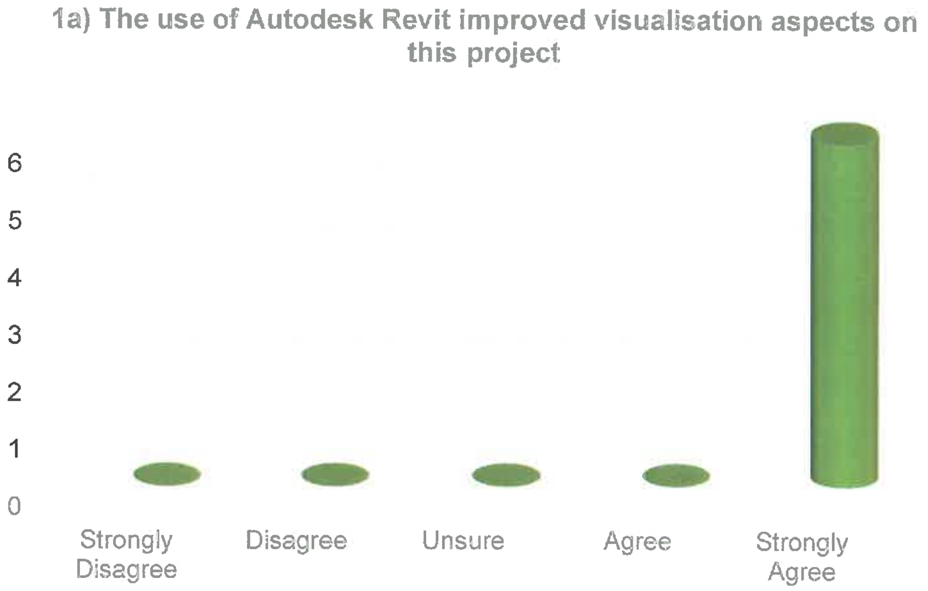


Figure 4-8: Visualisation Interview Results - Portion A

Portion B: Qualitative Explanation

The interview proceeded to investigate the reasoning behind each participant's response to Portion A. The following recurring themes and patterns relating to the visualisation benefits of BIM implementation on the project, were identified during the qualitative portion of the interview.

i. The 3D model aided in visualising the final building;

ii. The 3D model improved presentation to clients, and other design team members;

iii. The 3D model aided in understanding the complex design components;

iv. The 3D model improved visualisation of design clashes;

v. Easier to explain problems through 3D visualisation.

The chart below, graphically illustrates the percentage for each recurring theme and pattern. The percentage is based on the number of participants that identified the same visualisation benefits while using BIM technology on the project.

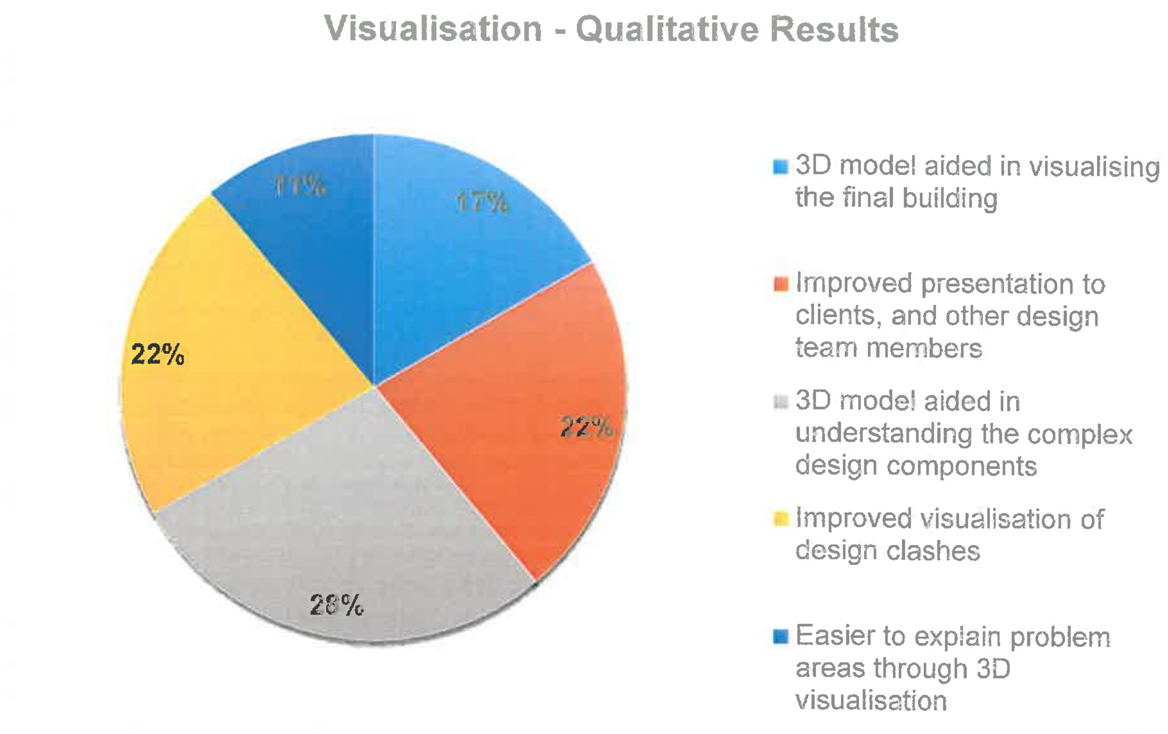


Figure 4-9: Visualisation Interview Results – Portion B

4.3.2 Visualisation Conclusion

The quantitative portion of the interview resulted in a resounding 100% of the participants strongly agreeing that BIM improved visualisation aspects on the project.

The qualitative portion of the interview identified five main recurring themes from the participants, and the highest number of them (28%) indicated that the 3D model aided in understanding complex design components.

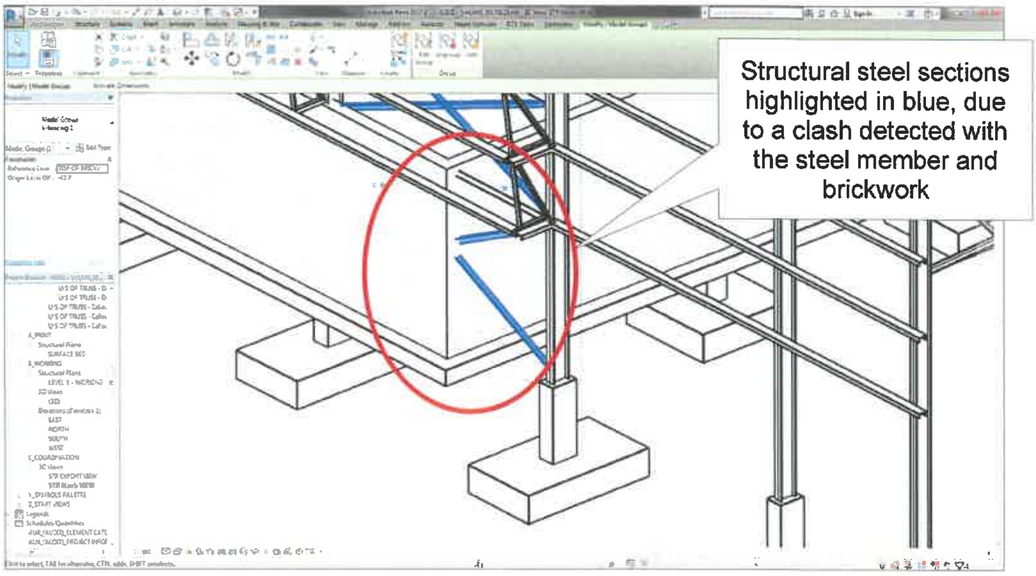
The results from the interviews, both quantitative and qualitative portions, indicated that the architects and structural engineers experienced significant visualisation benefits from implementing BIM technology on this project.

4.4 SIMULATION

The implementation of BIM technology on this project enabled the structural engineers to simulate their design digitally, before going to construction. The BIM simulation process identified any inconsistencies in the model which in turn, aided the structural engineers to rectify any problems at an early stage.

The use of BIM simulation technology also reduced the time required for checking the model for design clashes. The early identification of design clashes, and subsequent rectification thereafter, reduced the amount of costly on-site clashes.

The figure below, graphically illustrates a design clash that was identified on the manufacturing building. The structural steel sections, highlighted in blue, were clashing with the architectural brickwork. This was identified when the architect's model was merged, and then simulated, with the structural engineer's model. With the implementation of BIM technology, this clash was easily identified, and rectified with minimal disruption to the project.



Structural steel sections highlighted in blue, due to a clash detected with the steel member and brickwork

Figure 4-10: 3D BIM Image of a Design Clash on the Manufacturing Building

4.4.1 Simulation Interview Results

Portion A: Quantitative Rating

The interview followed the same structure as the previous sub-section whereby the participants of the interview were requested to provide an overall opinion related to the simulation aspects of the design, while using BIM technology on the project. The participants were requested to rate the following statement:

- *The use of Autodesk Revit improved simulation aspects on this project.*

The figure below, indicates that majority of the respondents **(67%) agreed** that, BIM technology improved simulation aspects on this project.

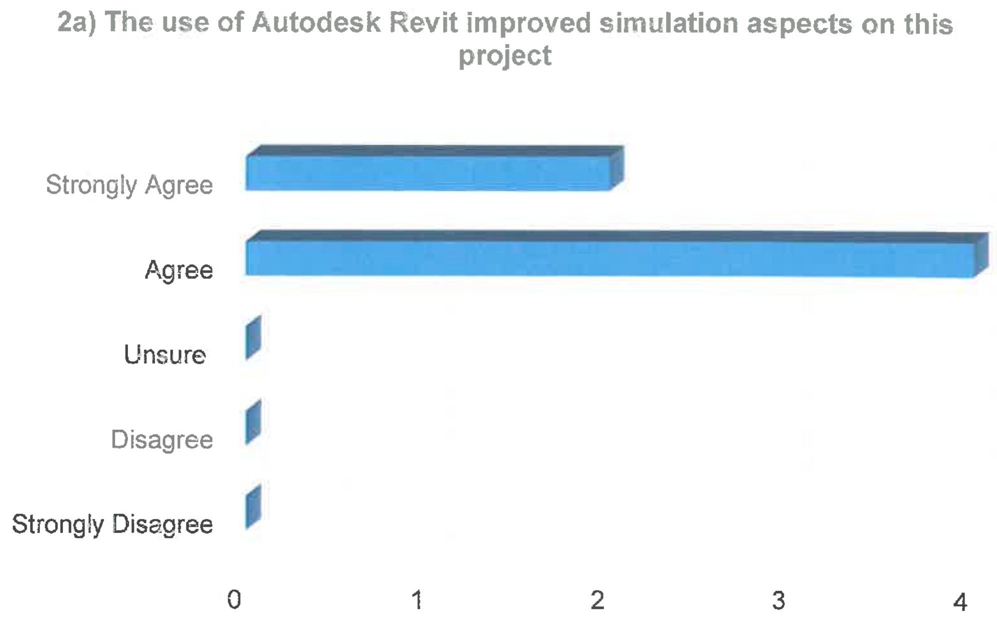


Figure 4-11: Simulation Interview Results - Portion A

Portion B: Qualitative Explanation

Once again, the interview proceeded to investigate the reasoning behind each participant's response to Portion A. The following recurring themes and patterns regarding the simulation benefits of BIM implementation on the project, were identified during the qualitative portion of the interview.

i. Faster clash detection;

ii. Easier to identify high priority and problem areas;

iii. Visual understanding of forces acting on the structure.

The chart on the following page graphically illustrates the percentage of these recurring themes and patterns. The percentage is based on the number of participants that identified the same simulation benefits while using BIM technology on the project.

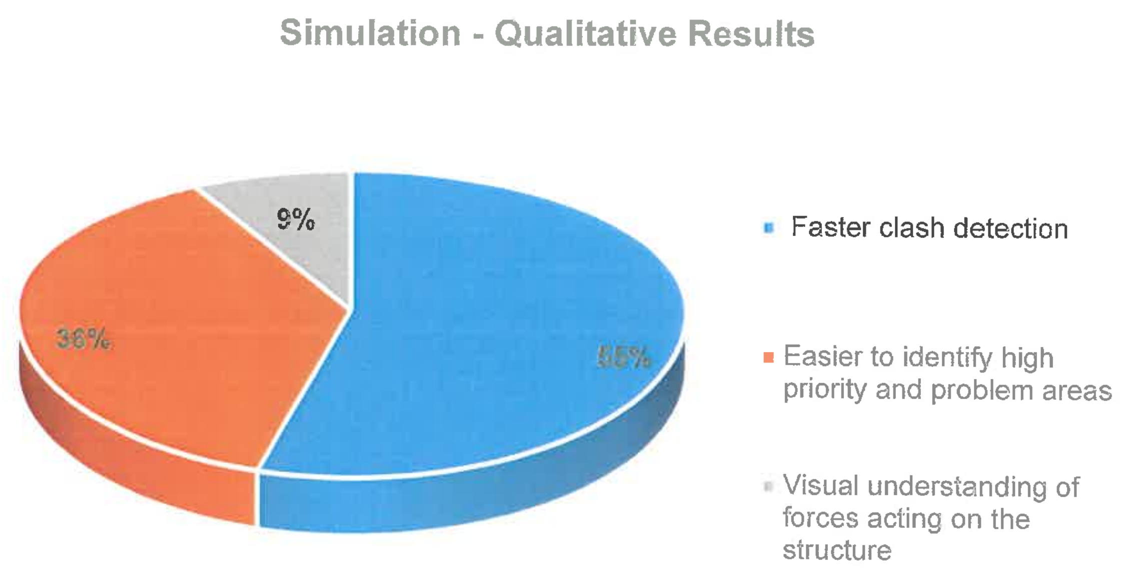


Figure 4-12: Simulation Interview Results – Portion B

4.4.2 Simulation Conclusion

The quantitative portion of the interview indicated that the majority (67%) of the respondents agreed that BIM provided simulation benefits on the project. The remainder of the respondents, strongly agreed with the statement, also indicating that they experienced simulation benefits while using BIM technology.

The qualitative portion of the interview identified three main recurring themes from the participants. A decisive 55% of the respondents indicated that the use of BIM technology aided in the faster identification of clashes.

The results from the interviews, both quantitative and qualitative, indicated that there were a number of simulation benefits experienced by the architects and structural engineers that implemented BIM technology on this project.

4.5 COLLABORATION

BIM implementation on this project enabled the architects and structural engineers to merge and simulate, their designs. Discrepancies were identified and graphically presented in minimal time. This graphical representation was then sent between the architects and structural engineers, in order to collaborate on possible solutions.

The use of BIM proved to minimise the collaboration time required to explain problem areas.

The figure on the right illustrates where sheeting rails clashed with the bullnose of the factory, and where an additional sheeting rail was required.

The figure below indicates a clash with the gutter downpipes and a concrete retaining wall.

Both of these images illustrate the ease of collaboration of designs and communicating any problems on the project.

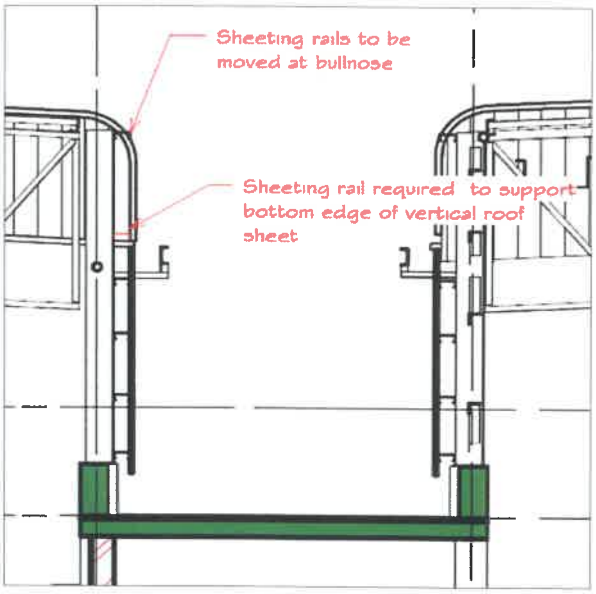


Figure 4-13: Section Generated, from the Model, Illustrating a Clash, and Additional Supports Required

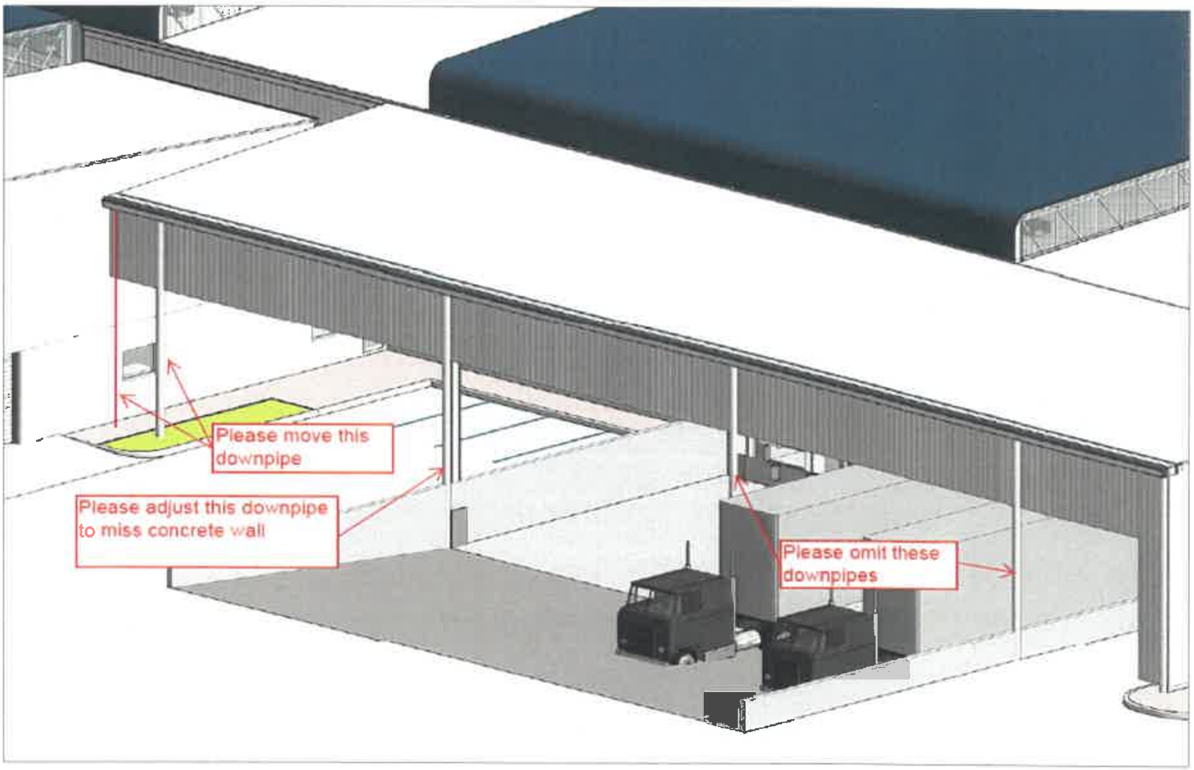


Figure 4-14: 3D BIM Image Illustrating Collaboration of Design Clashes

4.5.1 Collaboration Interview Results

Portion A: Quantitative Rating

The quantitative portion of the interview requested the participants to rate the following statement:

- *The use of Autodesk Revit improved collaboration between the architect and structural engineer on this project.*

The figure below indicates that majority of the respondents **(67%) strongly agreed** that BIM technology improved collaboration between the architect and structural engineer on this project.

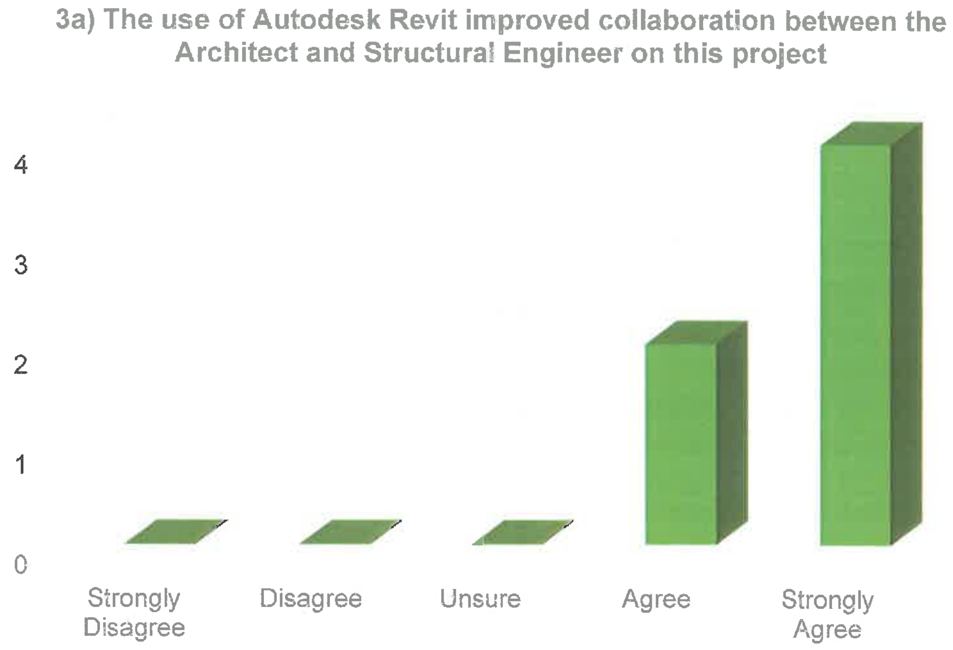


Figure 4-15: Collaboration Interview Results - Portion A

Portion B: Qualitative Explanation

The following recurring themes and patterns related to the collaboration benefits of BIM implementation on the project were identified during the qualitative portion of the interview.

i. Improved sharing of design information;

ii. Easier to identify clashes between designers;

iii. Easier to communicate problem areas;

iv. Reduced time required for collaboration between architect and structural engineer;

v. Information can be exported to multiple formats (DWG, DXF, DWF, PDF, etc.) which aids collaboration.

The pie chart below graphically illustrates the percentage for each recurring theme and pattern listed above.

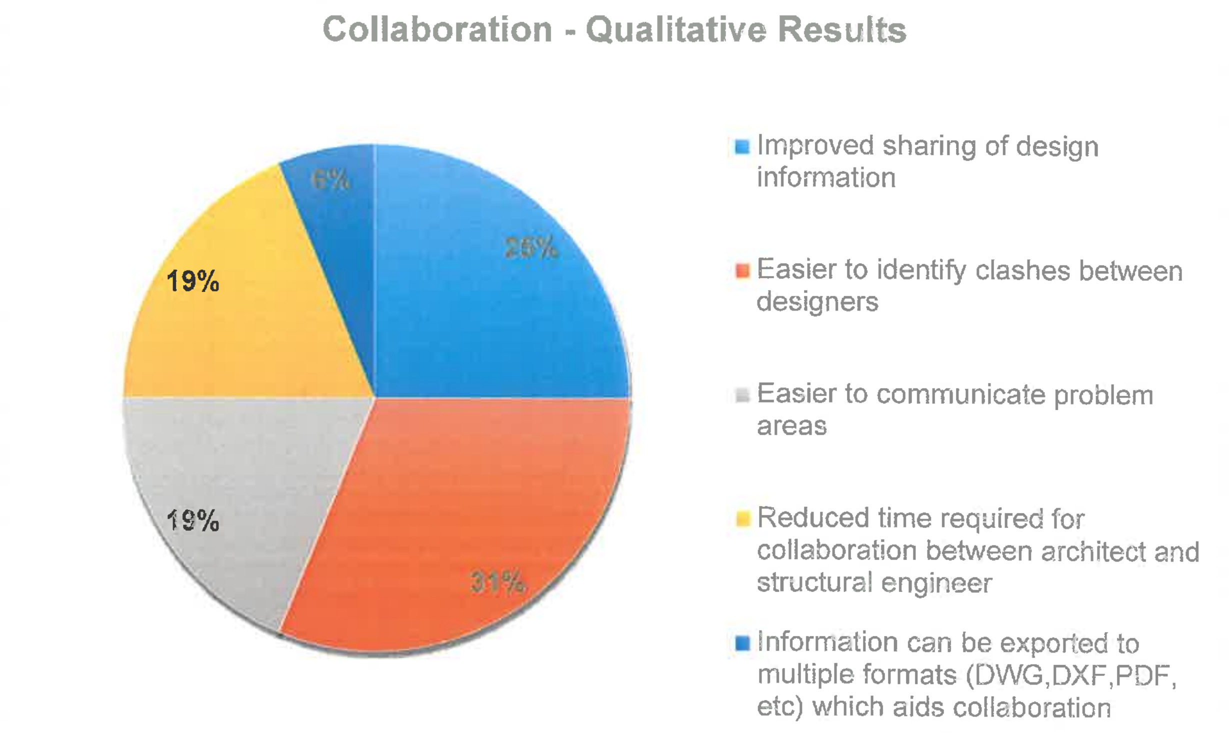


Figure 4-16: Collaboration Interview Results – Portion B

4.5.2 Collaboration Conclusion

The quantitative portion of the interview indicated that the majority (67%) of the respondents strongly agreed that BIM improved collaboration between the architects and structural engineers.

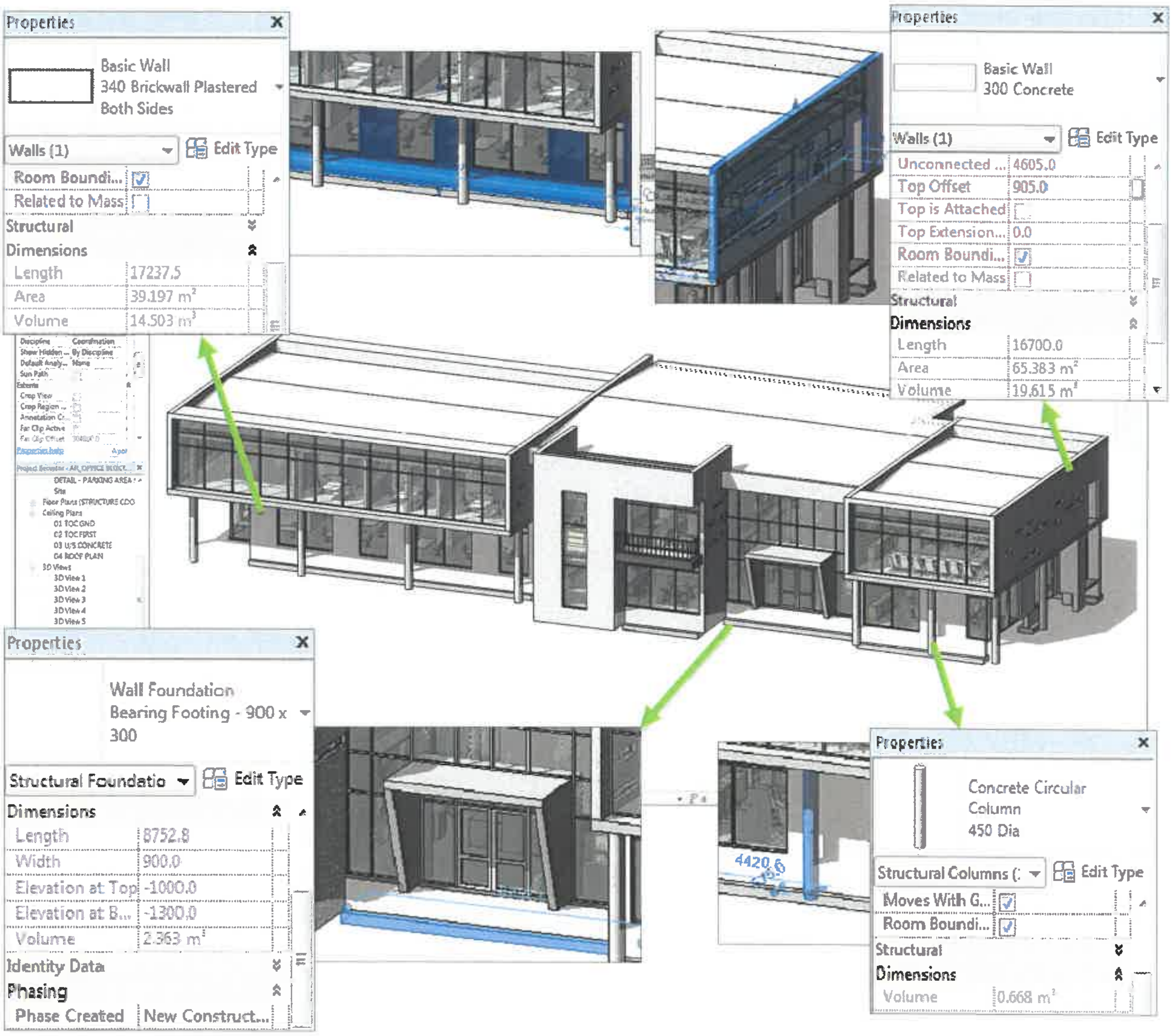
The qualitative portion of the interview identified five main recurring themes from the participants, and the highest number of them (31%) indicated that the use of BIM made it easier to identify clashes between the designers.

The results from the interviews, both quantitative and qualitative, indicated that the implementation of BIM technology on this project improved collaboration between the architects and structural engineers. This resulted in the reduction of the time required for collaboration, therefore allowing the structural engineers more time to focus on their designs.

4.6 DOCUMENTATION

BIM technology assisted the structural engineers in generating documentation (2D drawings, specifications, schedules, and production details) for the project in minimal time.

The 3D model was the most time-consuming process in the design, however, once the model was complete, required documentation was automatically generated with ease. This is due to the objects having their own set of properties. As the model was adjusted and modified, all documentation would automatically update in accordance to the modification. The figure below, highlights various structural elements of the administration building's 3D model. Individual objects have been selected to illustrate the property rich objects which make up the 3D model.



Properties
Basic Wall
340 Brickwall Plastered Both Sides
Walls (1)
Room Boundi... ☑
Related to Mass ☐
Structural
Dimensions
Length 17237.5
Area 39.197 m^2
Volume 14.503 m^3

Properties
Basic Wall
300 Concrete
Walls (1)
Unconnected ... 4605.0
Top Offset 905.0
Top is Attached ☐
Top Extension... 0.0
Room Boundi... ☑
Related to Mass ☐
Structural
Dimensions
Length 16700.0
Area 65.383 m^2
Volume 19.615 m^3

Properties
Wall Foundation
Bearing Footing - 900 x 300
Structural Foundatio
Dimensions
Length 8752.8
Width 900.0
Elevation at Top -1000.0
Elevation at B... -1300.0
Volume 2.363 m^3
Identity Data
Phasing
Phase Created New Construct...

Properties
Concrete Circular Column 450 Dia
Structural Columns (:
Moves With G... ☑
Room Boundi... ☑
Structural
Dimensions
Volume 0.668 m^3

Figure 4-17: 3D Image Illustrating Properties of Structural Objects from the Model

4.6.1 Documentation Interview Results

Portion A: Quantitative Rating

The quantitative portion of the interview requested the participants to rate the following statement:

- *The use of Autodesk Revit made the production of documentation easier on this project.*

The figure below, indicates that majority of the respondents **(67%) strongly agreed** that BIM technology made the production of documentation easier on this project.

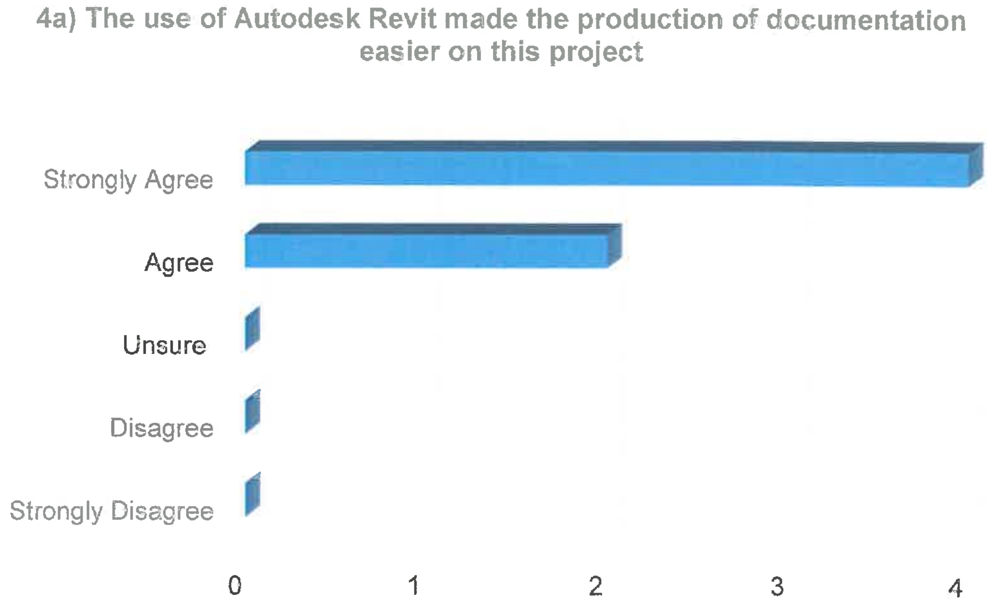


Figure 4-18: Documentation Interview Results - Portion A

Portion B: Qualitative Explanation

The following recurring themes and patterns related to the documentation benefits of BIM implementation on the project were identified during the qualitative portion of the interview.

i. Faster and easier to produce details, schedules, and specifications;

ii. Improved accuracy of documentation;

iii. Automatic update of documents as model is updated;

iv. Reduced time required for checking documentation.

The chart on the following page graphically illustrates the percentage for each recurring theme and pattern.

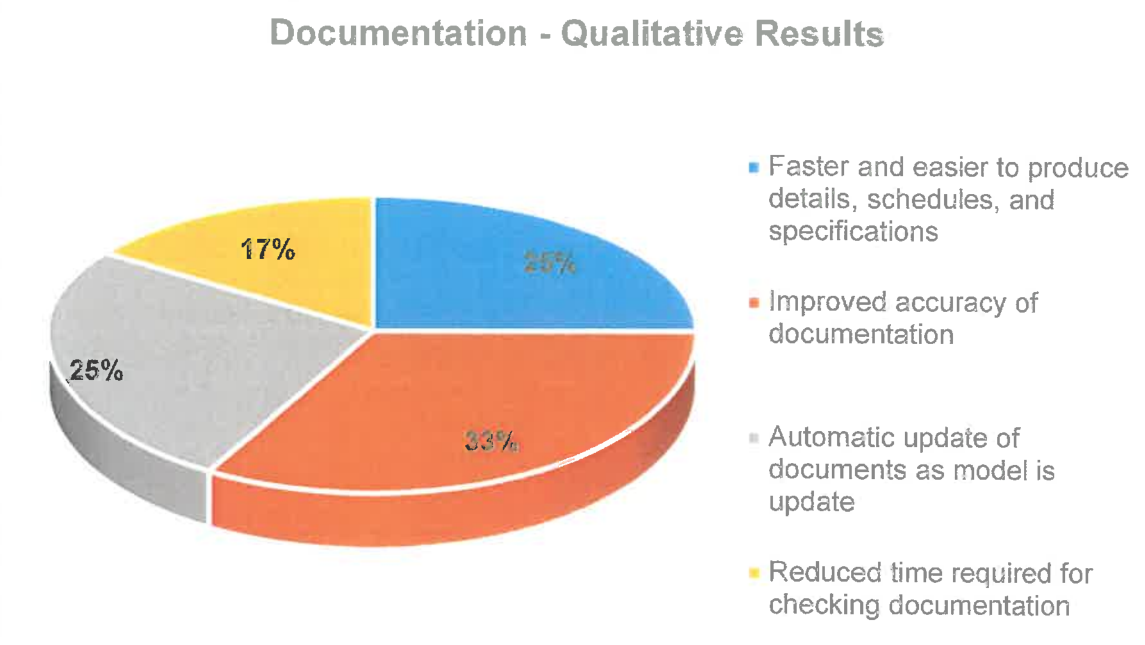


Figure 4-19: Documentation Interview Results – Portion B

4.6.2 Documentation Conclusion

The quantitative portion of the interview indicated that the majority (67%) of the respondents strongly agreed that BIM improved the production of documentation on the project. The remainder of the respondents agreed with the statement, also indicating that they were able to produce documentation with ease while using BIM technology.

The qualitative portion of the interview identified four main recurring themes from the participants, and the highest number of them (33%) indicated that the implementation of BIM technology improved the accuracy of documentation.

The results from the interviews, both quantitative and qualitative, indicated that the implemented BIM technology on this project reduced the time required to produce documentation and at the same time, improved the accuracy.

4.7 PRODUCTIVITY

The implementation of BIM technology on this project increased the productivity of the design process in a number of ways. The reduction in the time required for collaboration, checking for design clashes, and production of documentation. This all added to the overall increase in productivity on the project.

The production of 2D construction drawings is where the whole design process culminates. The automatic production of 2D plans, sections, and details, significantly improved the productivity of 2D construction drawings for the project. The figures below are graphical examples of a plan view and sections of the administration building. These 2D drawings were automatically produced from the 3D model.

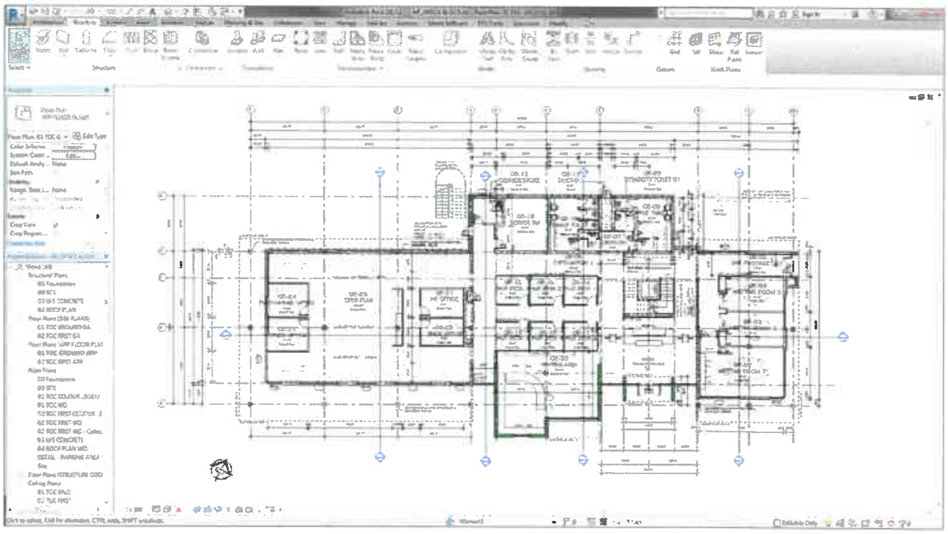


Figure 4-20: Plan View of the Administration Building automatically generated from the BIM Model

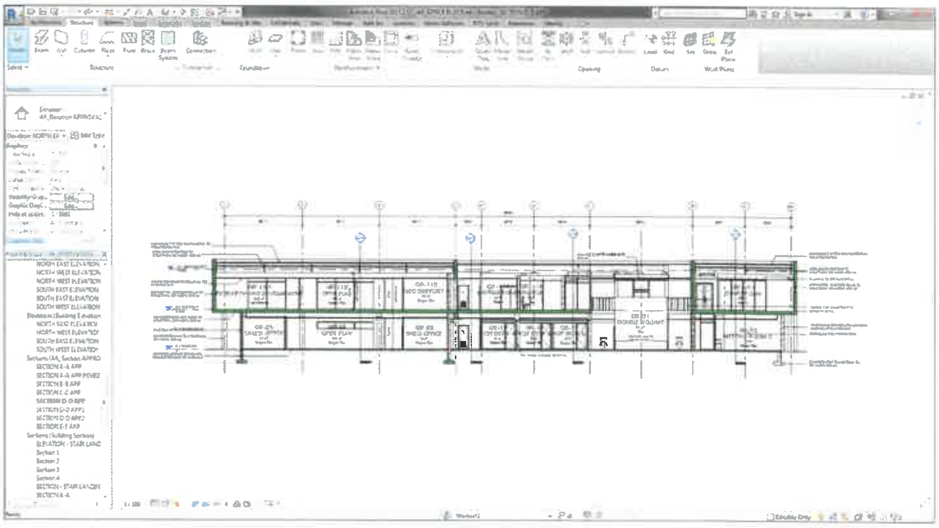


Figure 4-21: Section of the Administration Building automatically generated from the BIM Model

4.7.1 Productivity Interview Results

Portion A: Quantitative Rating

The interview followed the same structure as the previous sub-sections whereby the participants were requested to rate the following statement:

- *The use of Autodesk Revit improved productivity on this project.*

The figure below indicates that there was a 50/50 split between the responses received (everyone especially agreeing) from the quantitative portion of the interview. **50%** of the participants **agreed**, while the other **50% strongly agreed** that BIM technology improved productivity on this project.

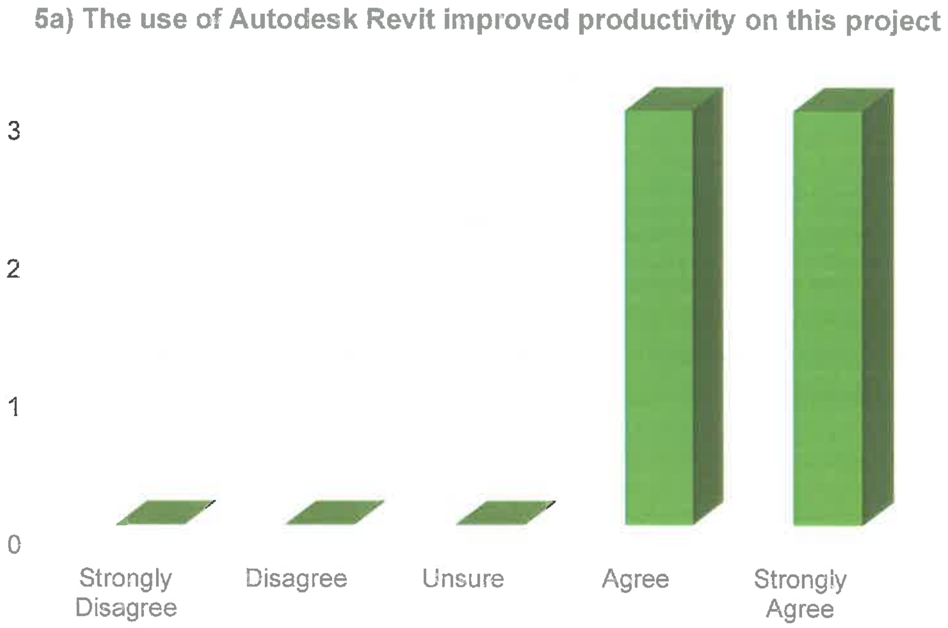


Figure 4-22: Simulation Interview Results - Portion A

Portion B: Qualitative Explanation

The following recurring themes and patterns related to the productivity benefits of BIM implementation on the project, were identified during the qualitative portion of the interview.

i. Increased speed of producing designs;

ii. Reduced time to check clashes between designers;

iii. Collaboration is streamlined;

iv. Reduced time required to produce documentation;

v. Changes are picked up by Revit, and all documentation is automatically updated.

The pie chart below, graphically illustrates the percentage for each recurring theme and pattern listed above.

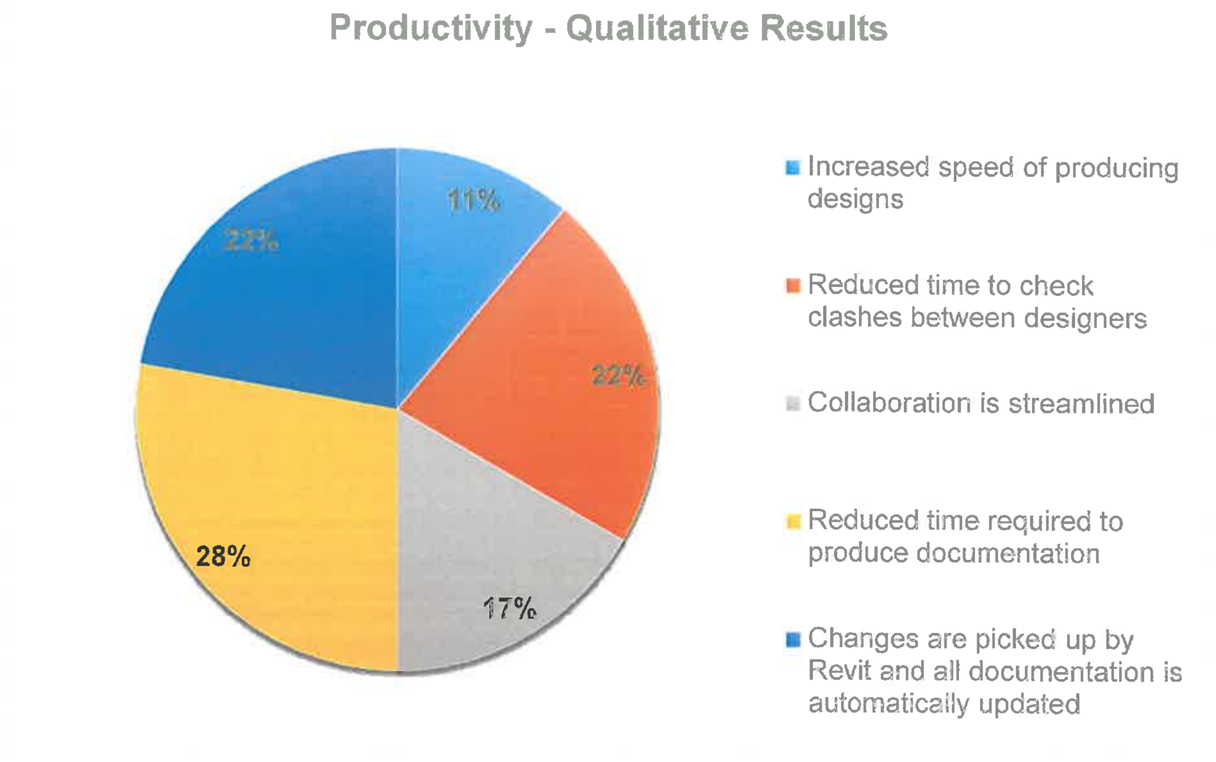


Figure 4-23: Productivity Interview Results – Portion B

4.7.2 Productivity Conclusion

The quantitative portion of the interview indicated that the participants either agreed or strongly agreed (50/50 split) that they were able to improve productivity on the project as a consequence of using BIM technology.

The qualitative portion of the interview identified five main recurring themes from the participants, and the highest number of them (28%) indicated that the use of BIM reduced the time required to produce documentation.

The results from the interviews, both quantitative and qualitative, indicated that there was an overall increase in productivity experienced by the structural engineers which implemented BIM technology on this project.

4.8 SUMMARY OF ADVANTAGES

A number of advantages were identified within this case study. The table below provides a summary of the advantages experienced while using BIM technology on the project.

Table 4-1: Summary of the Advantages

No	Aspect	Summary of Advantages
1	Visualisation	• The 3D model aided in visualising the final building; • The 3D model improved presentation to clients and other design team members; • The 3D model aided in understanding the complex design components; • The 3D model improved visualisation of design clashes; • Easier to explain problems through 3D visualisation.
2	Simulation	• Faster clash detection; • Easier to identify high priority and problem areas; • Visual understanding of forces acting on the structure.
3	Collaboration	• Improved sharing of design information; • Easier to identify clashes between designers; • Easier to communicate problem areas; • Reduced time required for collaboration between architect and structural engineer; • Information can be exported to multiple formats (DWG, DXF, DWF, PDF, etc.) which aids collaboration.
4	Documentation	• Faster and easier to produce details, schedules, and specifications; • Improved accuracy of documentation; • Automatic update of documents as model is updated; • Reduced time required for checking documentation.
5	Productivity	• Increased speed of producing designs; • Reduced time to check clashes between designers; • Collaboration is streamlined; • Reduced time required to produce documentation; • Changes are picked up by Revit and all documentation is automatically updated.

4.9 DISADVANTAGES / DRAWBACKS

While the architects and structural engineers experienced numerous advantages, the implementation of BIM also presented some drawbacks.

This section of the illustrative case study will investigate the drawbacks experienced by the designers of the project. The drawbacks were identified through the interviews, wherein the designers were requested to provide details of any disadvantages that they experienced as a consequence of using BIM technology.

4.9.1 Interview Results

The interviews included a qualitative open-ended question related to the disadvantages experienced while using BIM technology on the project. This was in order to allow designers the flexibility and freedom to describe any drawbacks that they experienced. The data from the interviews was first collated and then simplified. Thereafter, the data was organised into recurring themes and patterns. The organised data was then compressed and assembled into a pie chart from which conclusions were drawn.

The following recurring themes and patterns were identified from the interviews

i. BIM software used was costly;

ii. Could not use BIM to its full potential, due to lack of expertise;

iii. Challenging to use without formal training;

iv. It takes time to set up the initial model in Revit;

v. Combined model is too large to send via normal communication paths (email).

The table below indicates the number of participants that identified the same drawbacks and below that, the corresponding percentage for each recurring theme and pattern. The percentage is based on the number of participants that identified the same drawbacks.

Table 4-2: Drawbacks

Drawback	i	ii	iii	iv	v
No of times identified	2	4	3	4	1
Percentage	14%	29%	21%	29%	7%

The pie chart below, graphically illustrates the percentage for each recurring theme and pattern, identified by the participants of the interview.

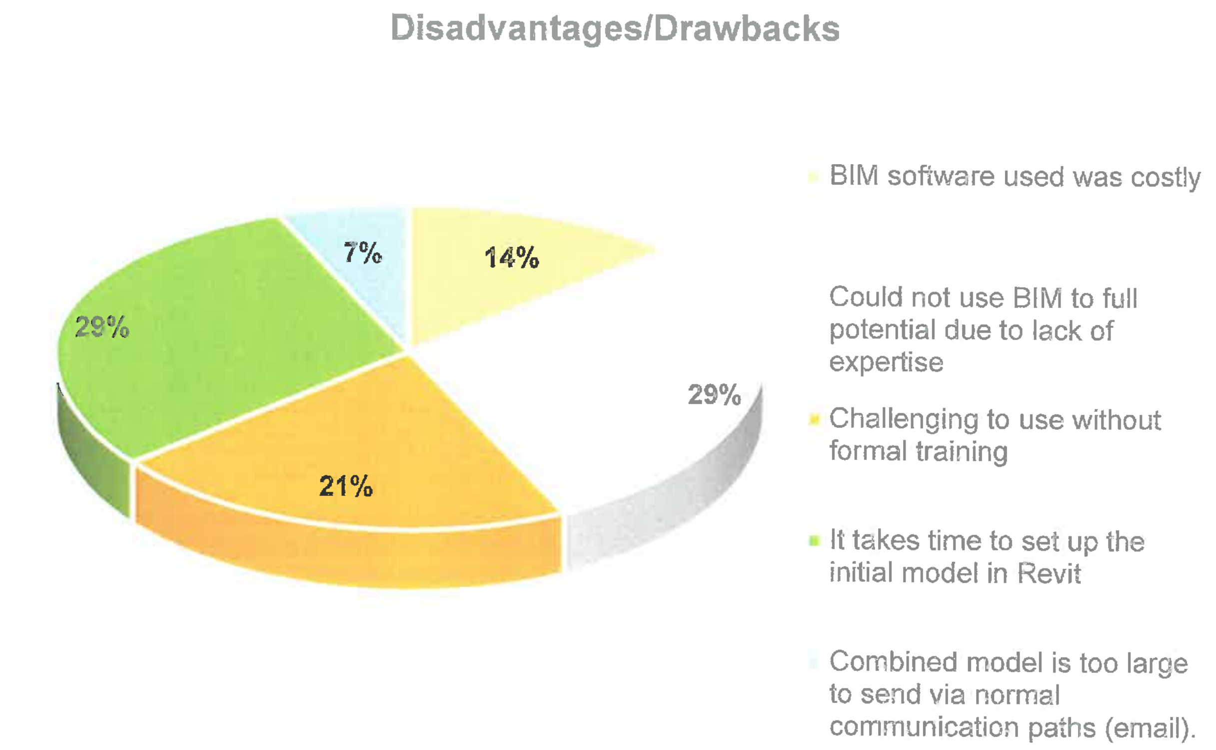


Figure 4-24: Disadvantage/Drawbacks Interview Results

4.9.2 Disadvantages/Drawbacks Conclusion

This section identified five main recurring drawbacks experienced by the participants. Of these five identified drawbacks, there were two which were highlighted more times than the others. The paragraphs below highlight these two drawbacks, and further provides possible mitigation measures for each.

1. 29% of the participants highlighted that due to lack of experience, they were unable to use BIM to its full potential. Even though this was highlighted as a drawback, benefits were still achieved with the current level of expertise. The usage of BIM on further projects will provide the designers with more experience as time goes on, resulting in even more future benefits.

2. 29% of the participants mentioned that the initial creation of the model took time. In the interview, as discussions progressed, it was uncovered that even though the initial model took time to set up, once it was completed, adjustments and production of documentation was easy. Drawing on the above, over time, increased experience will enable the designers to reduce the time required to set up the initial model, therefore mitigating this drawback in the future.

4.10 CHAPTER SUMMARY

This chapter presented an illustrative case study conducted on a recent project, within the Eastern Cape, that implemented BIM technology during its design stage. The case study focused on five important aspects of the design process, and identified the practical advantages arising from the use of BIM technology in relation to each aspect. Drawbacks were also highlighted in this chapter, along with proposed mitigation measures.

This illustrative case study revealed that a number of the advantages identified from the literature review, were confirmed by the practical application of BIM on this project within the Eastern Cape. Furthermore, the continued implementation of BIM technology in similar projects, will provide the designers with more experience using BIM, which will enable even further benefits in the future.

In conclusion, the illustrative case study presented in this chapter has shown that the implementation of BIM can provide a number of benefits for the structural engineering industry of the Eastern Cape. It is the view of the researcher that the results are clear and the results from this chapter will assist in providing solutions for objectives 1 and 2, of this dissertation.

The dissertation proceeds to the results and discussion chapter. The next chapter presents the results from the research questionnaires. The results are then discussed and summated into a logical structure.

CHAPTER 5

RESULTS AND DISCUSSIONS

5. CHAPTER 5: RESULTS AND DISCUSSIONS

5.1 CHAPTER INTRODUCTION

This chapter focuses on the presentation of the collected data from the research questionnaire, and the discussion of the results thereafter. The chapter first presents an overview of the research questionnaire and then the overall response rate attained. Following this, the chapter then focuses on the four main sections which made up the questionnaire. The chapter also presents findings from the desktop study, which was conducted in order to assist in providing recommendations on BIM implementation. The chapter then concludes with the chapter summation.

5.2 RESEARCH QUESTIONNAIRE

5.2.1 Overview of the Questionnaire

The research questionnaire was designed to include a combination of structured multiple choice questions, rating scales, and open-ended questions. The questionnaire was segmented into four main sections, which are as follows:

- **Section 1:** Gathered information in order to obtain a brief overview of the participants. This section consisted of four sub-questions.
- **Section 2:** Investigated the current structural engineering design methods that are being used in the Eastern Cape. This section consisted of six sub-questions.
- **Section 3:** Investigated the current state of BIM implementation, and the barriers hindering BIM implementation in the Eastern Cape. This section consisted of eleven sub-questions.
- **Section 4:** Gathered general information on the most used drafting and structural design software being used by the participants. This section consisted of two sub-questions.

The raw data obtained from the questionnaires was first collated using Microsoft Excel. The data was scrutinised for any inconsistencies, and then prepared for analysis. The data was then analysed and organised into graphs, tables, charts, and diagrams. Each of the four main sections includes a presentation of the results, and a discussion of the findings.

5.2.2 Questionnaire Response Rate

A total of thirty-four (34) questionnaires were circulated to structural engineering professionals within the Eastern Cape. Twenty-five (25) participants completed the questionnaire. Therefore, a response rate of 74% (25 responses, out of 34 questionnaires issued) was achieved for this study.
Figure 5-1 below, graphically illustrates the response rate attained:

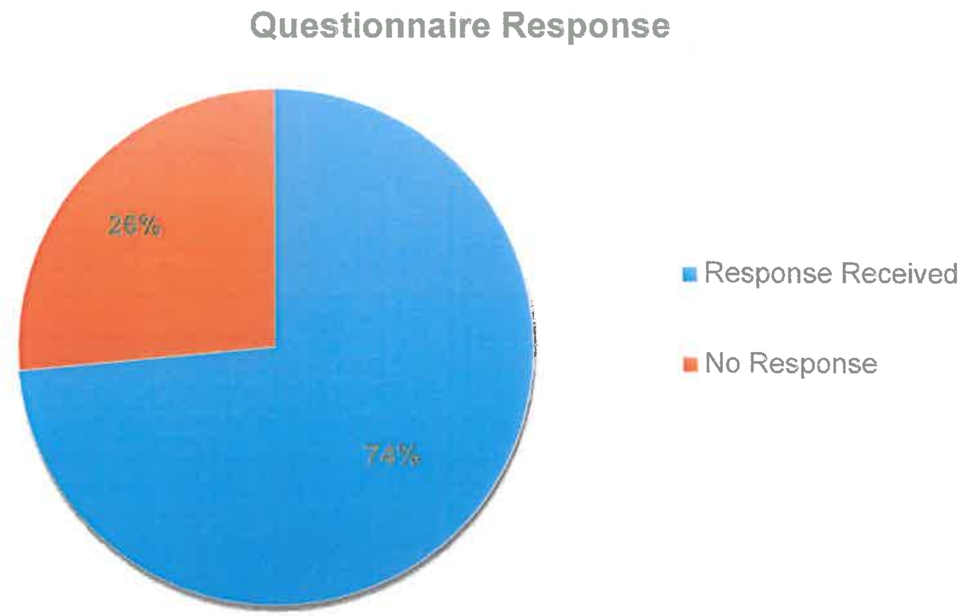


Figure 5-1: Questionnaire Response Rate

As specified in chapter 3, a response rate of 60%, or more, is regarded as very acceptable. Therefore, the 74% response rate, obtained for this dissertation, was deemed to be a very acceptable response rate for the collection of data.

The table below lists the appendices containing the documents related to this chapter:

Table 5-1: Questionnaire Documents

No	Appendix	Questionnaire Document
1	B	Research Questionnaire Covering Letter
2	C	Research Questionnaire
3	H	Questionnaire Results (Raw Data)

Having presented an overview of the questionnaire, this chapter proceeds to present the results for the first main section.

5.2.3 Section 1 – Overview of Participants

This section provides a summary of the demographic characteristics of the respondents.

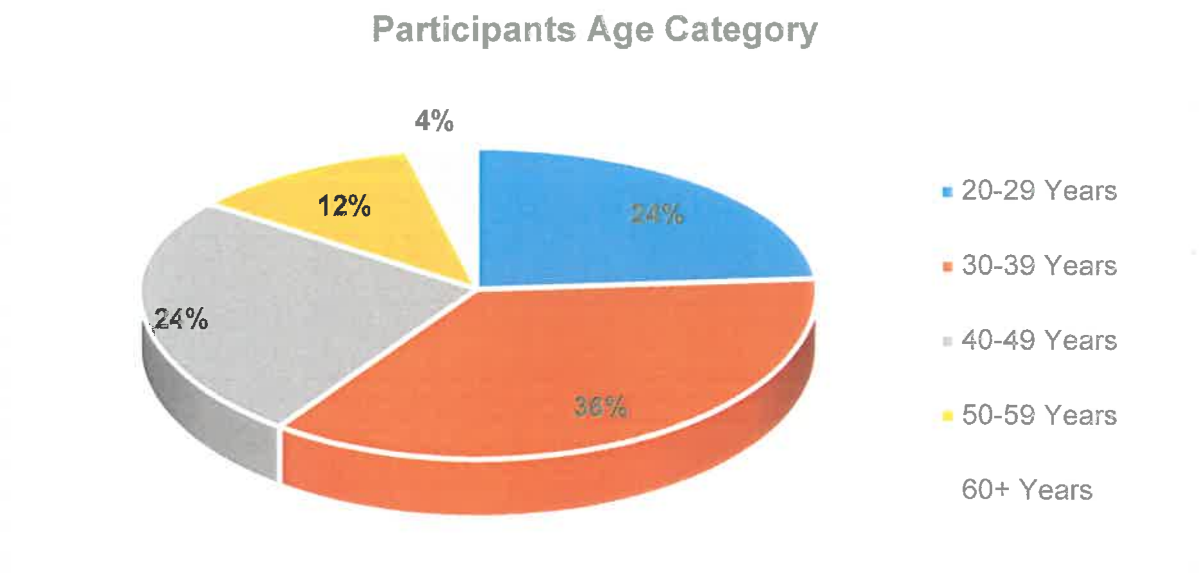


Figure 5-2: Participants Age Category – Section 1

Figure 5-2 above, illustrates that the highest number (36%) of the respondents were between the ages of 30 to 39 years of age.

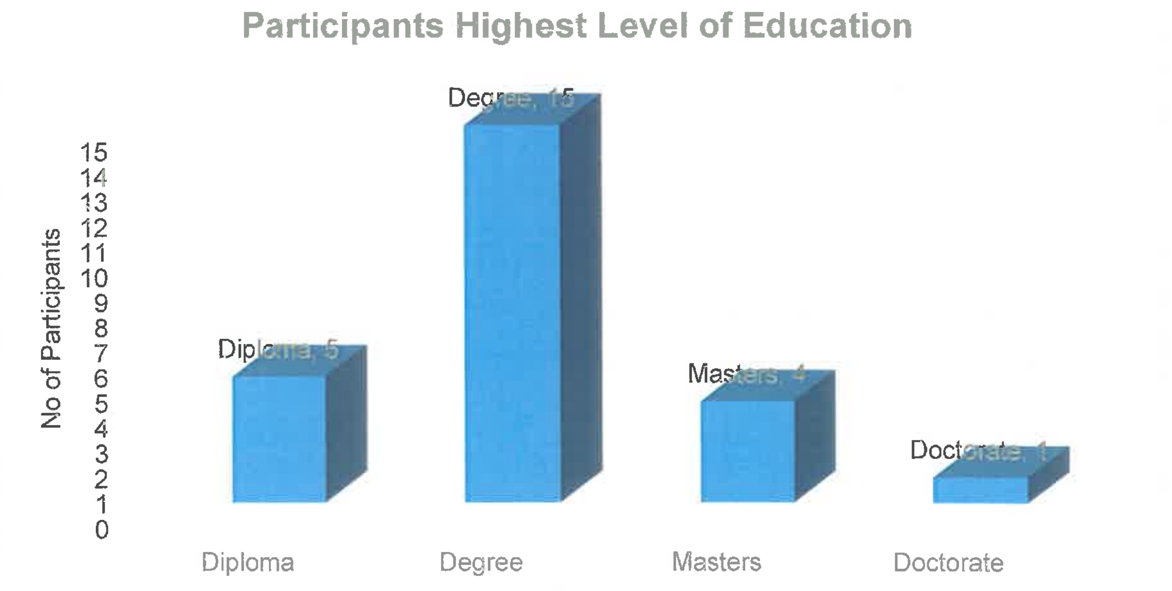


Figure 5-3: Participants Highest Level of Education – Section 1

The collected data highlighted, that the respondents have various levels of education. Figure 5-3 above graphically illustrates that the majority (60%) of the respondents were degree educated.

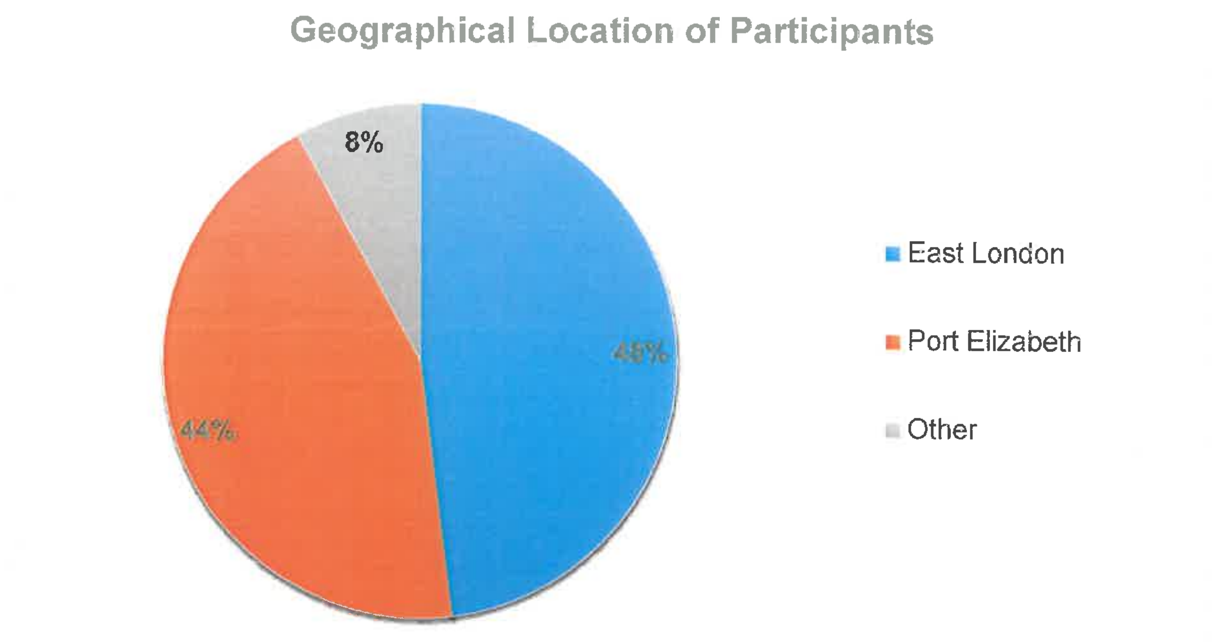


Figure 5-4: Geographical Location of Participants – Section 1

Questionnaires were widely distributed throughout the Eastern Cape. Figure 5-4 above, provides an overview of the geographic locational split of the participants. The highest number (48%) of the responses was received from East London.

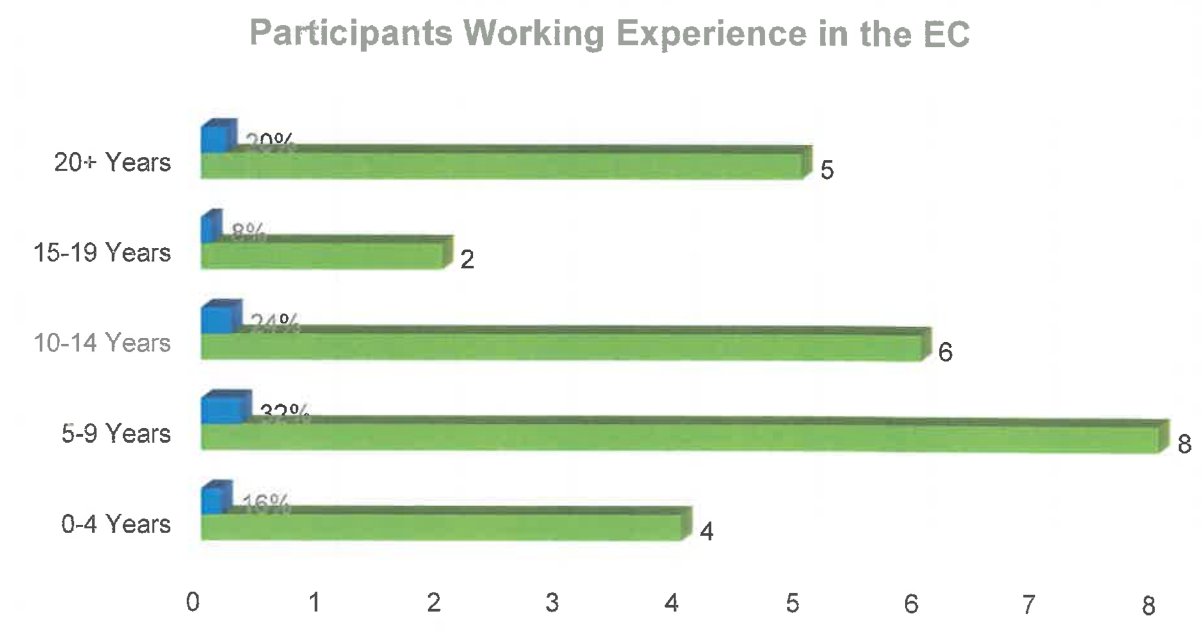


Figure 5-5: Participants Working Experience in the EC – Section 1

Figure 5-5 above, illustrates that the highest number (32%) of the participants had between five to nine years working experience within the Eastern Cape.

5.2.4 Section 2 – Current Structural Engineering Design Methods in the EC

This section provides results regarding the current structural engineering design methods used within the Eastern Cape. The structural engineering design process consists of a number of different aspects. Taking this into account, this section consisted of six sub-questions related to various aspects of the design process.

The first sub-question provided an overview of the design methods used by the participants. Table 5-2 below, highlights that the majority (60%) of the participants use first principles, and analysis software, to design individual components of a structure.

Table 5-2: Overview of Structural Design Methods Used – Section 2

Design method	i	ii	iii	iv
No of times identified	2	15	7	1
Percentage	8%	60%	28%	4%

i. Design using first principles (i.e. manual calculations)
ii. Design using first principles and analysis software to design individual components of a structure (i.e. Prokon Structural Analysis)
iii. Design entire structure as a complete model (i.e. Prokon Frame Analysis)
iv. Design using Building Information Modelling (BIM) software (i.e. Autodesk Revit)

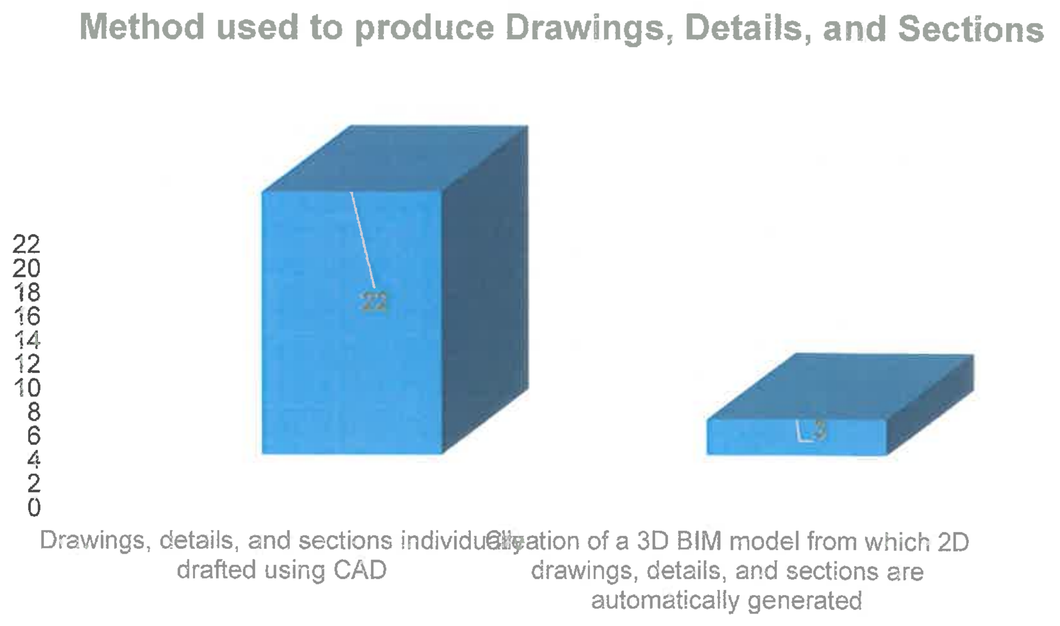


Figure 5-6: Method used to produce Drawings, Details, and Sections – Section 2

The second sub-question identified that the majority (88%) of the respondents produced drawings, details and sections, by individually drafting them using CAD. This is graphically illustrated in Figure 5-6 above.

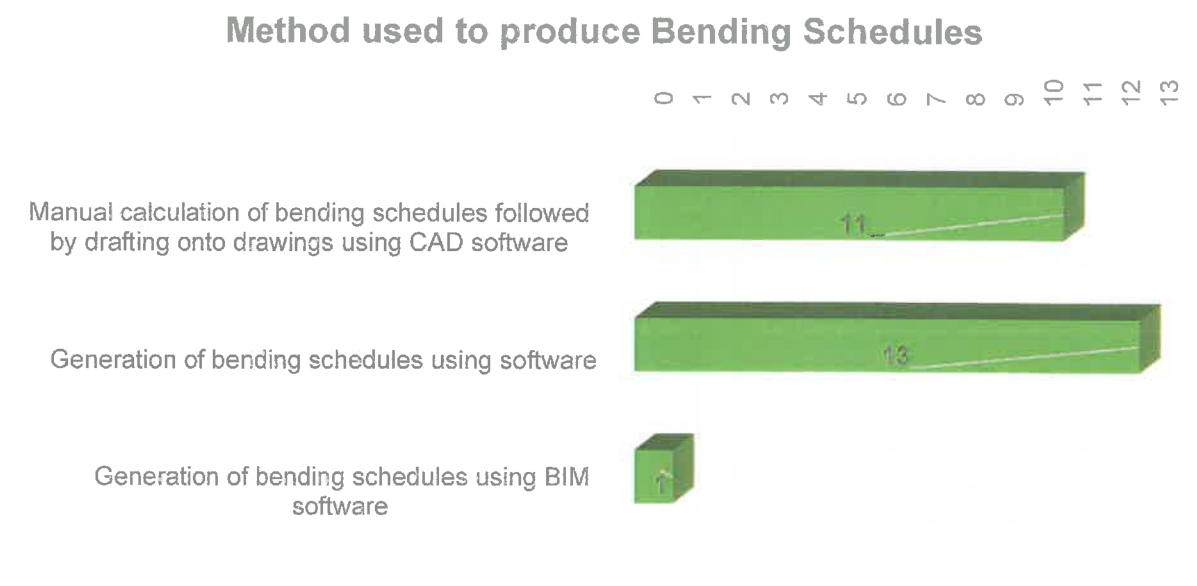


Figure 5-7: Methods used to produce Bending Schedules – Section 2

Figure 5-7 above, illustrates that the majority (52%) of the participants generated bending schedules using design software, while a significant number of participants (44%) indicated that they generated bending schedules by manual calculation, followed by drafting the schedule onto 2D drawings using CAD software.

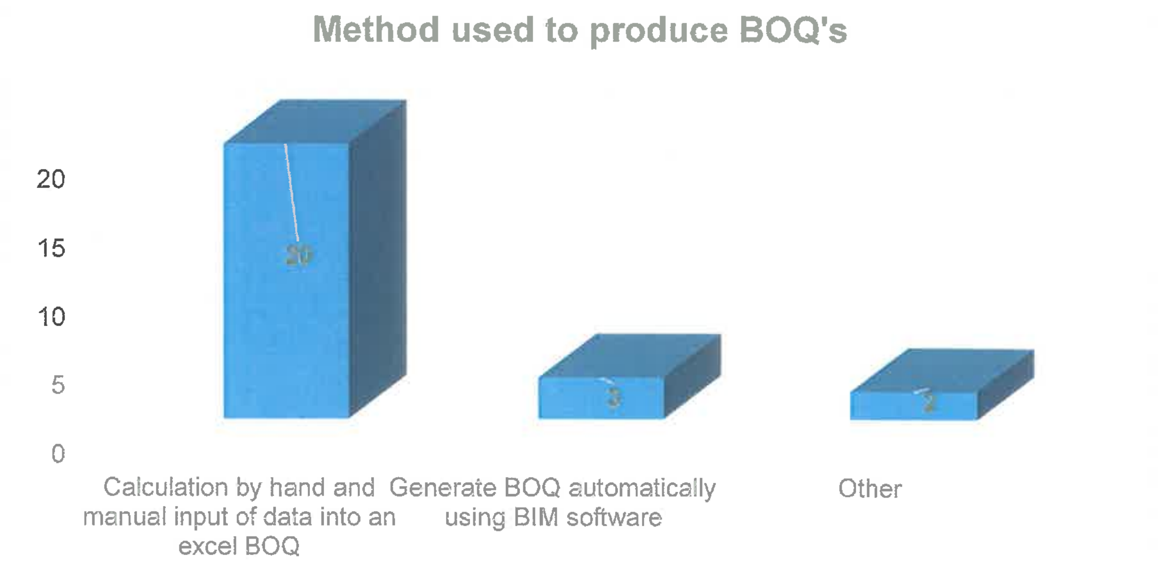


Figure 5-8: Method used to produce BOQ's – Section 2

A significant 87%, of the participants indicated that they calculated quantities by hand, and then manually collated the information into an excel BOQ. This is graphically illustrated in Figure 5-8 above.

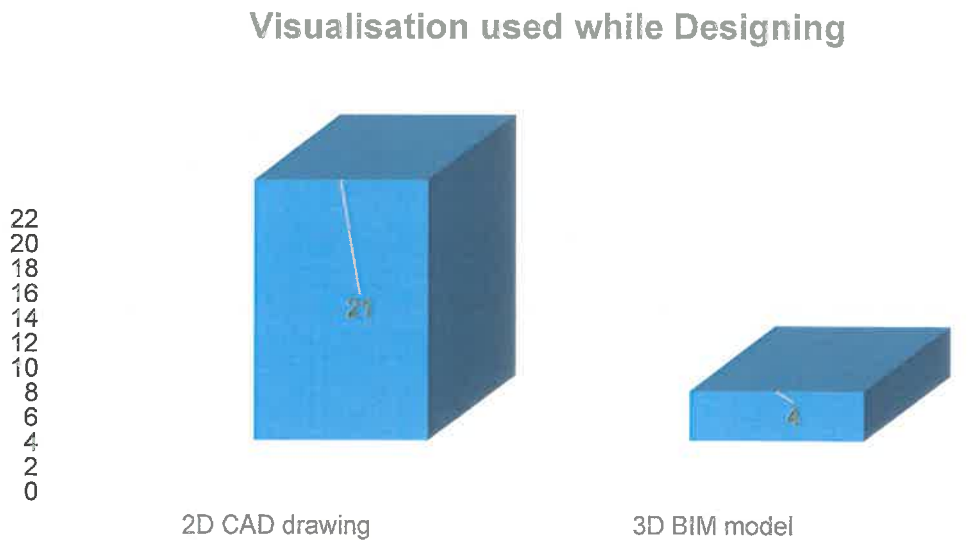


Figure 5-9: Visualisation used while Designing – Section 2

Figure 5-9 above, illustrates that 84% of the participants use 2D CAD drawings to visualise their design, while only 16% of the participants currently use 3D models as a visualisation tool while designing.

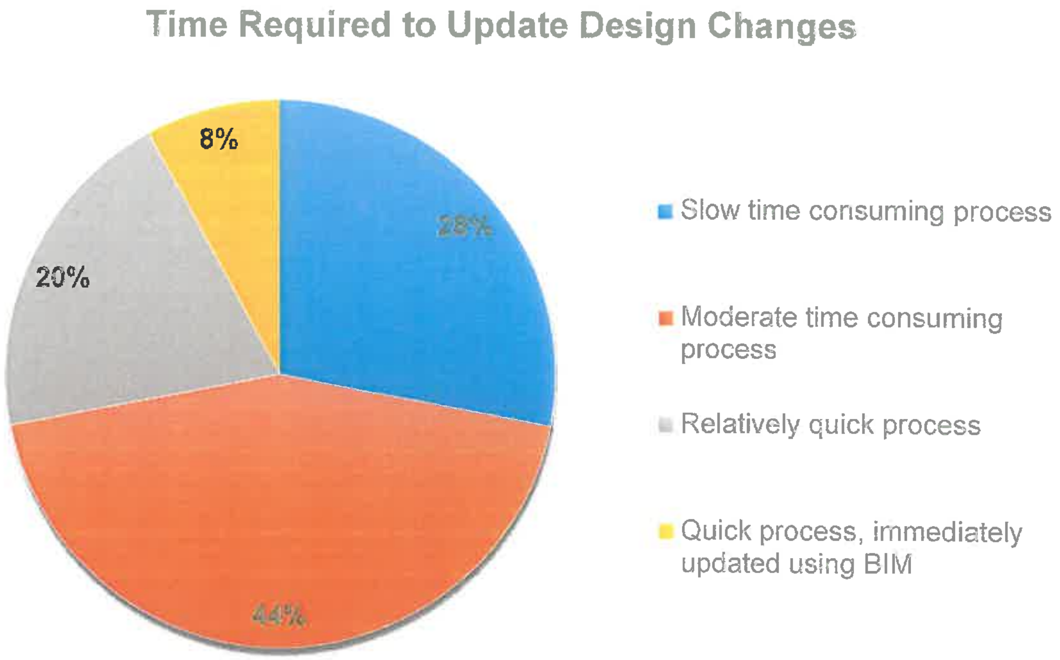


Figure 5-10: Time Required to Update Design Changes – Section 2

The highest number (44%) of the participants indicated that design changes required a moderate amount of time, while 28% of the participants indicated that it is a slow, time-consuming process.

5.2.5 Discussion of Results from Section 2

This portion of the chapter focuses on the discussion of the results obtained for section 2 of the questionnaire, while conclusions to the research objectives of this dissertation will be drawn in the proceeding chapter (Chapter 6 – Conclusions).

The results indicated that the majority of the participants designed structures by isolating individual components of a building, and then designed each component separately, as opposed to designing a structure as a composite model. This predominant design method indicated by the participants requires a high level of experience in order to understand how the forces will interact with each other when the individual components are composed back into a single structure.

Individual drafting using CAD software, was identified as the most common method for producing 2D drawings, details, and sections. This is a slow and time-consuming process, as opposed to automatically generating 2D drawings, details, and sections, from a 3D BIM model. Furthermore, there is an increased margin for human error with this predominant method of design.

The majority of the participants indicated that they were using software (AutoPadds, Prokon Padds) to produce bending schedules, which saves a significant amount of time. However, there are still a significant number (44%) of structural engineers who are still manually calculating bending schedules, and then drafting the information into tables. Apart from the time-saving aspect, there is a higher margin for error when calculating a high volume of bending schedules by hand.

The questionnaire proceeded to investigate the method used for the production of BOQ's. It was identified that manual calculations were the most popular method to produce BOQ's within the Eastern Cape. Similar to the paragraph above, manual calculations of BOQ's is a slow process, which is also accompanied with an increased likelihood for human error.

Section 2 of the questionnaire concluded with obtaining the participants comments on the time required to update design changes. This question was included due to that nature of the AEC industry, in which design changes are relatively common. Design changes may come from client requests, or from the architect. Therefore, design changes would preferably, need to be a relatively quick process.

The participants indicated that using their current methods of design, changes are a moderate (44%) to slow (28%) process. Participants who were already using BIM technology, indicated that design changes is a quick process, and that all documentation is immediately updated whenever changes are captured in the 3D model.

5.2.6 Section 3 – Current State of BIM Implementation in the EC

This section provides results regarding the current state of BIM implementation in the structural engineering organisations within the Eastern Cape. Section 3 of the questionnaire was developed to investigate a number of aspects related to BIM implementation within the province, such as awareness levels of BIM, availability of BIM software, and reasons for not using BIM.

Table 5-3 below, highlights that almost all of the participants were familiar with the concept of BIM.

Table 5-3: Participants Familiarity with BIM – Section 3

Familiar with the concept of BIM	Yes	No
No of times identified	23	2
Percentage	92%	8%

Furthermore, Figure 5-11 graphically illustrates that the highest number (36%) of the participants had a general idea of the benefits associated with BIM.

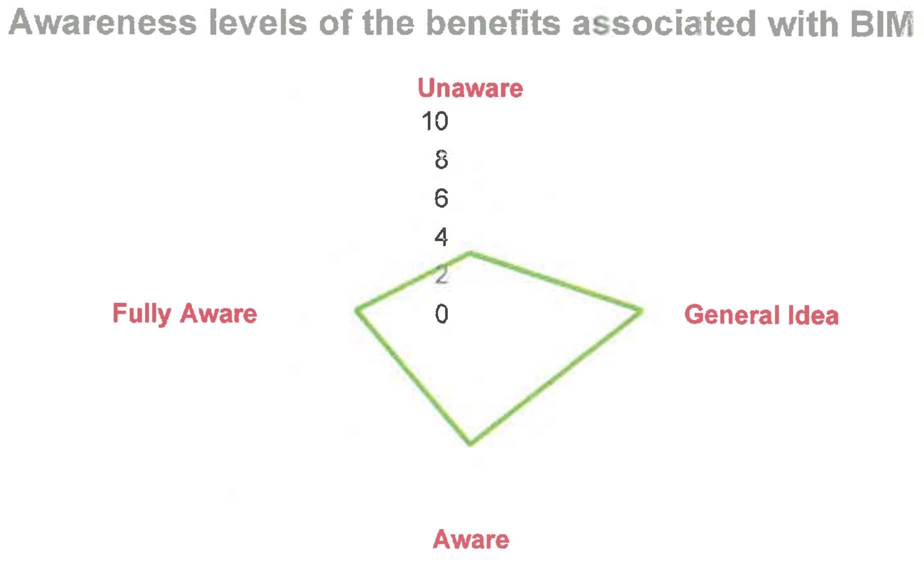


Figure 5-11: Awareness Levels of the Benefits Associated with BIM – Section 3

A significant number (64%) of participants already had access to BIM software within their organisation. This is reflected in Table 5-4 below.

Table 5-4: Access to BIM Software – Section 3

Access to BIM software within participant's organisation	Yes	No	Unsure
No of times identified	16	6	3
Percentage	64%	24%	12%

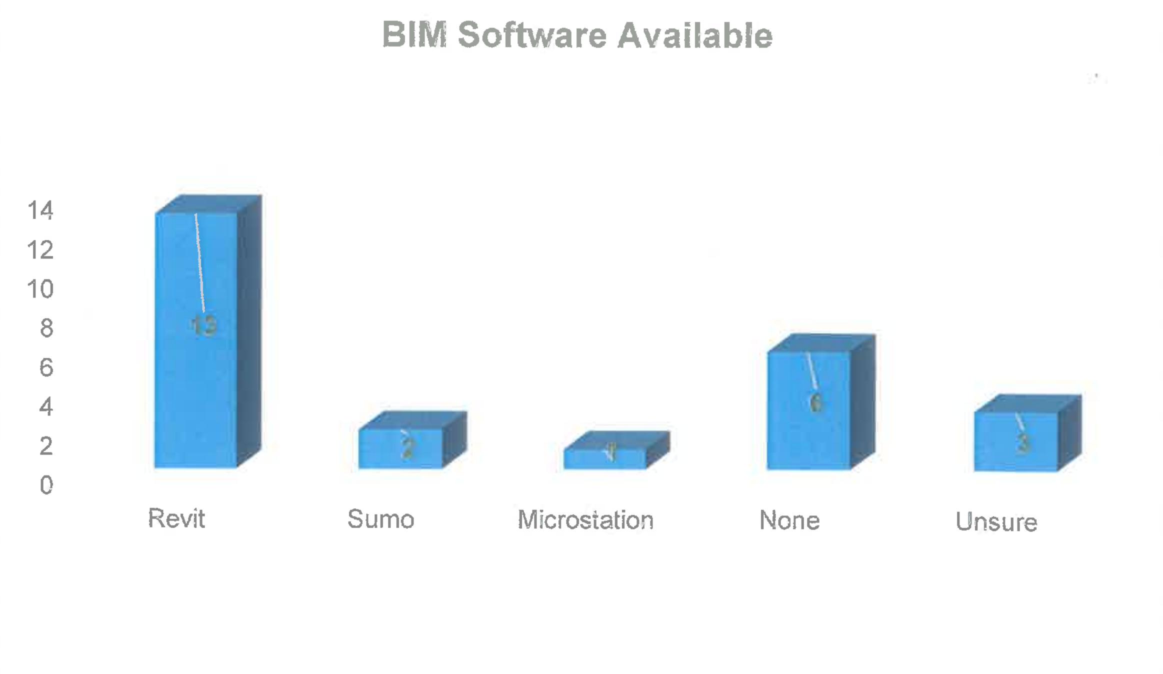


Figure 5-12: BIM Software Available – Section 3

Figure 5-12 above, indicates that, of the sixteen (16) participants which identified that they had access to BIM software, the majority (52%) had Autodesk Revit within their organisation.

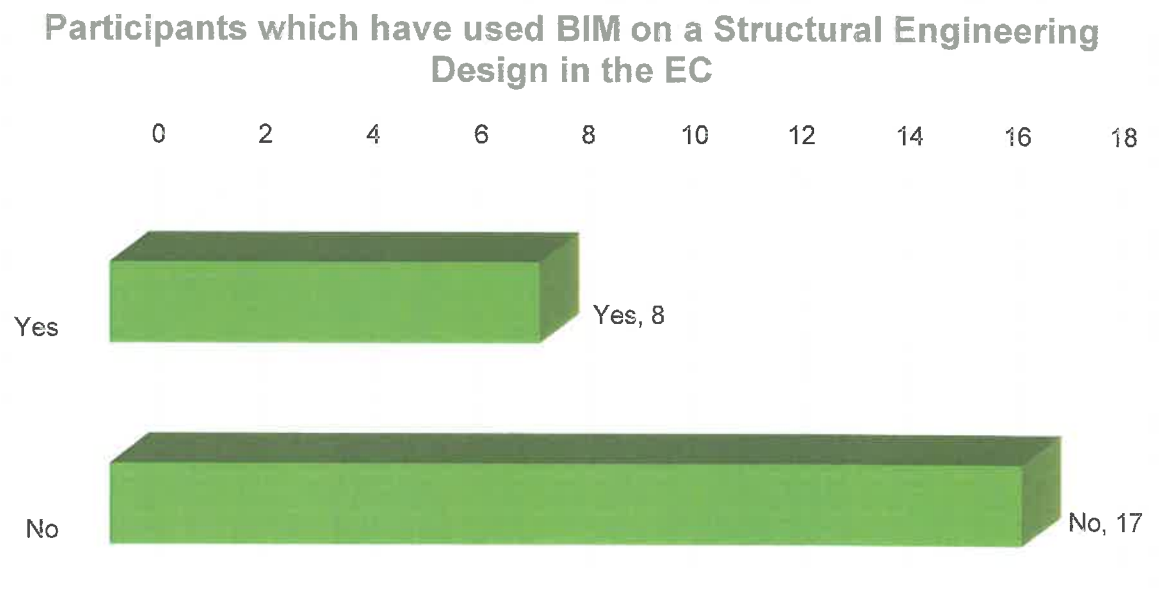


Figure 5-13: Participants which have used BIM in the EC – Section 3

Figure 5-13 above, graphically illustrates that only 32% of the participants had used BIM on a structural engineering design in the Eastern Cape.

Table 5-5: BIM required by Clients on Projects - Section 3

Do clients generally require BIM technology on projects in the EC	Yes	No	Unsure
No of times identified	1	22	2
Percentage	4%	88%	8%

Table 5-6: Projects where BIM was required by the Client - Section 3

Aware of, or worked on, a project in the EC where the client required the usage of BIM technology	Yes	No	Unsure
No of times identified	10	14	1
Percentage	40%	56%	4%

Table 5-7: Regulations and Legislation regarding BIM - Section 3

Do regulations and legislation require participants to use BIM software on certain projects	Yes	No	Unsure
No of times identified	0	20	5
Percentage	0%	80%	20%

Table 5-5 indicates that 88% of clients do not generally require the use of BIM technology on their projects, however Table 5-6 indicates that 40% of participants were aware of projects within the Eastern Cape, in which the client has required the usage of BIM. Table 5-7 indicates that there are currently no regulations or legislation, that requires the participants to use BIM on certain projects.

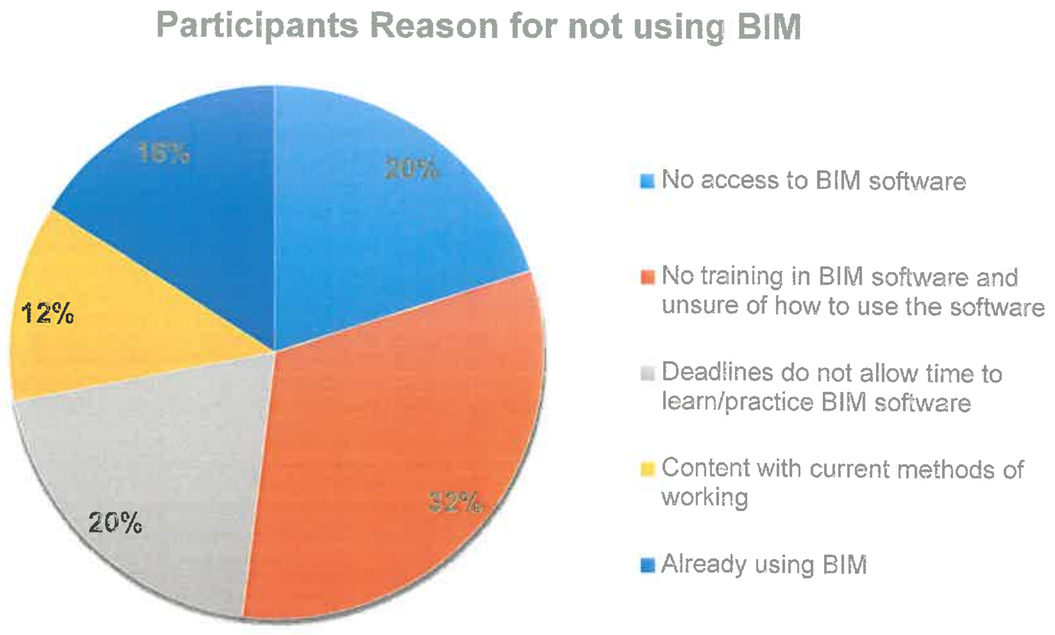


Figure 5-14: Reasons for not using BIM – Section 3

Figure 5-14 above graphically illustrates that the main reason why participants have not used BIM is due to no training on BIM software, and participants are unsure of how to use the software.

Table 5-8: Barriers Hindering BIM Implementation – Section 3

Category	1 (Most Significant)	2	3	4	5 (Least Significant)	**Overall Significance Ranking**
Human Factors	8	6	9	2	0	**2**
Software Factors	2	1	4	14	4	**4**
Legal Concerns	1	0	0	7	17	**5**
Lack of BIM Expertise	10	10	2	2	1	**1**
Cost of BIM Implementation	4	8	10	0	3	**3**

The majority of the participants indicated that the main barrier hindering them from implementing BIM was their lack of BIM expertise. This was closely followed by the human factor. The human factor, more specifically relates to the reluctance to change from traditional methods of design, to designing using BIM technology. Table 5-8 above indicates the overall significance ranking of each category, while Figure 5-15 below graphically illustrate the results from the questionnaires.

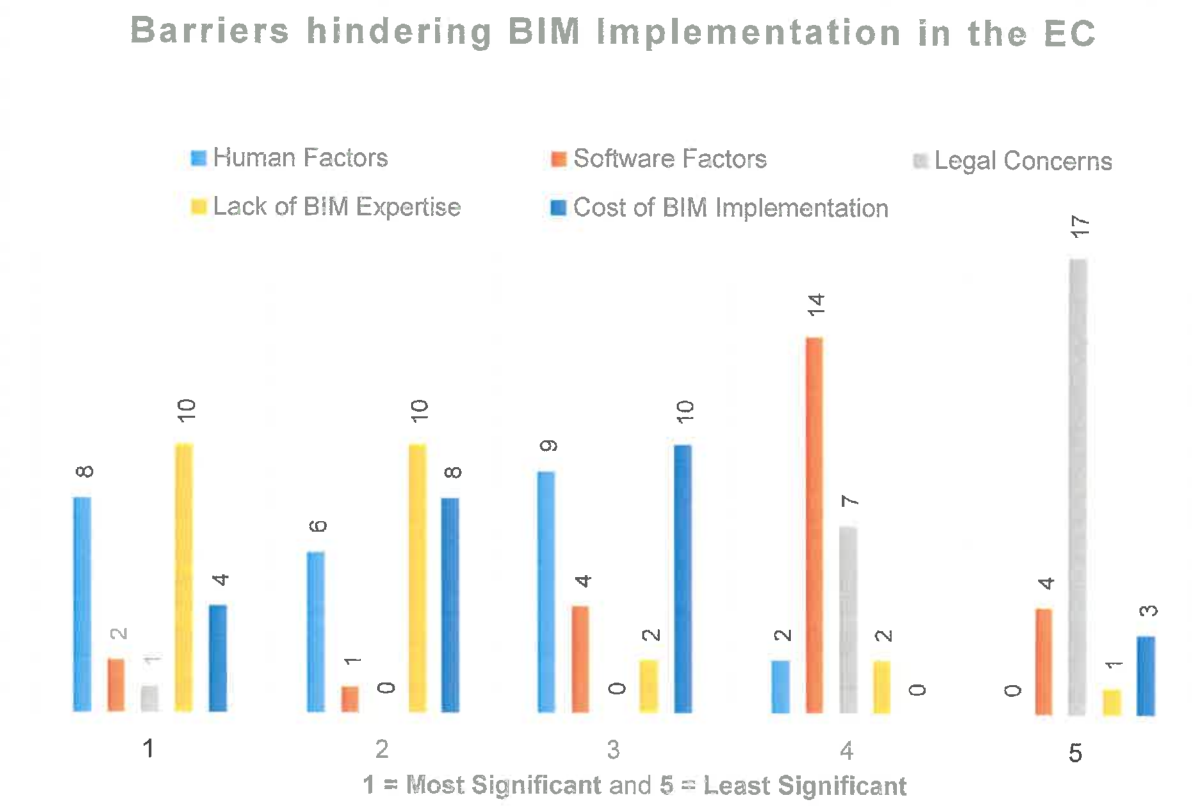


Figure 5-15: Barriers Hindering BIM Implementation – Section 3

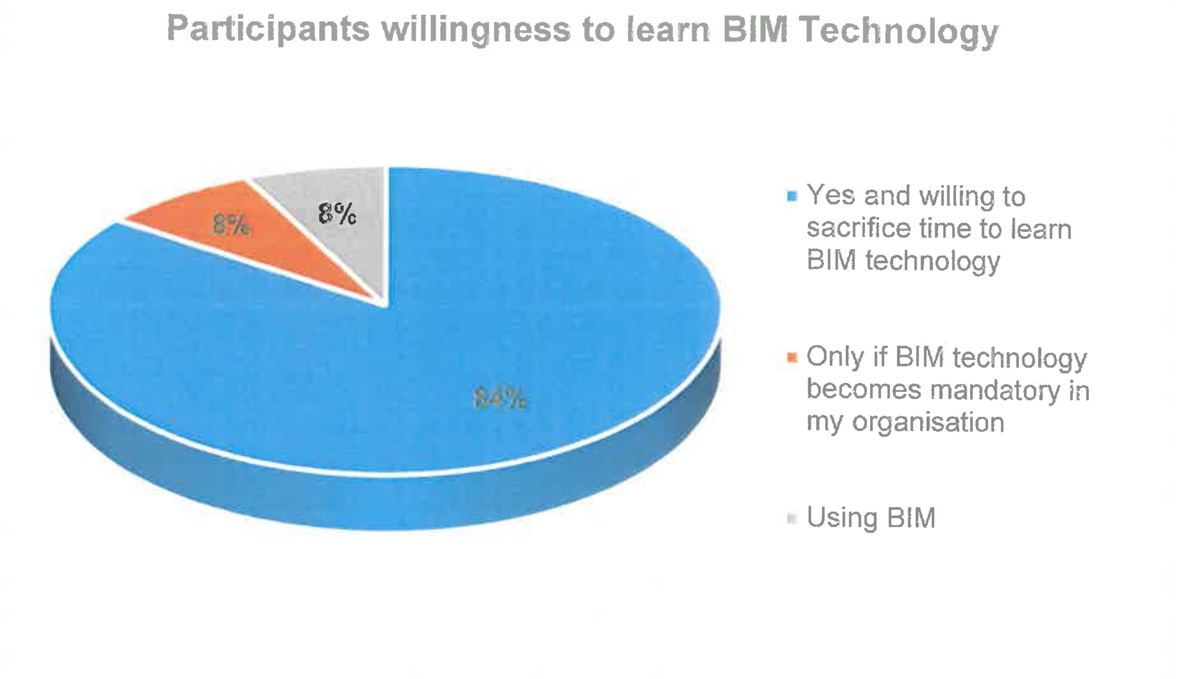


Figure 5-16: Willingness to Learn BIM Technology – Section 3

Figure 5-16 above graphically illustrates that a significant 84% of the participants were willing to sacrifice their time to learn BIM technology, while only 8% of the participants indicated that they would only learn BIM technology if it became mandatory within their organisation. The remaining 8% of the participants were already using BIM technology.

5.2.7 Discussion of Results from Section 3

This portion of the chapter focuses on the discussion of the results obtained for section 3 of the questionnaire, while conclusions to the research objectives of this dissertation will be drawn in the next chapter (Chapter 6 – Conclusions).

The results indicated that the majority of the participants were aware of the concept of BIM, and also had a general idea of the benefits associated with the implementation of BIM.

A high number of the participants indicated that they had access to BIM software within their organisation. The most common BIM software identified by the participants, was Autodesk Revit. It is noted that Autodesk Revit was the same BIM software package that was used for the illustrative case study presented in Chapter 4.

Autodesk Revit is popular due to its interchangeability and the ability to easily transfer design information to AutoCAD (drafting software). This is due to the fact that they are both packages developed by Autodesk.

The results indicated that BIM technology is not commonly used within the Eastern Cape. However, 32% of the participants indicated that they had used BIM on a project within the province.

The results demonstrated that within the Eastern Cape, there is a lack of drive from clients, regulations, and legislation, for structural engineers to use BIM technology. However, 40% of the participants were aware of projects within the province that required BIM technology.

This implies that even though BIM in not common practice in the province, certain clients have started to realise its benefits, and are starting to make BIM implementation a requirement on certain projects.

The questionnaire progressed to identify the reasons why participants do not use BIM technology. The majority of the participants highlighted that they do not use BIM due to insufficient training on BIM software, and that participants were unsure of how to use the software. This was closely followed by the comment that deadlines do not allow the participants' time to learn/practice BIM software.

Following the theme in the above paragraph, the participants indicated that the most significant barrier hindering BIM implementation within the Eastern Cape, is the lack of expertise in using the software.

These results clearly show that training and practice, is hindering BIM implementation within the Eastern Cape. However, the results from the final question in section 3, revealed that the majority of the participants were willing to sacrifice the time to learn BIM technology.

5.2.8 Section 4 – Drafting and Design Software

Section 4 of the questionnaire was developed to identify the most used drafting and structural design software within the Eastern Cape.

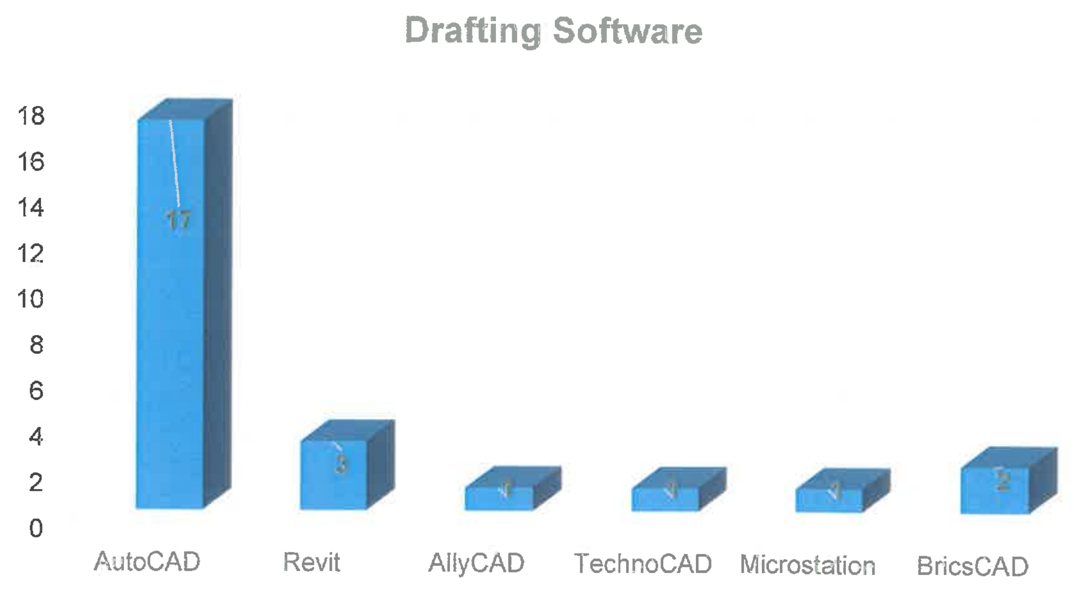


Figure 5-17: Most used Drafting Software – Section 4

The results from the questionnaires highlighted that the most used (68%) drafting software is AutoCAD (results are graphically displayed in Figure 5-17 above), and the most used (88%) structural design software is Prokon (results are graphically illustrated in Figure 5-18 below).

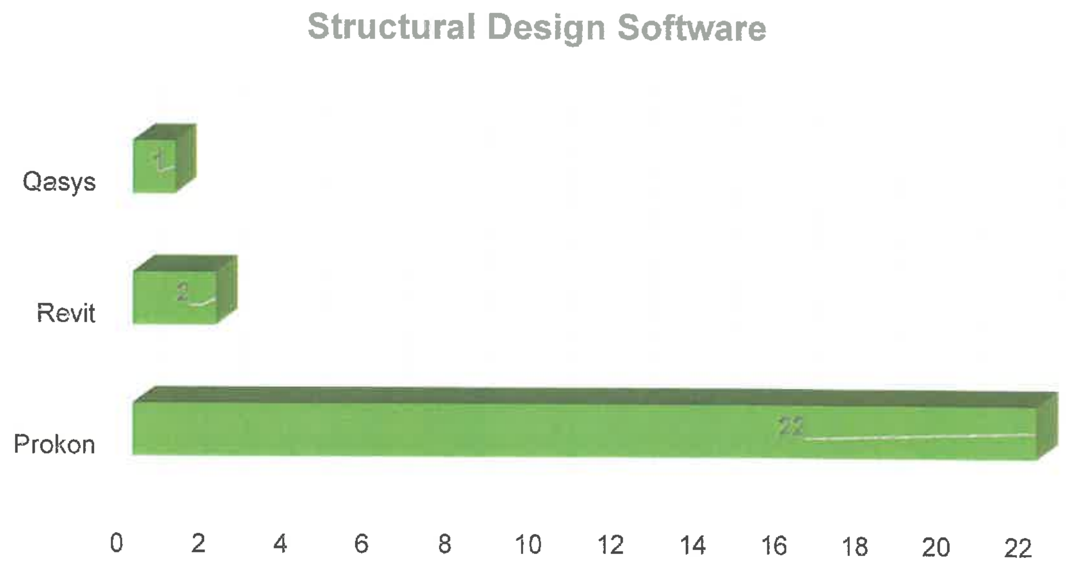


Figure 5-18: Most used Structural Design Software – Section 4

5.3 DESKTOP STUDY

This section presents the results from the desktop study regarding the most used drafting and design software, within South Africa. Following this, the desktop study then proceeded to investigate the available training course on the most used, BIM compatible, design software identified in the first portion of the study. The findings from this section will assist in providing recommendations to the structural engineering organisations within the Eastern Cape.

5.3.1 Drafting and Design Software Preferences

In December 2016, the BIM Institute conducted a national (SA) BIM survey in order to identify the current state of BIM implementation in the country. Figure 5-19 below, graphically illustrates the design software preferences identified by the survey participants.

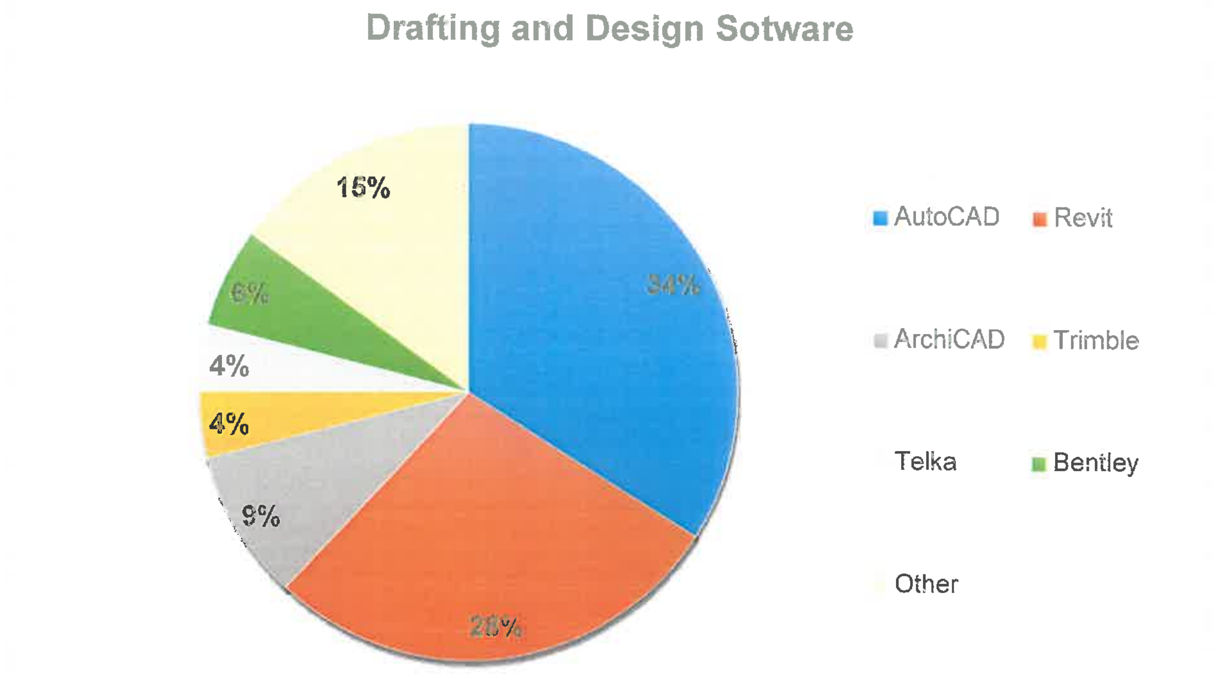


Figure 5-19: SA Design Software Preferences (based on SA BIM Survey, Harris, 2016)

The above pie chart shows that the majority of the designers within South Africa, were using AutoCAD (34%), and Autodesk Revit (28%).

The desktop study proceeded to identify training courses within the country, for the most used, BIM compatible, design software indicated in the first portion of the desktop study (i.e. Autodesk Revit).

5.3.2 Training Courses

The research questionnaire identified that the majority of the participants do not use BIM for structural designs due to their lack of training on BIM software, and that participants were unsure of how to use the software. Building on this finding from the questionnaires, the desktop study proceeded to identify BIM training courses within South Africa. The attendance of training courses will help mitigate the drawbacks pertaining to lack of BIM experience.

Prokon Software Consultants are accredited Autodesk training providers. Prokon provides a number of BIM software training courses throughout the year. Table 5-9 below, lists the BIM training courses available by Prokon.

Table 5-9: Prokon BIM Software Training Courses

Course	Duration	Details
Autodesk Revit Essentials Training Course	5 days	• Day 1 & 2: Basic Revit Training (Structural, Architectural & MEP users) • Day 3: On the 3rd day they offer either a full Structural Day or a full Architectural Day. The choice is up to the trainee. • Day 4: 1 x Full day on the H-VAC part of Revit MEP. • Day 5: 1 x Full day on the Electrical & Plumbing part of Revit MEP for the Revit MEP users.
Autodesk Revit Structure Essentials	3 days	• Provides training on the fundamentals of structural design using Revit.
Autodesk Advanced Steel	3 days	• Provides training on advanced fundamentals of steel.
Autodesk Revit Advanced (Families Level 1)	1 day	• Course focuses on the fundamentals of 2D Families in Revit.
Autodesk Revit Advanced (Families Level 2)	1 day	• Course focuses on the fundamentals of 3D Families in Revit.

5.4 CHAPTER SUMMARY

This chapter has discussed the results based on the data that was collected from the research questionnaire. The current structural engineering design methods have been identified, along with the current state of BIM implementation within the Eastern Cape. The chapter also presents findings from the desktop study, which was conducted to assist in providing recommendations on BIM implementation. The results from this chapter will assist in providing solutions for objectives 1, 2, and 4, of this dissertation.

The researchers view on the results in this chapter is that the Eastern Cape has not yet started implementing BIM and/or implementing BIM to its full potential. Furthermore, the concept of BIM is still new to the professionals within the province. It was also identified that larger organisations do not enforce BIM implementation in their smaller offices within the Eastern Cape. This lack of enforcement prevents the professionals in the province from developing at the same rate (in terms of BIM) of similar professionals within the lager organisational head offices. With this being said, the results also indicated that there is a willingness from the structural engineers in the province to learn and adapt to BIM, which is good for the future development of the Eastern Cape.

The dissertation proceeds to the conclusions chapter. This chapter will provide conclusions to the overarching aim of the research based on the results and findings, identified in chapters 2, 3, 4, and 5.

CHAPTER 6

CONCLUSIONS

6. CHAPTER 6: CONCLUSIONS

6.1 CHAPTER INTRODUCTION

This chapter revisits the research aims, objectives, and hypothesis, presented in the opening chapter. Following this, the chapter then proceeds to provide conclusions for this dissertation, based on the findings in the previous chapters. It will then conclude with a chapter summation.

6.2 CONCLUSIONS

The aim of this research study was to investigate the necessity for BIM implementation into structural engineering organisations, within the Eastern Cape.

The hypothesis of this dissertation was that the implementation of BIM technology will improve the efficiency of the structural design process currently being used by the structural engineering organisations within the province, and secondly that BIM will soon become standard practice for the AEC industry.

The preliminary objective of this research was to identify the current structural engineering design processes being used by structural designers within the Eastern Cape.

Following this, the study embarked on identifying the advantages and disadvantages associated with BIM implementation. The third objective was to determine the national and international implementation trends of BIM.
In addition, a final objective of the study was to provide recommendations for BIM implementation into a typical structural engineering organisation within the province.

The research discovered that the majority of structural engineers within the Eastern Cape designed structures by isolating individual components of a building, and then designed each component separately, as opposed to designing a structure as a composite model.

The study also highlighted that the production of 2D drawings, details, and sections, were individually drafted using CAD software, which was further identified as a slow and time-consuming process, as opposed to automatically generating them from a 3D BIM model.
Furthermore, it was clear that using current methods, subsequent design changes are notorious for also being a slow and time-consuming process.

The study identified that there are significant advantages related to the implementation of BIM for structural engineers, such as the improved visualisation, improved collaboration between design team members, reduction in design clashes, reduced time to produce documentation, and an overall increase in productivity.

While there were numerous advantages of BIM implementation identified, the implementation process also presented drawbacks. The research explored the potential disadvantages and challenges of BIM implementation for structural engineering organisations. Following this exploration, the study identified that the main drawback was the lack of BIM expertise within an organisation wanting to implement BIM.

The study proceeded to identify BIM training courses within South Africa. The attendance of training courses by structural engineers, was identified as a tool to help mitigate the drawbacks pertaining to lack of BIM experience.

The study proceeded to investigate the international and national implementation trends of BIM. It was discovered that a number of countries have various mandates in place for the implementation of BIM for projects of a certain type, size or value.

The decision to apply mandatory BIM implementation requirements by so many countries, was found to be due to increased efficiency and simultaneous financial savings, which are regarded as advantages of implementing BIM.

Despite the increase in BIM implementation around the world, it was identified that South Africa was still lagging behind. However, questions surrounding mandatory BIM implementation being able to increase BIM usage in South Africa, had already started circulating within South Africa's AEC industry.

Looking back at the initial hypothesis of this dissertation, which stated that the implementation of BIM technology will improve the efficiency of the structural design process currently being used by the structural engineering organisations, the research has showed that the engineers in the Eastern Cape are lagging behind with their current structural design methods. Furthermore, the implementation of BIM will in fact be able to improve on a number of current structural design methods being used within the province.

The second part of the hypothesis, which stated that BIM will soon become standard practice for the AEC industry, turned out be correct once investigated in this research study. It was identified that as of 2017, 12 countries already had mandatory BIM implementation regulations in place, with a further nine countries having mandatory regulations planned for the near future.

To review, the aim of this research study was to investigate the necessity for BIM implementation into the structural engineering organisations, within the Eastern Cape Province. The structural engineering organisations within the province face the threat of being left behind in terms of BIM technology, and therefore, losing out on reaping the benefits associated with BIM implementation.

Furthermore, BIM implementation is no longer a ‘nice beneficial technology to have’, but is fast becoming a global requirement within the AEC industry. Considering the current international trends of BIM implementation, it is highly possible that in the near future, South Africa will start requiring BIM implementation on projects of a certain type, size or value. This will also include projects within the Eastern Cape.

The structural engineering organisations within the province will then start losing larger projects to more technologically advanced companies within South Africa, and/or foreign companies, which are already well versed in using BIM technology.

6.3 CHAPTER SUMMARY

This chapter has provided conclusions for the research aims, objectives, and hypothesis, based on the findings of this study.

The dissertation proceeds to the final chapter. Recommendations stemming from the research will be provided in addition to further potential research.

CHAPTER 7

RECOMMENDATIONS AND FURTHER RESEARCH

7. CHAPTER 7: RECOMMENDATIONS AND FURTHER RESEARCH

7.1 CHAPTER INTRODUCTION

This chapter provides concluding recommendations based on the findings from this research study. Following this, the chapter then proceeds to provide potential further research opportunities stemming from this dissertation. The chapter then concludes with a chapter summation.

7.2 RECOMMENDATIONS

As a result of the findings from this research, it is recommended that the structural engineering organisations within the Eastern Cape adopt a proactive approach to BIM implementation. This involves starting the implementation process as soon as possible, rather than waiting until mandates are in place, which start requiring the use of BIM technology on projects of a certain type, size or value.

Apart from this, there are also numerous advantages associated with BIM implementation that have been presented in this study. The structural engineering organisations within the province, are encouraged to embark on pilot programmes in order to unlock these potential advantages and keep up to date with modern technology trends.

The first step in BIM implementation is the purchasing of BIM compatible software. The research identified that the most popular BIM compatible software within South Africa was Autodesk Revit. This leads to the recommendation that structural engineering organisations which are interested in implementing BIM, should choose to use Autodesk Revit.

Autodesk Revit is developed by the same company that developed AutoCAD. Following on from the findings of this study, the majority of the structural engineers indicated that they are already using AutoCAD. This will make the transition to Autodesk Revit that much easier, as the two packages are developed by Autodesk and therefore use similar concepts.

Furthermore, adopting the most popular software programme is generally the safe option as this will assist in collaboration with other organisations; there is also a higher availability of people to assist with any problems on that package, as opposed to a package that only has around 5% usage within the country.

A further recommendation to the structural engineering organisations which are interested in implementing BIM, is that they should invest in sending their employees on training courses. The research identified Autodesk Revit training courses that are available within South Africa.
The attendance of BIM training courses will help to mitigate the main drawback for an organisation starting to implement BIM, which is the lack of BIM experience.

7.3 FURTHER RESEARCH

This study has identified that BIM implementation is increasing at a rapid pace, and is fast becoming an industry standard around the world. With this in mind, the structural engineers within South Africa are falling behind in terms of BIM education.

During this research, it was identified that a number of international universities have started implementing BIM training courses and modules, as part of engineering degrees.

Potential further research presents itself regarding the inclusion of BIM modules into undergraduate and postgraduate degrees within the universities of South Africa.

7.4 CHAPTER SUMMARY

This chapter has provided recommendations, based on the findings of this study, and presented further research opportunities.

8. List of References

LIST OF REFERENCES

AGC (2006). *"The Contractors' Guide to BIM".* (First Edition). USA: The Associated General Contractors of America.

ArcDox (2016). Building Information Specialists. *"What is BIM"?* Available at: *http://www.arcdox.com/what-is-bim* [Accessed: 22 March 2016].

Austin, J. (2011). BIM Diagram, Opportunity Knocks. bdonline.co.uk. Available at: *http://www.bdonline.co.uk/opportunity-knocks/5016225.blog* [Accessed: 13 March 2016].

Autodesk. (2016). Building Information Modelling Overview. Available at: *http://www.autodesk.com /solutions/bim/overview* [Accessed: 27 February 2016].

Autodesk. (2012). *"Design, visualize, simulate, document, and build. The Power of BIM for Structural Engineering".* Available at: *https://www.yumpu.com/en/document/view/28659839/the-power-of-bim-for-structural-engineering-autodesk* [Accessed: 28 March 2016].

Azhar, S. (2011). *"Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry."* Leadership Manage. Eng., 10.1061/(ASCE)LM.1943-5630.0000127, p241-252.

Azhar, S. Khalfan, M. and Maqsood, T. (2012). *"Building Information Modelling (BIM): now and beyond".* Australasian Journal of Construction.

Baier, C.K. (2016). *"Development of a process model for the holistic use of BIM methodology for sustainable construction in the public sector".* PhD Thesis, Universidad De Cantabria.

Ball, M. (2014). *"Building Information Modeling for the Win: Top 10 Benefits of BIM".* Available at: *http://lineshapespace.com/building-information-modeling-top-10-benefits-of-bim/* [Accessed: 28 March 2016].

Barlish, K. (2011). *"How to Measure the Benefits of BIM, A Case Study Approach"*. Masters Thesis, Arizona State University.

Berard, O.B. (2012). *"Building Information Modeling for Managing Design and Construction: Assessing Design Information Quality"*. PhD Thesis, Technical University of Denmark.

Bhatia, N. (2015). *"Revealed: Dubai Municipality's updated BIM mandate"*. Available at: http://www.constructionweekonline.com/article-34893-revealed-dubai-municipalitys-updated-bim-mandate/ [Accessed: 9 April 2016].

BIMcrunch. (2015). *"BIM mandate for transport projects in Germany confirmed for 2020"*. Available at: *http://bimcrunch.com/2015/12/bim-mandate-for-transport-projects-in-germany-confirmed-for-2020/* [Accessed: 9 April 2016].

Bryman, A. and Bell, E. (2014). *"Research Methodology: Business Research Methods"*. (3rd Edition).Oxford University Press. ISBN 978 0 19907613 0. p31.

BuildingSMART, 2010. Investing in BIM competence, BuildingSMART: a guide to collaborative working for project owners and building professionals. BuidlingSMART UK.

BuildingSMART. (2012a). *"The BIM Evolution Continues with OPEN BIM"* – What is BIM? Draft V8 20120131 BuildingSMART International.

BuildingSmart, (2012b). National Building Information Modelling Initiative, Vol 1. *"A strategy for the focused adoption of building information modelling and related digital technologies and processes for the Australian built environment sector"*. A report for the Department of Industry, Innovation, Science, Research and Tertiary Education.

Burger, R. (2014). *"How to Integrate BIM into Small Practices"*. [Accessed: 27 February 2016]. Available at: *http://blog.capterra.com/integrate-bim-small-practices.*

Cabinet Office. (2011). Government Construction Strategy.

CAD Services India. (2015). *"BIM is Rapidly Getting Adopted by Most of The Countries in The World".* Available at: *https://medium.com/@cadservicesindia/bim-is-rapidly-getting-adopted-by-most-of-the-countries-in-the-world-9c562645839a#.wcc0u8kw8* [Accessed: 7 March 2016].

CIOB, (2015). BIM around the World – Country by Country, Construction Manager.

Civilax. (2017). *"Using Building Information Modeling (BIM) as a Structural Engineer: Looking at BIM through Case Studies".* [Accessed: 1 May 2017]. Available at: https:// www.civilax.com/using-building-information-modeling-bim-structural-engineerlooking-bim-case-studies/

Cohen, L. Manion, I. and Morrison, K. (2005). *"Research Methods in Education".* (5th Edition). New York. Taylor Francis Group.

Cooksey, J. (2011). "*The Integration of Building Information Modeling (BIM) Into Civil Engineering Curricula".* All Theses. Paper 1289. Clemson University.

Creswell, J.W. and Plano Clark, V.L. (2007). *"Designing and Conducting Mixed Methods Research".* California, Sage Publication Inc. p5.

Crotty, R. (2011). *"The impact of building information modelling: Transforming construction".* Routledge.

Daedal. (2016). "Global BIM Market: Size, Trends and Forecasts (2016 – 2020), Daedal Publications.

Daud, S. Abidin, N. Sapuan, N.M. and Rajadurai, J. (2010). *"Creating sustainable and competitive employees through the design of innovative higher education curriculum".* [Accessed: 5 March 2016].
Available at: http://www.ibimapublishing.com/journals/CIBIMA/cibima. html.

Eadie, R. Browne, M. Odeyinka, H. McKeown, C. and McNiff, S. (2013). *"BIM implementation throughout the UK construction project lifecycle: An analysis".* In: Automation in Construction 36. p145-151.

Eastman, C. Teicholz, P. and Sacks, R. (2011). BIM handbook: *"A guide to building information modelling for owners, managers, designers, engineers and contractors".* Second Edition. John Wiley & Sons.

Eckholm, A. Blom, H. Löwenertz, K. and Tarandi, V. (2015). BIM –Standardiseringsbehov, Sweden.

Erickson, C. Autodesk. (2015). "*Latest Updates for Autodesk Advance Steel Reflect Commitment to Serve the Steel Industry".* Available at: *http://inthefold.autodesk.com/in_the_fold/aec/* [Accessed: 28 March 2016].

ECSA. (2016). Engineering Council of South Africa, ECSA Brochure document. Section on: "*Professionalism for the Engineering Practitioner means:"* [Accessed: 3 March 2016]. Available at: *https://www.ecsa.co.za/news/SitePages/ECSA%20Brochure.aspx.*

ECSA. (2016). "*What is ECSA"?* [Accessed: 6 March 2016]. Available at: *https://www.ecsa.co.za/about/SitePages/What%20Is%20ECSA.aspx.*

English, J. (2012). *"Professional Communication: Deliver effective written, spoken and visual messages".* Third Edition. Juta and Company (Pty) Ltd. P239-282

Fleming, W.S. (2016). *"BIM Modelling for Structural Analysis".* Master of Technology: Structural Engineering Thesis, Poznan University of Technology. p21.

Froise, T. and Shakantu, W. (2014). "*Diffusion of Innovations: An Assessment of Building Information Modelling Uptake Trends in South Africa".* Journal of Construction Project Management and Innovation Vol. 4 (2): p895-911.

Goldswain, C.P. (2016). *"BIM as a Tool for Quantifying the Impact of Change on Labour Productivity".* Master of Engineering Thesis, Stellenbosch University.

Harris, V. (2016). South African BIM Survey report, BIM Institute.

Haron, A. (2013). *"Organisational Readiness to Implement Building Information Modelling: A Framework for Design Consultants in Malaysia".* PhD Thesis, University of Salford Manchester.

Hay, S. (2013). *"A Comparative Study of Trenchless Technologies versus Traditional Open Trenching for the Replacement of Ageing Potable Water Pipelines".* Matsters Dissertation, DUT.

Holzer, D. (2015). *"The BIM Manager's Handbook: Guidance for Professionals in Architecture, Engineering, and Construction".* Publisher: John Wiley & Sons. Part 1: Best Practice BIM.

Hore, A. McAuley, B. and West, R. (2017). *"Global BIM Study: Lessons for Ireland's BIM Programme".* Construction IT Alliance (CITA).

Hunt, C.A. (2013). *"The Benefits of Using Building Information Modelling in Structural Engineering".* All Graduate Plan B and other Reports. Paper 319. [Accessed: 13 March 2016]. Available at: *http://digitalcommons.usu.edu/gradreports/319.*

International BIM Services. (2016). *"Full BIM Management & Coordination".* Available at: *http://www.mv-bim.com/mobile/project.php?id=3* [Accessed: 29 March 2016].

Johns, R. (2010). *Likert Items and Scales. "Survey Question Bank Methods Fact Sheet".* Available at: *http://surveynet.ac.uk/sqb/datacollection/likertfactsheet.pdf.* [Accessed: 05 May 2016].

Johnson, P. (2012). *"How will Building Information Modelling impact on a Small to Medium Enterprise Curtain Wall Sub-contractor in the UK"?* Masters Thesis, University of Bath.

Khemani, H. (2008) *"Benefits of using the CAD Software".* [Accessed: 28 February 2016]. Available at: *http://www.brighthubengineering.com/cad-autocad-reviews-tips/17593-benefits-of-using-the-cad-software/*

Khemlani, L. (2012). Around the World with BIM, AEC Bytes Archive.

Kumar, R. (2005). *"Research methodology: A step-by-step guide for beginners".* London: SAGE Publications Ltd. p129.

Mann, B.L. (2006). *"Case Study Research on Web-Based Learning".* Styles Book, Chapter 5. p72.

McCuen, T. Suermann, P. and Krogulecki, M. (2012). *"Evaluating Award-Winning BIM Projects Using the National Building Information Model Standard Capability Maturity Model."* J. Manage. Eng., 10.1061/(ASCE)ME.1943-5479.0000062, p224-230.

McGraw Hill Construction. (2013). *"The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-12)".* Smart Market Report.

McGraw Hill Construction. (2014a). *"The Business Value of BIM for Construction in Global Markets".* McGraw Hill Construction, Bedford MA United States.

McGraw Hill Construction. (2014b). *"The Business Value of BIM in Australia and New Zealand: How Building Information Modelling is transforming the Design and Construction Industry".* Smart Market Report.

Merriam, S.B. (1988). *"Case Study Research in Education".* 1st Edition. San Francisco. Jossey-Bass Inc. p10.

Migilinskas, D. Popov, V. Juocevicius, V. and Ustinovichius, L. (2013). *"The benefits, obstacles, and problems of practical BIM implementation"* Procedia Engineering 57, p767-774.

Miles, M.B. and Huberman, A.M. (1994). *"Qualitative Data Analysis: An Expanded Sourcebook"*. London: Sage

NBS (2013). National BIM Report 2013 – *"National BIM Survey 2013"*. Royal Institute of British Architects.

National BIM Standard – United States. (2016). *"Frequently Asked Questions about the National BIM Standard-United States, What is BIM"?* Available at: *https://www.nationalbimstandard.org/faqs#faq1* [Accessed: 22 March 2016].

Panaitescu, R. (2014). *"Building Information Modeling Towards a Structured Implementation Process in an Engineering Organization"*. Masters Thesis, Delft University of Technology.

Parvan, K. (2012). *"Estimating the Impact of Building Information Modeling (BIM) Utilization on Building Project Performance"*. PhD dissertation, University of Maryland.

Poon, E. (2013). Worldwide BIM policy & strategy - fully collaborative 3D BIM as a minimum.

Punch, K.F. (1998). *"Introduction to Social Research: Qualitative and Quantitative Approaches"*. London: Sage p11&247.

Revit Modelling India. (2015). *"5 Worst Problems Faced During BIM Implementation"*. Available at: http://www.revitmodelingindia.com/the-5-worst-problems-faced-during-bim-implementation/ [Accessed: 27 April 2017].

Rooney, K. (2015). BIM Education - Global – 2015 Update Report, Issue Version: V2.0, NATSPEC Construction Information.

Sacks, R. and Barak, R. (2010). "*Teaching Building Information Modeling as an Integral Part of Freshman Year Civil Engineering Education.*" Available at: http://codebim.com/wp-content/uploads/2013/06/Sacks_Barak_2010.pdf [Accessed: 22 March 2016].

Schinler, D. and Nelson, E. (December, 2008). "BIM and the structural engineering community". STRUCTURE Magazine, p10-12.

Sculpteo (2017). *"3 Beautiful 3D Printed Stadium Models*". Available at: https: //www.sculpteo.com/blog/2012/05/22/3-beautiful-3d-printed-stadium-models/ [Accessed: 06 May 2017].

Tabesh, M. (2014). "An investigation to introduce BIM in undergraduate civil engineering teaching to improve construction processes". Master's Thesis. University of Stellenbosch.

Ter Maaten, J. (2015). *"BIM Horizon; BIM and its Envisioned Use in Engineering Infrastructure".* Masters dissertation, Delft University of Technology and Grontmij Nederland B.V.

VICOSoftware. (2016). *"3D BIM Visualization and Reporting".* Available at: *http://www.vicosoftware.com/products/3d-bim-software-visualization-and-reporting/tabid/229113/Default.aspx* [Accessed: 28 March 2016].

Waldeck Consulting. (2013) Image Available at: http://www.waldeckconsulting.com/wp-content/uploads/2013/04/BIM-Dimensions-e1470411621966.png [Accessed: 15 April 2017].

Welman, C. Kruger, F. and Mitchell, B. (2005). Research Methodology. 3rd. Cape town: Oxford University Press.

White, J. (2015) The CAD Corporation Cape Town host BIM event in South Africa. [Accessed: 27 February 2016]. Available at: *http://bimcrunch.com/2015/11/watch-the-cad-corporation-cape-town-host-bim-event-in-south-africa/*

Wiersma, W and Jurs, S.G. (2009). *"Research Methods in Education: An Introduction".* (9th Edition) Boston: Pearson Publications.

Willard, L. (2009). *"Proactive BIM implementation: A small-company case study"*. [Accessed: 27 February 2016]. Available at: *http://cenews.com/article/6552/proactive-bim-implementation-a-small-company-case-study.*

Yin, H. and Damian, P. (2008). *"Benefits and Barriers of Building Information Modelling"*. Loughborough University, UK.

Yin, R.K. (2014). *"Case Study Research, Design and Methods"*. (Applied Social Research Methods) 5th Edition. Sage, London.

9. Appendices

APPENDIX A

Typical Organisational Clearance Letter

CONFIDENTIAL INFORMATION
(Organisation Letterhead)

20 February 2017

Durban University of Technology
Faculty of Engineering and the Built Environment
Pietermaritzburg Campus
Institutional Research Ethics Committee

Dear Sir/Madam

Organisational Clearance Letter:

Mr David Jason Hiscock who is a post-graduate student studying towards his Master of Engineering Degree at the Durban University of Technology has requested permission from [redacted] to approach selected employees within the organisation.
He is conducting research on Building Information Modelling (BIM) in the field of Structural Engineering. His research aims to investigate if and how BIM implementation will improve the efficiency of the Structural Engineering design process in the Eastern Cape.

As part of his research methodology he has proposed the use of questionnaires to be distributed to the Structural Engineering professionals within the [redacted] Eastern Cape offices (East London and Port Elizabeth office) to provide foundation data for his research.

This letter confirms that Mr D. Hiscock has obtained consent from [redacted] to approach the above specified employees within the [redacted] East London and Port Elizabeth office. He has confirmed that employees and the organisation ([redacted]) will remain anonymous in his final thesis and information obtained will be used for academic research purposes only.

Yours sincerely

[redacted]
Technical Director (East London Office)

[redacted]
Technical Director (Port Elizabeth Office)

(Organisation Footer)

APPENDIX B

Research Questionnaire Covering Letter

DUT DURBAN UNIVERSITY OF TECHNOLOGY

8 February 2017

Durban University of Technology
Faculty of Engineering and the Built Environment
Pietermaritzburg Campus
Institutional Research Ethics Committee

Dear Sir/Madam

<u>Research Questionnaire Covering Letter:</u>

I, David Jason Hiscock, am a post-graduate student studying towards my Master of Engineering Degree at the Durban University of Technology.

I am conducting research on Building Information Modelling (BIM) in the field of Structural Engineering. My research aims to investigate if and how BIM implementation will improve the efficiency of the Structural Engineering design process in the Eastern Cape.

I have selected you due to your experience in Structural Engineering design and your geographical location (Eastern Cape) to participate in answering a few questions which will greatly assist with my research. The questionnaire should take no longer than 15 minutes of your time to complete.

<u>Please note that the answers which you provide shall remain anonymous and will be used for academic research purposes only.</u>

I would like to thank you in advance for taking time out of your day to provide your valuable input into my research. Your participation is greatly appreciated.

If you have any questions and/or require assistance, please do not hesitate to contact me via email at: Dave.Hiscock@aurecongroup.com or call: 082 573 8058.

Yours sincerely

Mr DJ Hiscock (M.Eng Candidate)

APPENDIX C

Research Questionnaire

DURBAN
UNIVERSITY OF
TECHNOLOGY

RESEARCH QUESTIONNAIRE

1.) Brief overview of questionnaire participant

a) Which age category do you fall into?

20-29	30-39	40-49	50-59	60+

b) What is your highest level of education?

Diploma	Degree	Masters	Doctorate

c) Which town do you work in within the Eastern Cape (EC)?

East London	Port Elizabeth

d) How many years have you been working within the EC?

0-4	5-9	10-14	15-19	20+

2.) Main Question 1 - What are the current structural engineering design methods being used in the EC?

a) What structural design methods do you mostly use in your organisation?

Method of design	Select most used method
Design using first principals (i.e. manual calculations)	
Design using first principals and analysis software to design individual components of a structure (i.e. Prokon Structural Analysis)	
Design entire structure as a complete model (i.e. Prokon Frame Analysis)	
Design using Building Information Modelling (BIM) software (i.e. Autodesk Revit)	
Other (please provide details)	

b) What method do you use to produce drawings, details and sections?

<u>Method of design</u>	<u>Select most used method</u>
Drawings, details and sections individually drafted using CAD (i.e. AutoCAD).	
Creation of a 3D BIM model from which 2D drawings, details and sections are automatically generated (i.e. Autodesk Revit).	
Other (please provide details)	

c) What method do you use to produce bending schedules?

<u>Method of design</u>	<u>Select most used method</u>
Manual calculation of bending schedules followed by drafting onto drawings using CAD software (i.e. AutoCAD).	
Generation of bending schedules using software (i.e. AutoPadds)	
Generation of bending schedules using BIM software (i.e. Autodesk Revit)	
Other (please provide details)	

d) What method do you use to produce a Bill of Quantities (BOQ) for a structural design?

<u>Method of design</u>	<u>Select most used method</u>
Calculation by hand and manual input of data into an excel BOQ.	
Generate BOQ automatically using BIM software.	
Other (please provide details)	

e) What form of visualisation do you work with while designing?

2D CAD drawings	3D BIM model

f) With reference to your current methods of design stated above, which statement below best applies to the process of updating bending schedules, drawings, details, sections and the BOQ due to design changes?

Method of design	Select most appropriate
Slow time consuming process	
Moderate time consuming process	
Relatively quick process	
Quick process, immediately updated using BIM software	

3.) Main Question 2 - What is the current state of BIM implementation and what are the barriers hindering BIM implementation in the EC?

a) Are you familiar with the concept of BIM?

Yes	No

b) Are you aware of the benefits associate with BIM?

Unaware	General idea	Aware	Fully aware

c) Do you have access to BIM software within your organisation? (i.e. Autodesk Revit)

Yes	No	Unsure

d) If yes to the previous question, what BIM software is available in your organisation? (i.e. Autodesk Revit)

e) Have you used BIM for a structural engineering design in the EC?

Yes	No

f) Do clients generally require you to use BIM technology on their projects in the EC?

Yes	No	Unsure

g) Are you aware and/or worked on a project in the EC where the client required the usage of BIM technology?

Yes	No	Unsure

h) Do regulations and legislation require you to use BIM software on certain projects?

Yes	No	Unsure

i) Why have you not used BIM and/or do not use BIM instead of other methods?

Reason	Select most appropriate
No access to BIM software	
No training in BIM software and unsure how to use the software	
Deadlines do not allow time to learn/practice BIM software	
Content with current methods of working	
Other (please provide details)	

j) What do you think are the barriers hindering BIM implementation in the EC? (rank according to significance (1 to 5) where; **1 = Most Significant** and **5 = Least Significant**)

Reason	Rank 1 to 5
Human Factors (reluctance to change from traditional methods of design)	
Software Factors (sluggish software with larger 3D BIM models)	
Legal Concerns (intellectual property copyright concerns with sharing BIM models)	
Lack of BIM expertise (training and time required to learn BIM)	
Cost of BIM implementation (software, licences and training costs)	
Other (please provide details)	

k) Would you like to learn how to design using BIM technology and be willing to take the time to learn?

Yes and willing to sacrifice time to learn BIM technology	Only if BIM technology becomes mandatory in my organisation

4.) General

a) What drafting software is most used in your organisation? (i.e. AutoCAD)

b) What structural design software is most used in your organisation? (i.e. Prokon)

Thank you for taking the time out of your day to provide your valuable input into my research. Your participation is greatly appreciated.

Yours sincerely

Mr DJ Hiscock

APPENDIX D

Case Study Interview Covering Letter

DUT DURBAN
UNIVERSITY OF
TECHNOLOGY

8 May 2017

Durban University of Technology
Faculty of Engineering and the Built Environment
Pietermaritzburg Campus
Institutional Research Ethics Committee

Dear Sir/Madam

Case Study Interview Covering Letter:

I, David Jason Hiscock, am a post-graduate student studying towards my Master of Engineering Degree at the Durban University of Technology.

I am conducting research on Building Information Modelling (BIM) in the field of Structural Engineering. My research aims to investigate if and how BIM implementation will improve the efficiency of the Structural Engineering design process in the Eastern Cape.

I have selected you due to your involvement on the ELIDZ Yekani project to participate in answering a few questions which will greatly assist with my research. The interview should take no longer than 15 minutes of your time.

Please note that the answers which you provide shall remain anonymous and will be used for academic research purposes only.

I would like to thank you in advance for taking time out of your day to provide your valuable input into my research. Your participation is greatly appreciated.

If you have any questions after the interview, please do not hesitate to contact me via email at: Dave.Hiscock@aurecongroup.com or call: 082 573 8058.

Yours sincerely

Mr DJ Hiscock (M.Eng Candidate)

APPENDIX E

Case Study Interview Guide

DURBAN UNIVERSITY OF TECHNOLOGY

CASE STUDY INTERVIEW GUIDE

This interview is focused on determining the Architects and Structural Engineers experience using BIM technology (Autodesk Revit) on the project.

1.) Visualisation

a) The use of Autodesk Revit improved visualisation aspects on this project.

Visualisation Aspects Include:
- Improved 3D visualisation
- Improved presentation of designs to clients
- Easier to visualise integrated connections and complex sections
- Visual representation of design clashes

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
Comments:				

2.) Simulation

a) The use of Autodesk Revit improved simulation aspects on this project.

Simulation Includes:
- Clash detection between architect and structural engineer simulation
- Structural design simulation

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
Comments:				

3.) Collaboration

a) The use of Autodesk Revit improved collaboration between the Architect and Structural Engineer on this project.

Collaboration Includes:

- Improved information sharing
- Improved design co-ordination

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
Comments:				

4.) Documentation

a) The use of Autodesk Revit made the production of documentation easier on this project.

Documentation Includes:

- Automatic generation of documentation:
  - 2D drawings
  - Specifications
  - Schedules
  - Production details
- Improved accuracy of documentation
- Documentation is automatically updated as the design is updated and/or adjusted

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
Comments:				

5.) Productivity

a) The use of Autodesk Revit improved productivity on this project.

Productivity Includes:

- Increased speed of designs
- Reduction in time for checking for design clashes
- Less time required for collaboration
- Less time required for the production of documentation
- The financial feasibility of a design is assessed in less time

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
Comments:				

6.) Disadvantages / drawbacks

a) Comment on any disadvantages / drawbacks encountered using Autodesk Revit on this project.

Disadvantage may include:

- Human Factor: prefer traditional methods
- Software: programme is sluggish with large models
- Legal aspects: copyright of work
- Lack of BIM expertise: slow due to inexperience on programme etc.
- Costs: expense of software

Comments:

Thank you for taking the time out of your day to provide your valuable input into my research. Your participation is greatly appreciated.

Yours sincerely

Mr DJ Hiscock

APPENDIX F

Ethical Checklist

Section C: Ethics
Note: Ethics requirements are faculty specific. Kindly ensure that you are aware of and have complied with the relevant ethics requirements.

Tick as appropriate:

Humans		**Organisations**		**Animals**		**Environment**	
[✓ **Yes**]	**No**	[✓ **Yes**]	**No**	**Yes**	**No**	**Yes**	**No**

Indicate Category (X)

1.	**Exempt from Ethics and Biosafety Research Committee Review (straightforward research without ethical problems)**	
2.	**Expedited review (minimal risk to humans, animals or environment)**	X
3.	**Full Ethics and Biosafety Research Committee review recommended (possible risk to humans, animals, environment, or a sensitive research area)**	

Attach Addendums (if any)

Please initial alongside if the project is to be registered as secret	

ETHICAL ISSUES CHECKLIST FOR RESEARCH APPROVAL

To be completed by all people wishing to conduct research under the auspices of Durban University of Technology.

1. Use the Durban University of Technology's Research Ethics Policy and Guidelines to ensure that ethical issues have been identified and addressed in the most appropriate manner, before finalising and submitting your research proposal.

2. Please indicate [by an X as appropriate] which of the following ethical issues could impact on your research.

3. Please type the motivations/further explanations where required in the cell headed COMMENTS.

4. The highlighted response cells indicate those responses which are of particular interest to the Ethics Committee

NO.	**QUESTION**	**YES**	**NO**	**N/A**
	DECEPTION			
1.	Is deception of any kind to be used? If so provide a motivation for acceptability.		X	
	COMMENTS:			

NO.	QUESTION	YES	NO	N/A
2.	Will the research involve the use of no-treatment or placebo control conditions? If yes, explain how the participant's' interests will be protected.		X	
	COMMENTS			
	CONFIDENTIALITY			
3.	Does the data collection process involve access to confidential personal data (including access to data for purposes other than this particular research project) without prior consent of participants? If yes, motivate the necessity.		X	
	COMMENTS			
4.	Will the data be collected and disseminated in a manner that will ensure confidentiality of the data and the identity of the participants? Explain your answer	X		
	COMMENTS	Names of participants and organisations will not be provided		
5.	Will the materials obtained be stored and ultimately disposed of in a manner that will ensure confidentiality of the participants? If no, explain. If yes specify how long the confidential data will be retained after the study and how it will be disposed of.	x		
	COMMENTS	6 months hard copy then shredded, soft copies will be deleted		
6.	Will the research involve access to data banks that are subject to privacy legislation? If yes, specify and explain the necessity.		X	
	COMMENTS			
	RECRUITMENT			
7	Does recruitment involve direct personal approach from the researchers to the potential participants? Explain the recruitment process	X		
	COMMENTS	Email, face to face and telephone calls		
8	Are participants linked to the researcher in a particular relationship, for example employees, students, family? If yes, specify how.	X		
	COMMENTS	Professional colleagues		

9	If yes to 8, is there any pressure from researchers or others that might influence the potential participants to enrol? Elaborate.		X	
	COMMENTS			
10	Does recruitment involve the circulation/publication of an advertisement, circular, letter etc.? Specify		X	
	COMMENTS			
11	Will participants receive any financial or other benefits as a result of participation? If yes, explain the nature of the reward, and safeguards		X	
	COMMENTS			
12	Is the research targeting any particular ethnic or community group? If yes, motivate why it is necessary/acceptable. If you have not consulted a representative of this group, give a reason. In addition explain any consultative processes, identifying participants. Should consultation not take place, give a motivation.		X	
	COMMENTS			
	INFORMED CONSENT			
13	Does the research fulfil the criteria for informed consent? [See guidelines]. If yes, no further answer is needed. If no, please specify how and why.	X		
	COMMENTS			
14	Does consent need to be obtained from special and vulnerable groups (see guidelines). If yes, describe the nature of the group and the procedures used to obtain permission.		X	
	COMMENTS			
15	Will a Letter of Information be provided to the participants and written consent be obtained? If no, explain. If yes, attach copies to proposal. In the case of participants who are not familiar with English (e.g. it is a second language), explain what arrangements will be made to ensure comprehension of the Letter of Information, Informed Consent Form and other questionnaires/documents.	X		
	COMMENTS			
16	Will results of the study be made available to those interested? If no, explain why. If yes, explain how	X		
	COMMENTS	Available from DUT open scholar		

	RISKS TO PARTICIPANTS			
17	Will participants be asked to perform any acts or make statements which might be expected to cause discomfort, compromise them, diminish self esteem or cause them to experience embarrassment or regret? If yes, explain.		X	
	COMMENTS			
18	Might any aspect of your study reasonably be expected to place the participant at risk of criminal or civil liability? If yes, explain.		X	
	COMMENTS			
19	Might any aspect of your study reasonably be expected to place the participant at risk of damage to their financial standing or social standing or employability? If yes, explain.		X	
	COMMENTS			
20	Does the protocol require any physically invasive, or potentially harmful procedures [e.g. drug administration, needle insertion, rectal probe, pharyngeal foreign body, electrical or electromagnetic stimulation, etc.?] If yes, please outline below the procedures and what safety precautions will be used.		X	
	COMMENTS			
21	Will any treatment be used with potentially unpleasant or harmful side effects? If yes, explain the nature of the side-effects and how they will be minimised.		X	
	COMMENTS			
22	Does the research involve any questions, stimuli, tasks, investigations or procedures which may be experienced by participants as stressful, anxiety producing, noxious, aversive or unpleasant during or after the research procedures? If yes, explain.		X	
	COMMENTS			
23	Will any samples of body fluid or body tissues be required specifically for the research which would not be required in the case of ordinary treatment? If yes, explain and list such procedures and techniques.		X	
	COMMENTS			
24	Are any drugs/devices to be administered? If yes, list any drugs/devices to be used and their approved status.		X	
	COMMENTS			

	GENETIC CONSIDERATIONS			
25	Will participants be fingerprinted or DNA "fingerprinted"? If yes, motivate why necessary and state how such is to be managed and controlled.		X	
	COMMENTS			
26	Does the project involve genetic research e.g. somatic cell gene therapy, DNA techniques etc.? If yes, list the procedures involved		X	
	COMMENTS			
	BENEFITS			
27	Is this research expected to benefit the participants directly or indirectly? Explain any such benefits.		X	
	COMMENTS			
28	Does the researcher expect to obtain any direct or indirect financial or other benefits (not including a qualification) from conducting the research? If yes, explain.	X		
	COMMENTS	Experience and knowledge of BIM software		
	SPONSORS: INTERESTS AND INDEMNITY			
29	Will this research be undertaken on the behalf of or at the request of a pharmaceutical company, or other commercial entity or any other sponsor? If yes, identify the entity.		X	
	COMMENTS			
30	If yes to 29, will that entity undertake in writing to abide by Durban University of Technology's Research Committees Research Ethics Policy and Guidelines? If yes, do not explain further. If no, explain.			X
	COMMENTS			
31	If yes to 30, will that entity undertake in writing to indemnify the institution and the researchers? If yes, do not explain further. If no, explain.			X
	COMMENTS			
32	Does permission need to be obtained in terms of the location of the study? If yes, indicate how permission is to be obtained.		X	
	COMMENTS			
33	Does the researcher have indemnity cover relating to research activities? If yes, specify. If no, explain why not.		X	
	COMMENTS	Not required for the nature of this study		

34	Does the researcher have any affiliation with, or financial involvement in, any organisation or entity with direct or indirect interests in the subject matter or materials of this research? If yes, specify.	X		
	COMMENTS	Employee of an organisation considering implementation of BIM		

N.B. For ethical clearance for categories 2 and 3, kindly refer to the IREC web page: http://www.dut.ac.za/research/institutional_research_ethics.

Declarations

Student Declaration

I, the undersigned, certify that:

- I am familiar with the rules regulating higher qualifications at Durban University of Technology, and understand the seriousness with which DUT will deal with violations of ethical practice in my research.
- Where I have used the work of others this has been correctly referenced in the proposal and again referenced in the bibliography. Any research of a similar nature that has been used in the development of my research project is also referenced.
- This project has not been submitted to any other educational institution for the purpose of a qualification.
- All subsidy-earning outputs (artefacts and publications) from postgraduate studies will be in accordance with the Intellectual Property Policy of the Durban University of Technology.
- Where patents are developed under the supervision of the Durban University of Technology involving institutional expenditure, such patents will be regarded as joint property entitling the Durban University of Technology to its share, subject to the Durban University of Technology's policy on the Management and Commercialisation of Intellectual Property.
- I understand that I am expected to publish an article based on my research results.
- I understand that plagiarism is wrong, and incurs severe penalties.

I HEREBY DECLARE THAT THE ABOVE FACTS ARE CORRECT.

Signed: ______ Date: 10/01/2017
(Student)

APPENDIX G

Cronbach Alpha Calculation

Cronbach's Alpha

Participant	Q1	Q2	Q3	Q4	Q5	Total
1	5	4	4	4	4	21
2	5	4	4	4	4	21
3	5	4	5	5	4	23
4	5	4	5	5	5	24
5	5	5	5	5	5	25
6	5	5	5	5	5	25
Total	30	26	28	28	27	139
Var	0.000	0.222	0.222	0.222	0.250	0.917

k	5
Sum of Var	0.917
Var	2.806
Conbach's Alpha	**0.842**

Cronbach's Alpha	Consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Therefore, the consistency of the data collected is "**good**".

APPENDIX H

Questionnaire Results (Raw Data)

QUESTIONNAIRE RESULTS

1.) Brief Overview of Questionnaire Participants

a) Which are category do you fall into?

20-29 Years	30-39 Years	40-49 Years	50-59 Years	60+ Years
6	9	6	3	1
24%	36%	24%	12%	4%

b) What is your highest level of education?

Diploma	Degree	Masters	Doctorate
5	15	4	1
20%	60%	16%	4%

c) Which town do you wok in within the EC

East London	Port Elizabeth	Other
12	11	2
48%	44%	8%

d) How many years have you been working within the EC?

0-4 Years	5-9 Years	10-14 Years	15-19 Years	20+ Years
4	8	6	2	5
16%	32%	24%	8%	20%

2.) Main Question 1 - What are the current structural engineering design methods being used in the EC?

a) What structural deign methods do you mostly use in you organisation?

i	ii	iii	iv
2	15	7	1
8%	60%	28%	4%

b) What method do you use to produce drawings, details and sections?

Drawings, details, and sections individually drafted using CAD	Creation of a 3D BIM mode from which 2D drawings, details, and sections are automatically generated
22	3
88%	12%

c) What method do you use to produce schedules?

Manual calculation of bending schedules followed by drafting onto drawings using CAD software	Generation of bending schedules using software	Generation of bending schedules using BIM software
11	13	1
44%	52%	4%

d) What method do you use to produce a Bill of Quantities (BOQ) for a structural design?

Calculation by hand and manual input of data into an excel BOQ	Generate BOQ automatically using BIM software	Other
20	3	2
87%	13%	9%

- Mainly QS (x2)

e) What form of visualisation do you work with while designing?

2D CAD drawing	3D BIM model
21	4
84%	16%

f) With reference to your current methods of design stated above, which statement below best applies to the process of updating bending schedules, details, sections and the BOQ due to design changes?

Slow time consuming process	Moderate time consuming process	Relatively quick process	Quick process, immediately updated using BIM
7	11	5	2
28%	44%	20%	8%

- quick noted by BIM users

3.) Main Question 2 - What is the current state of BIM implementation and what are the barriers hindering BIM implementation in the EC?

a) Are you familiar with the concept of BIM?

Yes	No
23	2
92%	8%

b) Are you aware of the benefits associated with BIM?

Unaware	General Idea	Aware	Fully Aware
3	9	7	6
12%	36%	28%	24%

c) Do you have access to BIM software within your organisation?

Yes	No	Unsure
16	6	3
64%	24%	12%

d) If yes to the previous question, what BIM software is available in your organisation?

Revit	Sumo	Microstation	None	Unsure
13	2	1	6	3
52%	8%	4%	24%	12%

e) Have you used BIM for a structural engineering design in the EC?

Yes	No
8	17
32%	68%

f) Do clients generally require you to use BIM technology on their projects in the EC?

Yes	No	Unsure
1	22	2
4%	88%	8%

g) Are you aware and/or worked on a project in the EC where the client required the usage of BIM technolog

Yes	No	Unsure
10	14	1
40%	56%	4%

h) Do regulations and legislation require you to use BIM software on certain projects?

Yes	No	Unsure
0	20	5
0%	80%	20%

i) Why have you not used and/or do not use BIM instead of other methods?

No access to BIM software	No training in BIM software and unsure to use the software	Deadlines do not allow time to learn/practice BIM software	Content with current methods of working	Already using BIM
5	8	5	3	4
20%	32%	20%	12%	16%

- *"I always use BIM when possible, whether it's a requirement or not".*
- *"lack of support/drive from management".*
- *"the use of BIM is project intricacy of structure, architect and client dependant".*

j) What do you think are the barriers hindering BIM implementation in the EC? (rank according to significance (1 to 5), where **1 = Most Significant** and **5 = Least Significant**)

i	ii	iii	iv	v
55	92	114	49	65
2	4	5	1	3

<u>3j) - Calculation</u>

Participant	i	ii	iii	iv	v
1	1	4	5	2	3
2	2	4	5	1	3
3	3	2	4	1	5
4	1	4	5	3	2
5	1	4	5	2	3
6	2	4	5	1	3
7	3	1	4	2	5
8	4	3	5	1	2
9	1	5	4	2	3
10	3	4	5	1	2
11	3	4	1	5	2
12	2	3	5	4	1
13	3	4	5	1	2
14	4	3	5	1	2
15	3	5	4	2	1
16	3	4	5	1	2
17	3	4	5	2	1
18	3	4	5	2	1
19	2	4	5	1	3
20	1	5	4	2	3
21	1	5	4	2	3
22	2	3	4	1	5
23	2	1	5	4	3
24	1	4	5	3	2
25	1	4	5	2	3
***Total**	**55**	**92**	**114**	**49**	**65**

* Lowest Total = Most Significant
Highest Total = Least Significant

- Poor marketing of programmes and what they can do.

Category	1 (Most Significant)	2	3	4	5 (Least Significant)
Human Factors	8	6	9	2	0
Software Factors	2	1	4	14	4
Legal Concerns	1	0	0	7	17
Lack of BIM Expe	10	10	2	2	1
Cost of BIM Imple	4	8	10	0	3

k) Would you like to learn how to design using BIM technology and be willing to take the time to learn?

Yes and willing to sacrifice time to learn BIM technology	Only if BIM technology becomes mandatory in my organisation	Using BIM
21	2	2
91%	9%	8%

4.) General

a) What drafting software is most used in your organisation?

AutoCAD	Revit	AllyCAD	TechnoCAD	Microstation	BricsCAD
17	3	1	1	1	2
68%	12%	4%	4%	4%	8%

b) What structural design software is most used in your organisation?

Prokon	Revit	Qasys
22	2	1
88%	8%	4%

Questionnaire response rate

Response Received	No Response
25	9

APPENDIX I

Interview Results (Raw Data)

CASE STUDY INTERVIEW RESULTS

1. Visualisation

a) The use of Autodesk Revit improved visualisation aspects on this project.

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
0	0	0	0	6
0%	0%	0%	0%	100%

Comments:

3D model aided in visualising the final building	Improved presentation to clients, and other design team members	3D model aided in understanding the complex design components	Improved visualisation of design clashes	Easier to explain problem areas through 3D visualisation
3	4	5	4	2
17%	22%	28%	22%	11%

2. Simulation

a) The use of Autodesk Revit improved simulation aspects on this project.

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
0	0	0	4	2
0%	0%	0%	67%	33%

Comments:

Faster clash detection	Easier to identify high priority and problem areas	Visual understanding of forces acting on the structure
6	4	1
55%	36%	9%

3. Collaboration

a) The use of Autodesk Revit improved collaboration between the Architect and Structural Engineer on this project.

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
0	0	0	2	4
0%	0%	0%	33%	67%

Comments:

Improved sharing of design information	Easier to identify clashes between designers	Easier to communicate problem areas	Reduced time required for collaboration between architect and structural engineer	Information can be exported to multiple formats (DWG,DXF,PDF , etc) which aids collaboration
4	5	3	3	1
25%	31%	19%	19%	6%

4. Documentation

a) The use of Autodesk Revit made the production of documentation easier on this project

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
0	0	0	2	4
0%	0%	0%	33%	67%

Comments:

Faster and easier to produce details, schedules, and specifications	Improved accuracy of documentation	Automatic update of documents as model is update	Reduced time required for checking documentation
3	4	3	2
25%	33%	25%	17%

5. Productivity

a) The use of Autodesk Revit improved productivity on this project.

Strongly Disagree	Disagree	Unsure	Agree	Strongly Agree
0	0	0	3	3
0%	0%	0%	50%	50%

Comments:

Increased speed of producing designs	Reduced time to check clashes between designers	Collaboration is streamlined	Reduced time required to produce documentation	Changes are picked up by Revit and all documentation is automatically updated
2	4	3	5	4
11%	22%	17%	28%	22%

6. Disadvantages/drawbacks

a) Disadvantages/drawbacks encountered using Autodesk Revit on this project.

BIM software used was costly	Could not use BIM to full potential due to lack of expertise	Challenging to use without formal training	It takes time to set up the initial model in Revit	Combined model is too large to send via normal communication paths (email).
2	4	3	4	1
14%	29%	21%	29%	7%

APPENDIX J

Illustrative Case Study Images

10. Illustrative Case Study Images

The figure below, graphically illustrates the 3D model of the entrance structure designed for the project. The use of the 3D model aided the structural engineers to clearly understand what the client and architect envisioned and, therefore, were able to design accordingly.

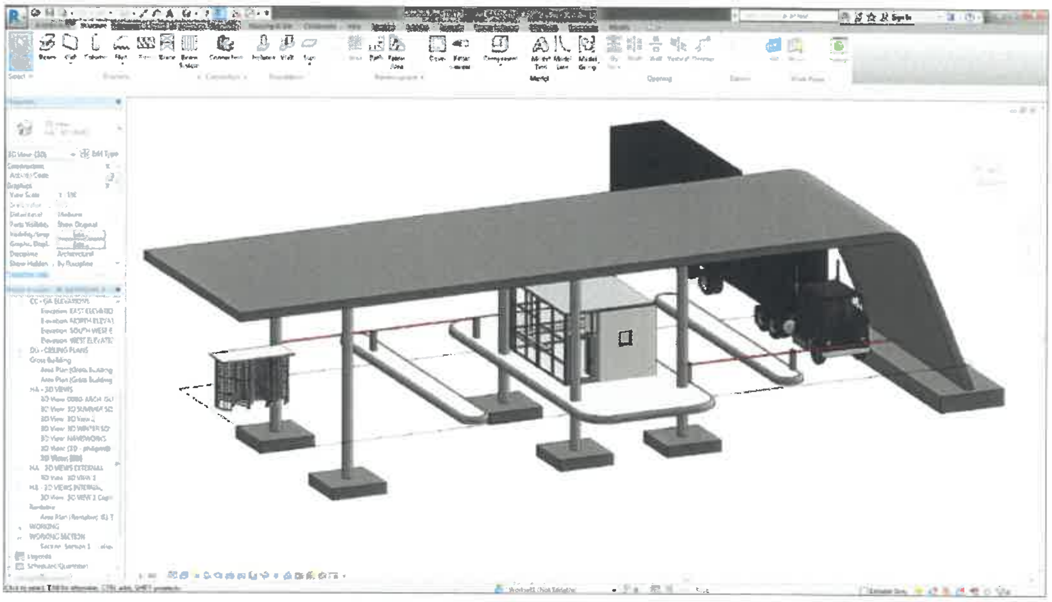
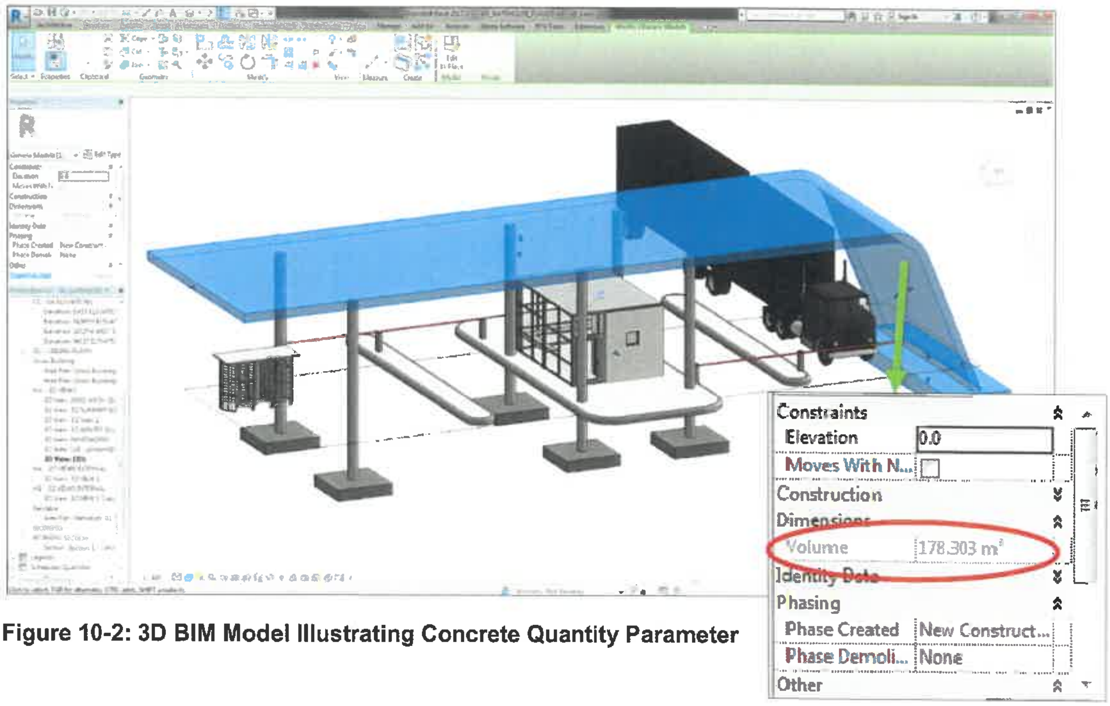


Figure 10-1: 3D BIM Model of Entrance Structure

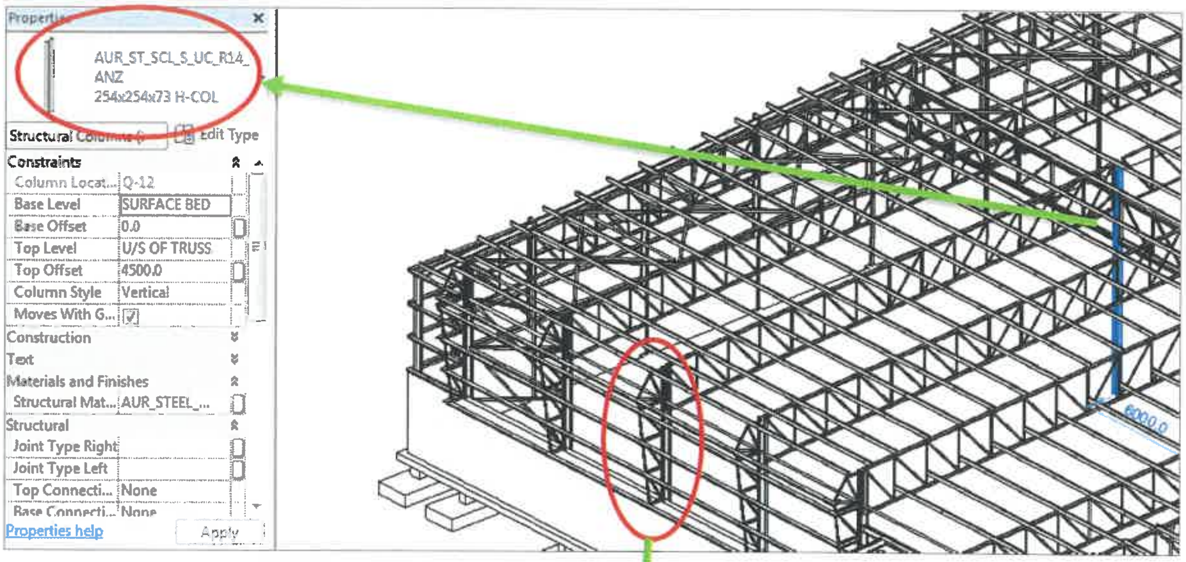
The figure below, graphically illustrates the ease of generating quantities of complex shapes from a 3D BIM model.



Constraints
Elevation 0.0
Moves With N... ☐
Construction
Dimensions
Volume 178.303 m³
Identity Data
Phasing
Phase Created New Construct...
Phase Demoli... None
Other

Figure 10-2: 3D BIM Model Illustrating Concrete Quantity Parameter

The figures below, graphically illustrates the advantages of investigating the properties of an isolated column, and the ease of generating sections/details from a 3D BIM model.



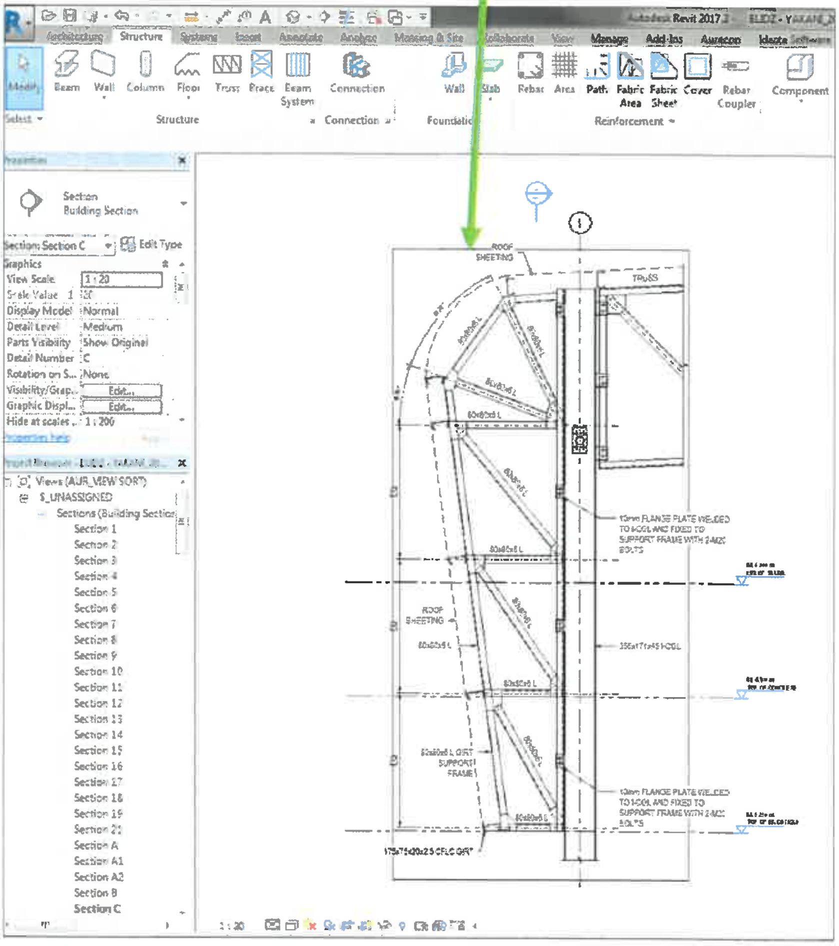
Properties

AUR_ST_SCL_S_UC_R14_ANZ
254x254x73 H-COL

Structural Columns (1) — Edit Type

Constraints
Column Locat... Q-12
Base Level SURFACE BED
Base Offset 0.0
Top Level U/S OF TRUSS
Top Offset 4500.0
Column Style Vertical
Moves With G... ☑
Construction
Text
Materials and Finishes
Structural Mat... AUR_STEEL_...
Structural
Joint Type Right
Joint Type Left
Top Connecti... None
Base Connecti... None
Properties help — Apply

Figure 10-3: 3D BIM Model of the Structural Steel Design



Properties

Section
Building Section

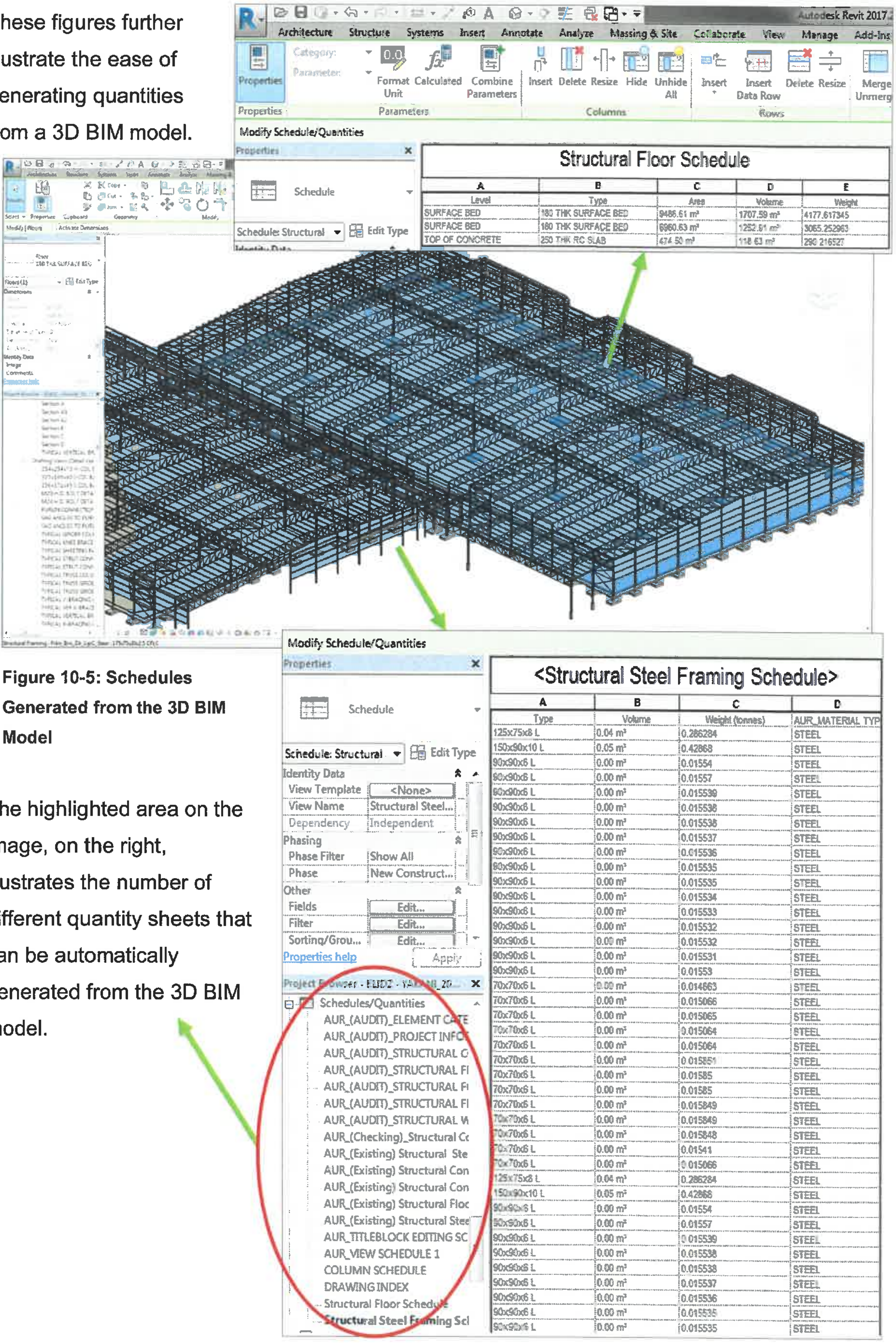
Section: Section C — Edit Type

Graphics
View Scale 1 : 20
Scale Value 1 20
Display Model Normal
Detail Level Medium
Parts Visibility Show Original
Detail Number C
Rotation on S... None
Visibility/Grap... Edit...
Graphic Displ... Edit...
Hide at scales ... 1 : 200
Properties help

Project Browser
Views (AUR_VIEW SORT)
$_UNASSIGNED
Sections (Building Section)
Section 1
Section 2
Section 3
Section 4
Section 5
Section 6
Section 7
Section 8
Section 9
Section 10
Section 11
Section 12
Section 13
Section 14
Section 15
Section 16
Section 17
Section 18
Section 19
Section 20
Section A
Section A1
Section A2
Section B
Section C

Figure 10-4: Section Generated from the 3D BIM Model

These figures further illustrate the ease of generating quantities from a 3D BIM model.



Schedule: Structural Steel

Identity Data
View Template: <None>
View Name: Structural Steel...
Dependency: Independent

Phasing
Phase Filter: Show All
Phase: New Construct...

Other
Fields: Edit...
Filter: Edit...
Sorting/Grou...: Edit...

Structural Floor Schedule

A	B	C	D	E
Level	Type	Area	Volume	Weight
SURFACE BED	180 THK SURFACE BED	9486.61 m²	1707.59 m³	4177.617345
SURFACE BED	180 THK SURFACE BED	6960.63 m²	1252.91 m³	3065.252963
TOP OF CONCRETE	250 THK RC SLAB	474.50 m²	118.63 m³	290.216527

<Structural Steel Framing Schedule>

A	B	C	D
Type	Volume	Weight (tonnes)	AUR_MATERIAL TYP
125x75x8 L	0.04 m³	0.286284	STEEL
150x90x10 L	0.05 m³	0.42868	STEEL
90x90x6 L	0.00 m³	0.01554	STEEL
90x90x6 L	0.00 m³	0.01557	STEEL
90x90x6 L	0.00 m³	0.015539	STEEL
90x90x6 L	0.00 m³	0.015538	STEEL
90x90x6 L	0.00 m³	0.015538	STEEL
90x90x6 L	0.00 m³	0.015537	STEEL
90x90x6 L	0.00 m³	0.015536	STEEL
90x90x6 L	0.00 m³	0.015535	STEEL
90x90x6 L	0.00 m³	0.015535	STEEL
90x90x6 L	0.00 m³	0.015534	STEEL
90x90x6 L	0.00 m³	0.015533	STEEL
90x90x6 L	0.00 m³	0.015532	STEEL
90x90x6 L	0.00 m³	0.015532	STEEL
90x90x6 L	0.00 m³	0.015531	STEEL
90x90x6 L	0.00 m³	0.01553	STEEL
70x70x6 L	0.00 m³	0.014663	STEEL
70x70x6 L	0.00 m³	0.015066	STEEL
70x70x6 L	0.00 m³	0.015065	STEEL
70x70x6 L	0.00 m³	0.015064	STEEL
70x70x6 L	0.00 m³	0.015064	STEEL
70x70x6 L	0.00 m³	0.015851	STEEL
70x70x6 L	0.00 m³	0.01585	STEEL
70x70x6 L	0.00 m³	0.01585	STEEL
70x70x6 L	0.00 m³	0.015849	STEEL
70x70x6 L	0.00 m³	0.015849	STEEL
70x70x6 L	0.00 m³	0.015848	STEEL
70x70x6 L	0.00 m³	0.01541	STEEL
70x70x6 L	0.00 m³	0.015066	STEEL
125x75x8 L	0.04 m³	0.286284	STEEL
150x90x10 L	0.05 m³	0.42868	STEEL
90x90x6 L	0.00 m³	0.01554	STEEL
90x90x6 L	0.00 m³	0.01557	STEEL
90x90x6 L	0.00 m³	0.015539	STEEL
90x90x6 L	0.00 m³	0.015538	STEEL
90x90x6 L	0.00 m³	0.015538	STEEL
90x90x6 L	0.00 m³	0.015537	STEEL
90x90x6 L	0.00 m³	0.015536	STEEL
90x90x6 L	0.00 m³	0.015535	STEEL
90x90x6 L	0.00 m³	0.015535	STEEL

Figure 10-5: Schedules Generated from the 3D BIM Model

The highlighted area on the image, on the right, illustrates the number of different quantity sheets that can be automatically generated from the 3D BIM model.

The figures below, provide 3D images of reinforcing within a concrete beam, base, and stub columns. The 3D models could be rotated, and zoomed, which provided the structural engineers an improved understanding of the reinforcing, while they were designing.

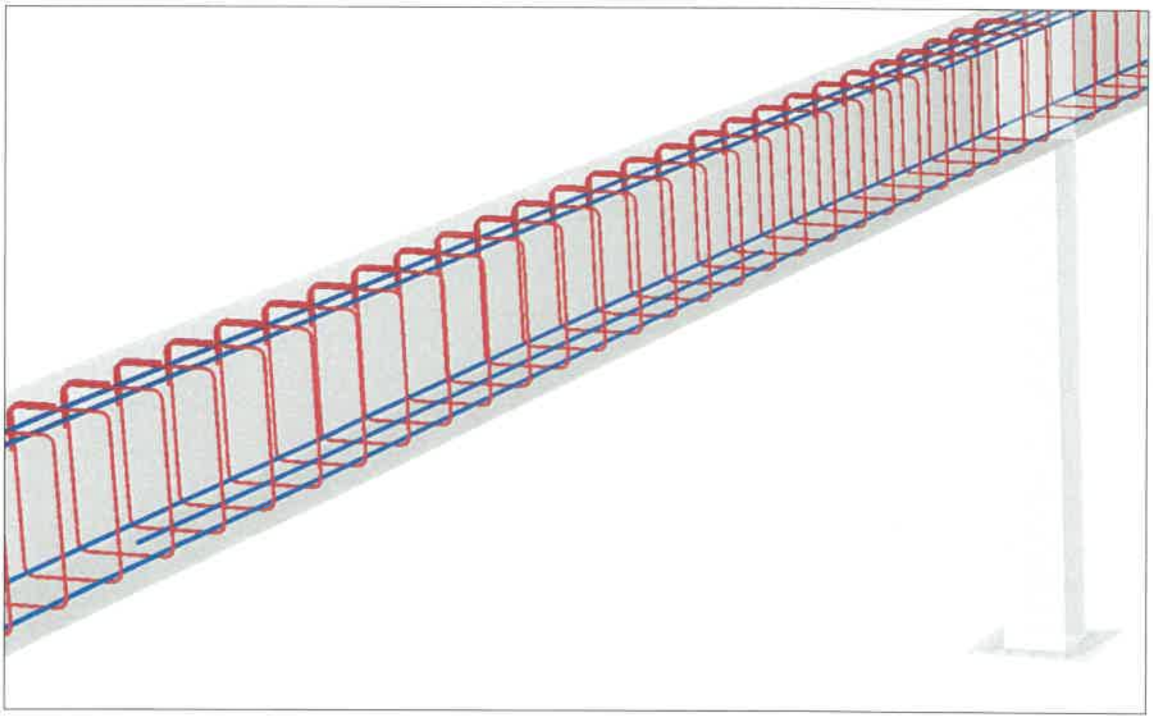


Figure 10-6: 3D Model of a Reinforced Concrete Beam

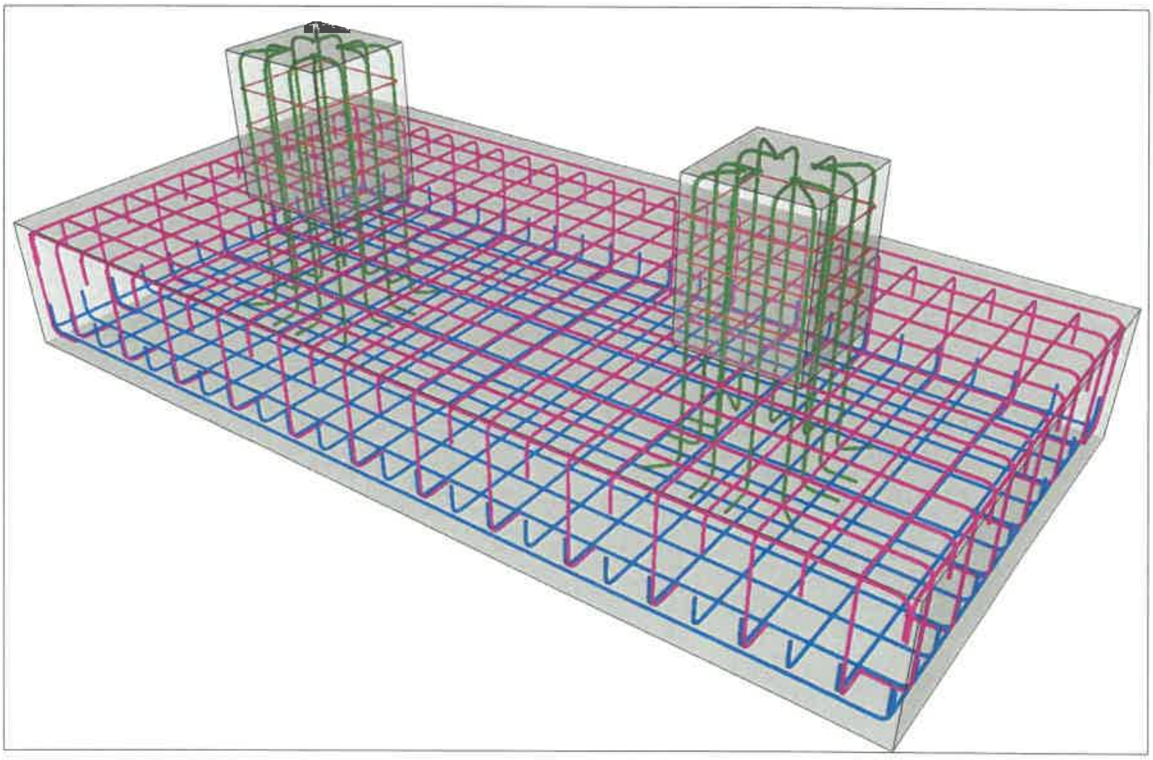
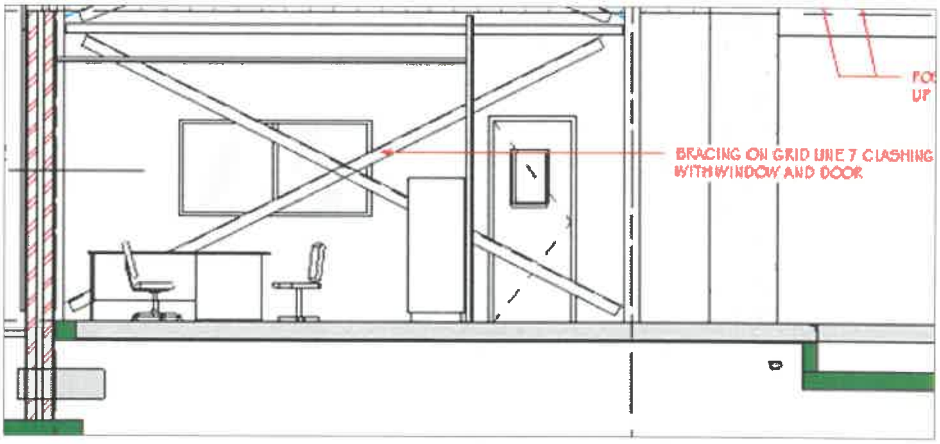


Figure 10-7: 3D Model of a Reinforced Concrete Base and Stub Columns

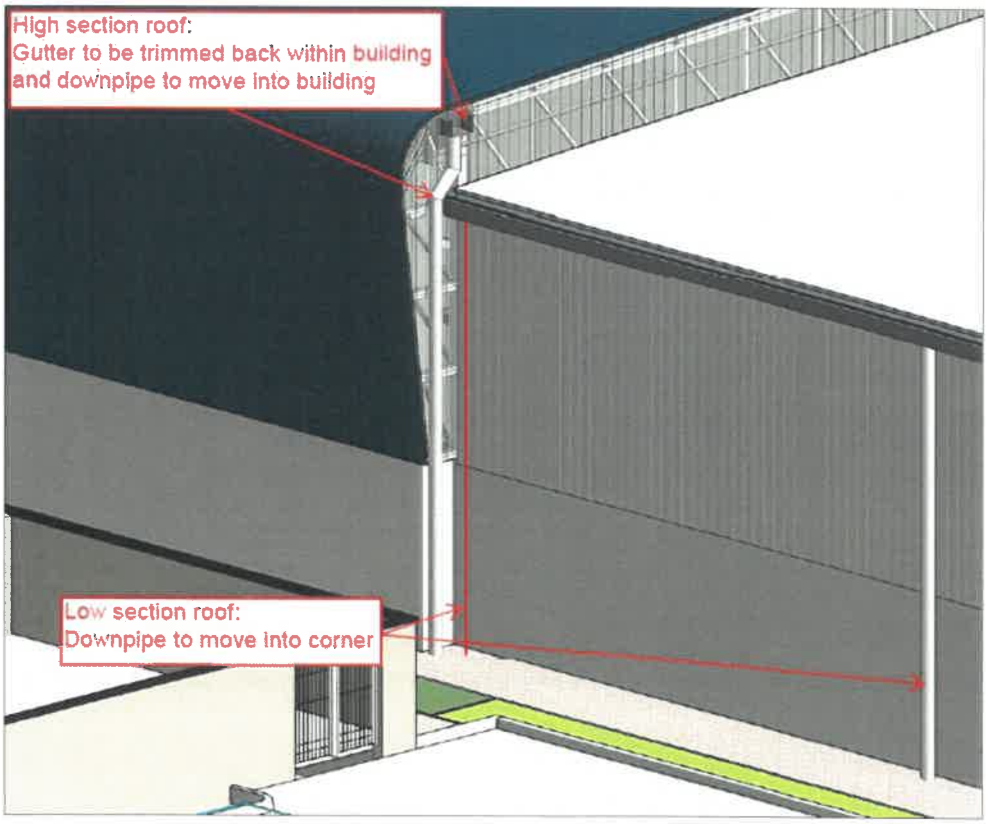
The implementation of BIM by the architects and structural engineers, on the project, improved collaboration of designs. The figure below, illustrates where bracing clashed with a window, and door, in the manufacturing building. The early identification of this clash reduced costly on-site adjustments.



BRACING ON GRID LINE 7 CLASHING WITH WINDOW AND DOOR

Figure 10-8: Section generated from the Model Illustrating a Design Clash

The figure below, illustrates how 3D images were used to improve collaboration. This image illustrates the ease of collaboration of designs, and communicating any problems.



High section roof:
Gutter to be trimmed back within building and downpipe to move into building

Low section roof:
Downpipe to move into corner

Figure 10-9: 3D BIM Image Illustrating Collaboration of Designs