An investigation to introduce BIM in undergraduate civil engineering teaching to improve construction processes

by
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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

The popularity of Building Information Modelling (BIM) has grown rapidly within the construction industry, motivated by its potential advantages for improving construction processes. A majority of the world's leading firms have adopted BIM solutions by moving from 2D or even 3D CAD to BIM techniques. However, for companies in South Africa this transition has not been the same as for firms in Europe and the USA.

Besides the improvements which can be achieved by viewing a computer model of the designed facility, BIM provides a multi-disciplinary tool, to be used for collaboration of all project parties in a real-time simulated model of construction process. Due to this remarkable feature, the way of constructing a designed facility can be viewed and analysed from the conceptual stages and can improve design and construction processes.

As this object-oriented approach has been developed in the industry, handbooks and standards have been released to support BIM utilization. A considerable amount of research has been conducted to establish the advantages and barriers in applying BIM. A large number of investigations have also been performed for reporting quantified achievement of construction projects executed in BIM environment.

As such, a new knowledge field has been added to the industry requirements. BIM knowledge has become more demanding and BIM-specialist requirements have been enhanced. As a result, academia have been stimulated to raise BIM awareness among engineers, architects and construction managers to train sufficiently qualified professionals for applying BIM tools. Universities started offering different courses and programmes to fulfil this need while a variety of strategies have been developed for introducing BIM to the students at different levels.

This research studied the current industry situation in South Africa regarding application of BIM and the role of universities to achieve a suitable level of BIM capability. The industrial and educational situations from some pioneering countries are reviewed as lessons for the South African adoption of BIM. Comparing these facts, proposals for introducing BIM through university courses are provided to satisfy industry requirements for the application of BIM in projects.

Opsomming

Die gewildheid van Bou Inligtingsmodelle (Building Information Modelling (BIM)) het vinnig gegroei in die konstruksie bedryf as gevolg van die voordele wat dit vir die verbetering van konstruksieprosesse inhou. ŉ Groot aantal van die wêreld se voorste konstruksie maatskappye het al die oorgang vanaf 2D en selfs 3D RGT (Rekenaar Gesteunde Tekenstelsels) na BIM gemaak. Ongelukkig is hierdie oorgang na BIM metodes nog nie so doeltreffend vir maatskappye in Suid-Afrika soos in die geval van Europese en Amerikaanse maatskappye nie.

Daar is al bewys dat die vermoë om na ŉ rekenaarmodel van ŉ ontwerpte fasiliteit te kan kyk baie voordelig is. Daarbenewens bied BIM ŉ multidissiplinêre grondslag wat vir die samewerking van alle betrokke partye van die projek gebruik kan word en die projek kan simuleer as ŉ funksie van tyd. Hierdie tyd-afhanklike simulasie stel die bestuur in staat om die manier waarop ŉ ontwerpte fasiliteit gebou word, reeds vanaf die konsepsuele fase, te beskou en te ontleed. Hierdie vermoë kan die ontwerp en konstruksieproses asook die fasiliteitsbestuur proses merkwaardig verbeter.

As gevolg van die ontwikkeling van hierdie objek georiënteerde benadering deur die bedryf, is handboeke en standaarde vrygestel om die gebruik van BIM te ondersteun. ‘n Merkwaardige hoeveelheid navorsing is al gedoen om die voordele en struikelblokke in die toepassing van BIM te identifiseer. ‘n Groot aantal ondersoeke is ook al geloots om verslag te doen op die prestasie van konstruksie projekte wat deur middel van BIM uitgevoer was.

Vanuit die bogenoemde ondersoeke en navorsing is 'n nuwe kennisveld gevoeg by die vereistes van die bedryf. Die kennis van BIM het al hoe meer veeleisend geword en die vereistes vir ŉ BIM-spesialis het verhoog. As gevolg hiervan is akademici aangemoedig om ingenieurs, argitekte en konstruksie bestuurders meer bewus te maak van BIM sodat daar genoeg professionele werkers opgelei kan word wat BIM kan implementeer. Universiteite het begin om kursusse en programme aan te bied om hierdie behoefte te bevredig, terwyl 'n verskeidenheid metodes om studente bloot te stel aan BIM op verskillende vlakke ontwikkel is.

In hierdie navorsingsprojek is die huidige stand van Suid-Afrikaanse konstruksiemaatskappye ten opsigte van die toepassing van BIM ondersoek. Daarbenewens is die rol wat universiteite speel om 'n voldoende vlak van BIM vaardigheid te bereik ook ondersoek. Die industriële en opvoedkundige omgewings van 'n paar vooraanstaande lande word gebruik as lesse vir die Suid-Afrikaanse aanvaarding van BIM. Deur hierdie feite te vergelyk, is voorstelle gemaak vir die bekendstelling van BIM in universiteitskursusse om aan industrievereistes te voldoen vir die toepassing van BIM op projekte.

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Glossary of Abbreviations

AEC	Architecture, Engineering and Construction
AGC	Associated General Contractors of America
AIA	American Institute of Architects
AMCA	Australian Air Conditioning and Mechanical Contractors' Association
ASC	Associated Schools of Construction
BIM	Building Information Modelling
BOM	Bill of Material
BOQ	Bill of Quantity
BOT	Build-Operate-Transfer
BSI	British Standards Institution
CAD	Computer Aided Design
CE	civil engineering
CIC	Computer Integrated Construction
CIFE	Centre for Integrated Facilities Engineering
CM	construction engineering and management
CM@R	Construction management at Risk
CO	Change Order
CPD	Continuing Professional Development
CPE	Continuing Professional Education
CPM	Critical Path Method
DB	Design- Build
DBB	Design-Bid-Build
DBOM	Design- Build-Operate-Maintenance
DGR	Digital Graphic Representation
ECSA	Engineering Council of South Africa
ERP	Enterprise Resource Planning
FIC	NIBS Facility Information Council
GMP	Guaranteed Maximum Price

GUI	Graphical User Interface
IAI	Norwegian International Alliance for Interoperability
IFC	Industry Foundation Classes
IP	Intellectual Property
IPD	Integrated Project Delivery
IT	Information Technology
JIA	Japan Institute of Architects
LCA	Life Cycle Analysis
LOD	Level of Development
NBIMS	National Building Information Modelling Standard
NBS	National Building Specification
NCR	Non-Conformance Report
NIBS	National Institute of Building Sciences
NIST	American National Institute of Standards and Technology
PAS	Publicly Available Specification
PI	Professional Indemnity
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
QS	quantity surveyors
RFI	Request for Information
ROI	Return on Investments
SADC	Southern African Development Community
TOP	Take-Over Points
VDC	Virtual Design and Construction

Chapter 1 – Research Overview

1.1 Introduction

This opening chapter provides a background to Building Information Modelling (BIM). A brief description of BIM technology and its rapid growth is provided which leads to the formulation of the research problem statement. The research goals are explained as well as the scope and limitation of the study. The development plan of the research is discussed, followed by a summary of the thesis document. Figure 1.1 shows an outline of the subjects discussed in this chapter.

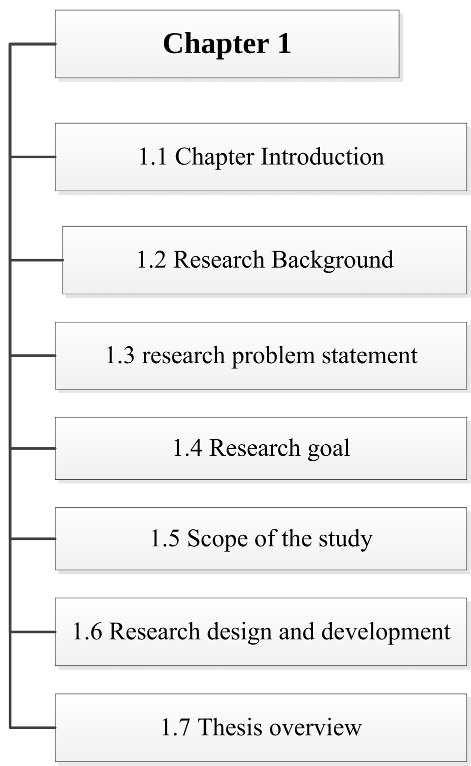

Figure 1.1: Chapter 1 diagram

1.2 Research background

Information sharing plays an important role in a construction process. From the design phase up to the construction and project close out phases, information sharing and management amongst the project participants is crucial. Information on construction projects can be processed and shared either as paper files or as electronic files. Depending on the level of communication, collaboration and interpretation, information on construction projects is always subject to changes, corrections and updates regardless of the project phase or the file format.

Teicholz (2004) found that the productivity of the construction industry has declined during the 45 year period between 1964 and 2009 as depicted in figure 1.2 Teicholz attributed the decline primarily to subdivided responsibilities in the traditional construction contract models of Design-Bid-Build (DBB), lack of sufficient collaboration amongst project team members, lack of top organizational directors' support and the lack of investment in and adoption of new technologies (Eastman, Teicholz, Sacks & Liston, 2011:10).

Figure 1.2: Labour productivity index for US construction industry and all non-farm industries (Teicholz, 2004)

Proper flow of information on a construction project is considered to cut project cost by as much as 25% (Baldwin, Thorpe & Carter, 1999:651). The American National Institute of Standards and Technology (NIST) report shows (GCR, 2004) that inadequate interoperability and poor communication cost the capital facility industry approximately USD 15.8 billion in 2002. Half of this cost (almost USD 9.1 billion) is generated at the operation and maintenance phase of projects and is associated with issues of information exchange and reliability of 'As-Built' data.

In this regard, Information Technology (IT) is growing and developing rapidly and is being applied in different aspects of construction works. It is believed that the use of IT facilitates better management of projects as information is more accurate and reliable when IT tools are applied. Therefore, the project management role and responsibility is affected by development in IT which in turn would influence the practice of construction management (Yalcinkaya & Arditi, 2013:619).

For many years, 2D models and paper-based file formats have been in use. It is however, apparent that paper-based file formats for communication on construction projects has the disadvantage of not being able to apply required changes as soon as they are identified. Also a paper-based file format has not been practical to achieve lower project budgets or to provide reliable 'As-built' drawings and data. The connection between dimensional factors and other information of designed objects is of great interest to project stakeholders. Also the data exchange during the construction and transferring of project information to the facility manager at project closing phase is another demand which needs to be fulfilled. Jung and Gibson (1999:217) state that the foundation for the efficient management of construction projects through centralization of project information was established in the mid -1990s. This was tried by the application of Computer Integrated Construction (CIC) tools for the integration of graphical and informatics data on construction project in the 1990s. However, 2D drawings still used to be the most reliable project documentation tools. Presently, the previous notion of drawings as the main reference for project information is no longer valid as they are just an automated report on design information (Sacks & Barak, 2008:439; Goedert & Meadati, 2008:509; Jung & Joo, 2011:126). As a result, a variety of tools have been applied to facilitate collaboration and communication on construction projects and one of the most recent tools is Building Information Modelling technology.

Woo et.al (2010:538) define BIM as "an intelligent 3D virtual building model that can be constructed digitally by containing all aspects of building information into an intelligent format that can be used to develop optimized building solutions with reduced risk and with increased value before committing to a design proposal". This definition focuses on the design aspect of the construction process.

BIM also has been defined as "the process of creating and using digital models for design, construction and/or operations of projects" (McGraw Hill report, 2009). However, this definition is more from a contractor's prospective and focuses on technical features of BIM as a model and its documentation function (Barlish & Sullivan, 2012:149).

Zuppa et al. (2009:503) - defined BIM as "a tool for visualizing and coordinating Architecture, Engineering and Construction (AEC) work and avoiding errors and omissions". However, this definition does not cover all aspects of this tool.

BuildingSmart Alliance Council of NIBS (National Institute of Building Sciences) defines BIM as "the act of creating an electronic model of a facility for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes" (NIBS, 2007).

Similarly, the National Building Information Modelling Standard (NBIMS) committee of the NIBS Facility Information Council (FIC), defined BIM as "an improved planning, design, construction, operation and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format usable by all throughout its lifecycle." (NIBS, 2008a; Eastman, Teicholz, Sacks & Liston, 2011:16)

Referring to the NBIMS definition which is the preferred definition for the purpose of this study, BIM is a process and may be referred to as an activity (as building information modelling) rather than an object (as building information model) (Eastman, Teicholz, Sacks & Liston, 2011:vii). This activity starts with the very first step of the project and keeps updating while the process of developing the project continues.

Furthermore, it includes all the required information at the heart of facility design, procurement or construction, and is not limited by dimension and size. In other words, it is a giant database where all the initial information and later changes can be stored and accessed.

Additionally, BIM covers the entire lifecycle of the project and is not confined to the design phase where 3D models are often used. These special features of BIM allow it to be applied right from the conceptual phase of a project all through the design, construction and commissioning phases as well as the facility management phase. BIM also provides a web-based multidisciplinary collaborated model which enhances the interoperability and communicating amongst project teams by allowing information to be added on a unique model by all the parties and disciplines involved with the project.

The application of BIM which was previously restricted to its 3D geometric feature is now extended to utilize it as a 5D model adding time and cost as fourth and fifth dimensions. This allows BIM to be an understandable model for all the project participants based on their needs and skill level. BIM is also expanding into other organizational and business purposes (Mahalingam, Kashyap & Mahajan, 2010: 148). For example, project management can derive considerable benefits through utilizing 4D and 5D BIM models which would results in improved project performance (Yalcinkaya & Arditi, 2013:619; Jung & Joo, 2011:126) It is also reported that half of companies who had started using BIM and offered new services to the clients, achieved remarkable benefits in their business (McGraw-Hill Construction, 2009). Thus, BIM is presently helping organizations to extend their businesses by improving their competitive advantage.

1.3 Research problem Statement

During the past seven years, "Building Information Modelling" (BIM) dramatically affected the AEC (Architecture, Engineering and Construction) industry in various aspects, consisting of design, construction and operation (Eastman, Teicholz, Sacks & Liston, 2011). A majority of the world's leading firms could not resist adapting to BIM solutions by getting a well-defined way to move from 2D or even 3D CAD to BIM techniques.

Besides the improvements which can be achieved by the visualization feature that provides a comprehensive concept of design steps, BIM enables a multi-disciplinary model, which is based on collaboration of all project parties in a real-time simulated model. Due to this remarkable feature, the way of constructing a designed facility can be viewed and analysed at the very first stages and therefore it can improve design and construction processes.

To fulfil the requirements of industry, a large number of universities worldwide have already started exposing their students to BIM and made considerable effort to teach construction issues through BIM application. In other words, as a BIM approach is developed in industry, BIM knowledge has become more demanding and BIM specialist requirements have been enhanced; therefore, academia have been stimulated to raise BIM awareness amongst engineers and architects and to train sufficiently qualified graduates for applying BIM tools.

Although adopting BIM technology for companies in South Africa has not been as fast as for firms in Europe and the USA, its utilization is nevertheless influencing the South African industry. To accelerate the BIM adoption amongst the local industry and catching up to the world's fast growth in this regard, qualified specialists and engineers are required who are enabled to make use of the tools and who have obtained fundamental knowledge in this regard. Therefore, South African academia should consider introducing the application of BIM to the students to prepare them for the industry.

1.4 Research goals

The main research aim is to investigate teaching Building Information Modelling to the civil engineering students at undergraduate level to provide them with an understanding of making use of the relevant tools to improve construction processes.

The outcome of the research will contribute to integrate BIM to the undergraduate civil engineering programme while fulfilling the local industry requirements in this regard. The following explicit goals are obtained through this research:

- Understanding the extent to which BIM can improve construction processes, exploring its advantages and the main obstacles while implementing it

- Studying BIM application within industry worldwide as well as teaching strategies in universities around the world
- Investigating the level of awareness in terms of this innovative technology amongst local students
- Investigating the extent to which BIM is used in South African firms and their expectations from graduated students in this regard
- Investigating the possibility of adding BIM concepts to the undergraduate civil engineering curricula from lecturers' prospective
- Considering all abovementioned items, providing conclusions and suggestions on how BIM can be introduced to the students during their undergraduate civil engineering studies

1.5 Scope of the study and limitations

BIM can affect design, analysis, construction and implementation of the facilities at different levels; however, in this research not all these aspects will to be addressed. The research aim has been narrowed down to focus on the advantage of BIM tools regarding construction processes in general which includes collaboration and coordination as well as design and construction management. Based on the PMBOK (Project Management Institute., 2013) a construction project, like any other project, can be broken down either based on the project management process, which is the focus of this research, or product-oriented process which is out of the scope of this study.

Besides, although BIM can be taught for a variety of objectives which is beneficial for the students, in this research BIM application for teaching knowledge of construction processes by using the collaboration and management capabilities is considered. The research, however, is not focusing on a specific university for investigating the students' level of awareness and for recommending course content. Furthermore, a majority of BIM courses are offered through institutes and organizations which are not necessarily via an academic degree, such as online or short courses. An investigation of these courses is not part of this study.

The organization infrastructure requirement for applying BIM, such as internet facilities and high speed web access availability is not discussed in this research. Also, the cost of implementing BIM technologies within an organization is not a part of this study. There are different tools and software that can be utilized for BIM application which are not discussed within this research.

Organization should be prepared for adopting BIM through training their employees and it affects organizational culture in many aspects; however in this research the training target group is limited to civil engineers in particular.

Although value management is under the umbrella of construction management and there are different methods for measuring the value versus cost for value management via BIM falls outside the scope of this research.

1.6 Research design and development

To address the problem statement of the research, a development plan was structured through which the following steps were defined for the study:

1. A preliminary literature review to understand the nature of BIM and construction processes and exploring the main advantages and benefits of using BIM while understanding its drawbacks and also difficulties
2. A comprehensive study to gain a broad view of BIM application in industry and the teaching methods which are used in pioneer countries
3. Identifying some problems and concepts that should be addressed through literature review, which formed the preliminary problem statement
4. Surveying local universities to identify the level of awareness amongst students regarding BIM concepts
5. Investigating local industry to define the extent to which BIM is applied as well as their needs in terms of BIM that can be satisfied through degree programmes
6. Receiving the results of the surveys and analysing them to refine the areas where student knowledge should be enhanced
7. Investigating the lecturers' opinion and comments for adding BIM concepts to the undergraduate civil engineering curricula
8. Providing a comprehensive conclusion based on the identified needs together with the lecturers' concerns and formulating a suggestion to enrich the civil engineering curricula by integrating BIM concept into it

The methodology which is applied to achieve the requirements of this developed plan is detailed in chapter 5.

1.7 Thesis overview

Chapter 1- Introduction

This chapter provides a general view to the study and its background, as well as a comprehensive definition of BIM. The research problem statement and aims are defined in this chapter in addition to the research scope and limitation. A road map to response to the problem statement is provided and a summary of the thesis chapters is presented.

Chapter 2- BIM: Definition and applications

This chapter provides a background to BIM utilization in construction projects; the areas of application of BIM on construction projects are discussed in line with the various construction phases itemized in the Construction extension to the Project Management Body of Knowledge (PMBOK) guide published by the Project Management Institute (PMI). The advantages of implementing BIM at the various construction phases are also discussed as well as barriers and difficulties to its utilisation.

Chapter 3- BIM application in industry

This chapter provides an overview about BIM application in the industry. The worldwide business achievement of BIM is discussed briefly and the trend of BIM adoption in some pioneer countries is provided. The current situation of BIM and guidelines and standards in these countries are discussed as well as a summary of the possible future of BIM. The utilization of BIM in South Africa is provided and its limitation and maturity is discussed.

Chapter 4- BIM education

This chapter provides an overview about BIM education. A brief history of BIM teaching is discussed and the current situation is provided of BIM programs in some pioneering countries. The strategies in BIM training are discussed as well as different methods of introducing BIM including variety of collaboration in the courses. The main challenges of teaching BIM are also mentioned. Furthermore, an overview is provided of BIM teaching in South Africa

Chapter 5- Methodology

To address the problem statement, formulated in chapter 1 together with the research development plan, led to the research methodology which is presented in this chapter.

Chapter 6- Findings, results and analysis

This chapter provides the result of the three surveys. The result of the survey amongst students is provided in four sections. Finally an overall outcome of the survey is presented. The questionnaire amongst industry practitioners is discussed in the same three main parts as the survey questions, while the last section is provided separately based on the application of BIM in the companies. An overall conclusion of the results from the survey amongst companies is then provided. The results of interviews with lecturers are also provided.

Chapter 7- Discussing of the results and suggestions

This chapter provides the overall discussion on the three surveys which are explained in chapter 6. Also, the suggestion is discussed for making use of the results in teaching BIM to the students. As such, further study that might be carried out considering this research topic is suggested.

Chapter 8- Conclusions

The comprehensive conclusion of the study, findings and result analysis are provided in this final chapter.

Chapter 2 - Building Information Modelling (BIM): Definition and applications

2.1 Chapter Introduction

This chapter provides a background to BIM utilization in construction projects. The areas of application of BIM in construction projects are discussed in line with the various construction phases itemized in the Construction extension to the Project Management Body of Knowledge (PMBOK) guide, published by the Project Management Institute (PMI). The advantages of implementing BIM at the various construction phases are also discussed as the barriers and difficulties to its utilisation. Figure 2.1 shows an outline of the subjects discussed in this chapter and the section contents.

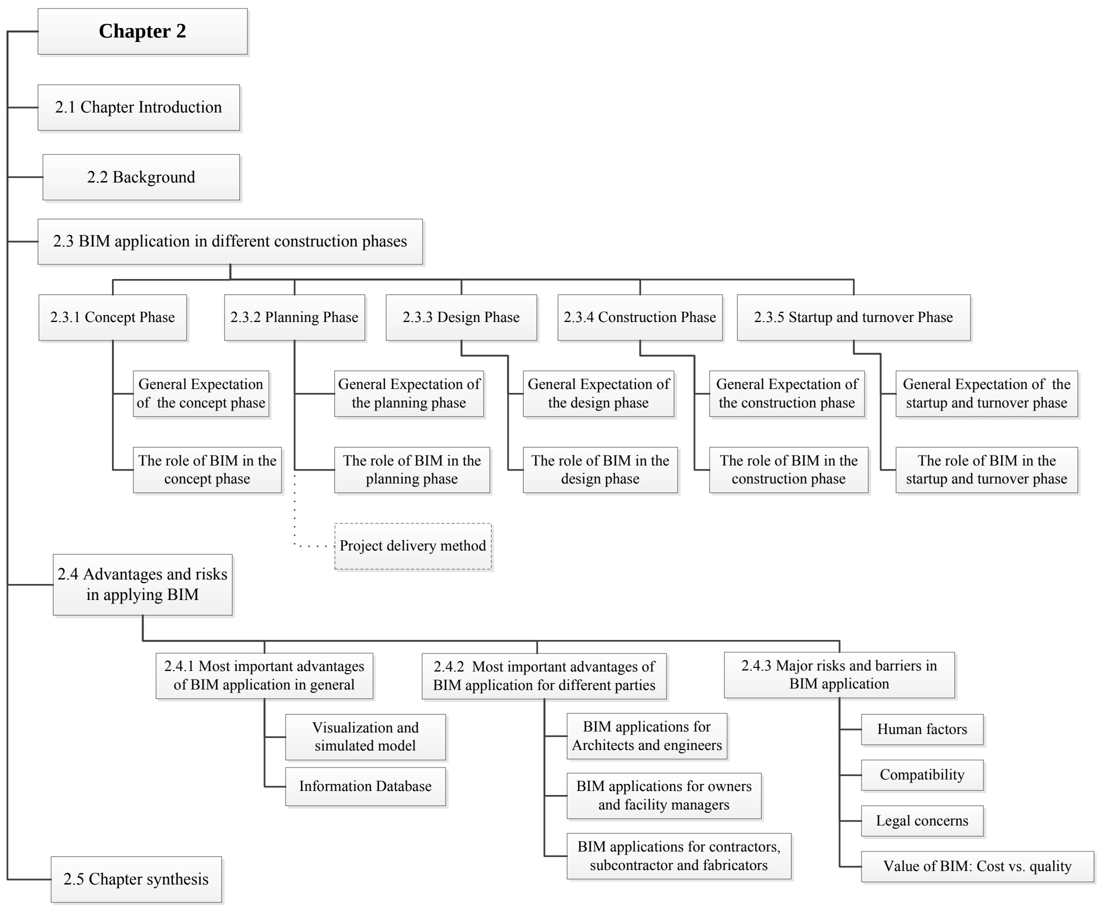

Figure 2.1: Chapter 2 diagram

2.2 BIM application in different construction phases

Construction projects can be broken down into five main phases (Project Management Institute, 2008), namely:

- Concept- including project feasibility study
- Planning- including project planning and pre-design, basic/schematic design, schedule and budget baselines and work plan
- Design- including detailed design, design development, implementation documents and construction documentation based on the planning phase criteria
- Construction- it can be done either after finalizing all the design processes and bidding the contract (Design-Bid-Build), or almost simultaneously with design process packages (Design -Build)
- Start up and handover- including commissioning and contractual completion followed by operation and maintenance

These phases also clarify the main milestones in a construction project, which include following:

- Confirming the main concept of the project with a feasibility study
- Approving the work plan of the project by configuring the criteria and baselines of the project
- Being prepared for start-up and commissioning by the end of construction
- Contract completion of the project by handover to the owner

It is claimed that BIM supports the main part of the project management role and therefore it can affect every single phase of the construction process (Yalcinkaya & Arditi, 2013:619).

2.2.1 Concept Phase

General expectation of the concept phase:

The initial step in making decisions about a proposed project is to evaluate and investigate its potential of being implemented within the targeted cost and time towards a business benefit, while assigning resources as it is planned. This is the purpose of carrying out a feasibility study at the conceptual phase of the project. In this stage the project will be analysed and examined to identify its strengths as well as weaknesses, in order to assist the owner making a decision on whether to proceed with the project or not. If the project is found feasible for implementation, the project manager would have an overview of different factors which may affect it during its life cycle. An estimate of the project cost is usually arrived at during the conceptual stage of the project which needs to get more accurate within the design and bid process. Identifying the stakeholders is the other output of the concept phase.

The role of BIM in the concept phase:

BIM has the ability to estimate project cost which makes it a powerful tool for use when carrying out feasibility studies for a construction project. The feature enables the client to make project decision based on some level of certainty about project cost and schedule. According to the BIM guide published by the Indiana University, BIM tools are useful at the conceptual stage of a project because of their ability to integrate information of landscaping, topography, energy consumption optimization and other basic information required to implement the project, thereby helping project planners make more accurate decisions about project cost, schedule and feasibility (Indiana University, 2012).

Besides, due to the integrated features of BIM, there is the possibility of continuity in information sharing as information can be stored and transmitted for use beyond the feasibility stage to other stages of the project. This means that by providing reliable early project estimates, BIM can save considerable time and cost associated with reproducing information. According to Eastman and Laiserin (2005) BIM should be considered as a tool to be employed throughout the project life cycle for collecting and reusing information and should be introduced at the start of the project (Ham, Min, Kim, Lee & Kim, 2008:42).

A study of 32 major projects conducted at the Stanford University Centre for Integrated Facilities Engineering (CIFE) showed that having project information early on in 3D/4D models had the advantage of a long-term positive impact on the facility during its operation time as well as design and construction phases of the project (Gao & Fischer, 2008).

Azhar and Brawn (2011) were of the opinion that sustainable designs should be the target at the early stages of a project. BIM can help achieve this because it fosters multidisciplinary information sharing and covers the whole project life cycle (Azhar, Carlton, Olsen & Ahmad, 2011:217; Schlueter & Thesseling, 2009:153; Autodesk, 2008).

Cheung et al. (2012:67) suggest a method which includes cost estimation as the very first steps of the design for a BIM model (Azhar, Carlton, Olsen & Ahmad, 2011:217).

2.2.2 Planning Phase

General expectation of the planning phase:

As Ham and et al. (Ham, Min, Kim, Lee & Kim, 2008:42) observe, there are a variety of definitions for the planning phase of a project based on the aim of the researchers for the study. This forms a range of definitions from information gathering and analysing to solving design problems. The Construction extension to the PMBOK guide defines the planning phase of a project to include better clarification of the project concept as well as defining the project criteria in addition to producing the basic drawings and baselines for the project time and budget. This would be the project work plan which usually needs to be approved by the owner to be used as a guideline for the next steps of the project (Project Management Institute, 2008). In addition, initial project risks can be extracted at this phase and some treatment measures can be considered to mitigate, avoid, accept or transfer them.

Pre-design can affect the whole project life cycle as it is the principal of the design and construction phase; therefore the way of performing pre/schematic design is significantly important.

The role of BIM in the planning phase:

Based on Indiana University BIM Guideline (2012), applying BIM at the planning phase has the advantage of being able to estimate the cost for each square meter of the project, as well as all the requirements for enhancing energy performance. It is also possible to identify clashes in design from the various professionals on the project through the use of BIM tools which may prevent errors in detail design and in construction. This allows the project manager to be proactive regarding the project risks and to find a suitable solution to overcome such issues. The initial space planning can be another output of applying BIM tools in pre-design (Ham, Min, Kim, Lee & Kim, 2008:42) The continued data gathering in BIM model, from project concept and data updating until completion, optimize risk management and may lead to optimized safety in the construction work (Lew & Lentz, 2010:37).

There is a variety of software packages which can ease the scheduling and budgeting process of a project. Adding the schematic design to the time schedule and predicting the cost of drawings issuance besides constructing them, makes BIM one of the most useful tools for project managers. As such, linking BIM to the Enterprise Resource Planning (ERP) systems has proved to be beneficial as it makes it significantly easier for clients to keep track of status of progress on a project (Babič, Podbreznik & Rebolj, 2010:539).

BIM can provide a virtual simulated model for the construction project based on the same limitation and goals which are required by real construction processes. However, the role and responsibility of parties should be clear enough within the planning stage. The type of contract would is important in defining such roles and responsibilities.

Project delivery methods:

Choosing a procurement method for a project is dependent on the owners' criteria, such as: flexibility, level of involvement, previous experience, technical knowledge and risk toleration. Project specifications are also important considerations for the choice of procurement method and can vary based on the project size, type, duration and cost restrictions. There are also some external factors which affect the decision of the contract method to be used, for example, the availability of the information about the site conditions or experienced contractors (Stauffer, 2006:17). The business model is also highly effective in determining the project management approach, as the responsibilities of the parties would vary in different models.

Two methods of procurement are most popular on construction projects, namely: Design-Bid-Build (DBB) and Design- Build (DB). The DB procurement method has many variants that include Build-Operate-Transfer (BOT) or Design- Build-Operate-Maintenance (DBOM). Construction management at Risk (CM@R) is the other popular project delivery method, particularly used in the USA.

In Design-Bid-Build (DBB) procurement model, the designer provides the framework of the project by defining the objectives, basic design and also detail design, as it is more common in South Africa. The general contractor, who wins the bid usually at the lowest price and probably with less responsibility, should do the shop-drawing, fabrication and construction. As the responsibilities and work process are fragmented, any changes, omissions or modifications would be time and/or cost consuming. For this reason, DBB is not regarded as an efficient contract type.

Watermeyer (2014) believes that if integration in the design process is achieved before completing 25% of the design, delays and cost overruns can be avoided, while the use of project resources would be optimized. Watermeyer also observes that integration can be gained by sharing the design responsibility between the designer and contractor and by bringing in the contractor in the early stage of the design.

These issues can be handled properly in a Design-Build (DB) model, as design and construction responsibilities have been integrated. In other words, in DB model, the owner delegates both design and construction responsibility to a single main contractor who should provide an estimate for the project time and cost. This estimate can be modified based on the owner's preferences or requirements at the earlier stage of the project life cycle. This would save a considerable amount of cost and time which could be raised due to the changes and corrections.

Under the CM@R contract type, the owner secures not only a designer but also a construction manager. The construction manager's role is that of a consultant at the design phase and as a general contractor at the construction phase. Moreover there is a Guaranteed Maximum Price (GMP) that the construction manager should control the project cost to not exceed. In this contract type, the owner is involved in the design process while the contractor is involved from the early stage of design which is the main advantage of this contract type.

The Integrated Project Delivery (IPD) is one of the most recent types of the contracts and is likely to become more popular especially on projects where BIM is used. The main distinguishing feature of IPD is that it engenders effective collaboration among all the project parties, including the owner, designers, contractors and sub-contractors. Therefore, applying a collaborative tool, such as BIM, is required to support an IPD contract throughout the project lifecycle. The responsibilities and tasks, however, need to be clearly defined in order to address any legal issue that may occur (Eastman, Teicholz, Sacks & Liston, 2011:648; Hardin, 2009).

The more integrated the contract type is, the more suitable it is to apply BIM. So, except under the DBB procurement method, all the other procurement models already discussed can implement the use of BIM tools on construction projects. However, if the DBB contract model is applied, tender related documentation should be included in the BIM model to decrease the fragmentation in the process.

The first contract type that emphasized the use of BIM is the Consensus DOCS 300 'Tri-Party Collaborative Agreement', which included a Building Information Modelling addendum document as Consensus DOCS 301. It was published by the Associated General Contractors of America in 2007 (Yalcinkaya & Arditi, 2013:619). This followed by The American Institute of Architects (AIA) who also developed a new type of contract called the A195™-2008 for standardizing the agreement between the owner and contractor for Integrated Project Delivery. Later, A295™-2008 was published by AIA stipulating that all the parties should employ Building Information Modelling for the IPD method (AIA, 2008).

The University of Colorado-Denver Health Sciences Centre is one of the projects where BIM was applied in most of the project phases from planning to construction and commissioning. Developing the model was very time-consuming for the project team but the developed construction model helped them to save considerable time afterwards (McGraw-Hill Construction, 2009).

2.2.3 Design Phase

General expectation of the design phase:

According to the Construction Extension to the PMBOK, detail design drawings and specifications are developed during the design phase (Project Management Institute, 2008). This may vary based on the project contract. For example, in a DBB type of contract, the design process would be finalized first and construction would start when the all the design documents have been approved before construction by a contractor who has been chosen through a bid. Despite, in DB and other contract types discussed in 2.3.2, the design and construction processes go on concurrently. Each drawing that is completed and confirmed can be implemented on site by the contractor as long as it is not strictly dependent on the detailed design of other parts of the project. The layout of the construction site and Take-Over Points (TOP) would be developed simultaneously in the design phase.

Collaboration and integration of the different disciplines and making appropriate decision for controversial issues, is part of the design process that is mostly handled by the project manager. It is worth mentioning that the cost for constructing or fabricating can be estimated more accurately during this step.

The role of BIM in the design phase:

Eastman et al. (2011:648) state that using parametric objects makes BIM different from other CAD applications. This specific feature which makes BIM application more desirable to designers given that, in spite of the objects with fixed specification and size, parametric objects can be defined and updated based on variable parameters.

This eases providing architectural details such as site plans as well as structural details including foundation and civil engineering details consisting of topography and landscaping. Besides all the information regarding different systems such as HVAC, electrical, plumbing, fire detection and fighting, more precise optimized energy consumption can be included in the model (Indiana University, 2012). Thus, integration and collaboration amongst all disciplines is straightforward when all these details are gathered into one single Building Information Model. This helps the project manager to facilitate the cooperation between specialists and keep them informed of the updated model within the design process.

BIM models have already been utilized to enhance site layout development as well as its logistics and work space assignment (Akinci, Fischer, Kunz & Levitt, 2002:296; Yalcinkaya & Arditi, 2013:619; Zhang, Anson & Wang, 2000:15). As such, BIM models allow the designer to evaluate the different options available to enhance creativity in the construction process (Zarzycki, 2009).

The equipment specifications, fabrication and lead-time should also be considered while the design work is going on. These have to be detailed enough to make it smooth/seamless to supply or fabricate them. Also, the installation procedure and the guarantee or warranty on the equipment should be deliberated during the design phase. Providing detailed and accurate shop-drawing as well as efficient drawing review process, are some of the benefits of using BIM model for the fabrication phase (Luth, Schorer & Turkan, 2013:103).

In this stage of the project, constructability issues can be identified and corrected within the model and before starting construction. Scheduling and cost estimation are more accurately done at this stage. Thus, BIM becomes a helpful tool for controlling the project to ensure it is completed on schedule and within budget.

A BIM model can be used to provide a Bill of Quantity (BOQ) which would be updated by changes on the model, so it is helpful for obtaining a more precise estimation of project cost. In a time schedule which is linked to the BIM model, the activities are clarified and the cost for each individual task can be defined. Therefore, the project manager can understand the coast of each activity in addition to the cost associated with each work package and the project as whole (Yalcinkaya & Arditi, 2013:619).

BIM can also improve the design-ability, constructability and contractibility. This is because it allows the design to be based on the project specification and on material availability. Conflicts and clashes can also be avoided by modelling all the details and the responsibilities and work procedures can be defined clearly by applying BIM. Since value management is also a way of optimizing these three elements of design-ability, constructability and contractibility, it can be derived that BIM has the advantage of improving the value management process (Hartmann, Gao & Fischer, 2008:776; Yalcinkaya & Arditi, 2013:619).

Azhar and Brawn (2009:276) through an analysis of case studies identified the advantages of introducing BIM at the pre-construction phase of a project to provide more accurate estimation of cost and time schedules, improved site coordination and constructability. The use of BIM for sustainability analysis during the design phase as well as the whole project life cycle has been evaluated effectively through a theoretical framework developed by Azhar and Brawn (Azhar, Khalfan & Maqsood, 2012:15).

2.2.4 Construction Phase

General expectation of the construction phase:

As discussed earlier, construction can be carried out either after the detail design has been completed or concurrently with the design process. During the construction processes, the availability of resources and funds is crucial for enabling the project manager to control the progress of the work. The equipment which requires time to be fabricated by a supplier will need to be ordered well in time to prevent delays in the construction process and also imposition significant storage cost to the project due to the early arrival. Proper management of material and equipment on a project can have a remarkable impact on productivity (Navon & Berkovich, 2005:1328).

The Critical Path Method (CPM) is usually employed by planners in managing time schedules on projects and providing required reports and information to the project manager (Yalcinkaya & Arditi, 2013:619). The cost estimates for the project arrived at during the planning and design phase of the project are also relied upon for determining cash flow requirements during the project. A responsibility of project managers is to balance the project budget with project expenses to ensure that the project does not over run on cost and that no payments are outstanding.

The role of BIM in the construction phase

The application of BIM tools at the design phase of a project has the advantage of capturing cost and time schedules associated with the fabrication and assembly steps. This enables a retrospective look at how these components of the project affect and/or contribute to overall project duration and cost (Navon & Berkovich, 2005:1328; Popov, Juocevicius, Migilinskas, Ustinovichius & Mikalauskas, 2010:357). Simulating the equipment handling and movement for assembly through a 4D model (a 3D model which also includes time as the 4th dimension) can help to find a more suitable material for construction and inspect the safety condition for movement of the equipment (Mahalingam, Kashyap & Mahajan, 2010:148) (Yalcinkaya & Arditi, 2013:619).

The process of applying changes on a project requires that the reason for the change and the party or team to effect the change be first identified. Also, the cost and time associated with effecting the change needs to be evaluated. Typically, a Request for Information (RFI) would be issued, which should be transferred to the designers to process consequences of applying the change. If the change is confirmed, the process would be finalized by issuing of a Change Order (CO) with its own procedure to complete. Then all related parties would be informed of their role in implementing the change order. Although this is a time-consuming procedure, it may have some influences on the project, which may only be noticed in later stage. Having a simulated and integrated BIM model makes it a simpler and faster process while the probable conflicts or effects would also be noticed in the model (Eastman, Teicholz, Sacks & Liston, 2011:648).

BIM also allows both the owner and the contractor to save considerable cost of reconstructing and modifying. As Dawood et al. (2005) state, the application of BIM for reducing errors and for enhancing the performance of the project team is getting more common (Dawood, Scott, Sriprasert & Mallasi, 2005).

Another benefit of using BIM is its ability to link the time schedule and project cash flow which provides the project manager with efficiently control. Having this connection between the model and time schedule helps the planner to practically identify issues which may affect the construction work and the interpretation of the time schedule activities is easier.

In conventional way of scheduling and planning, planners work on an abstract schedule and their perceptions may vary. The limitations in traditional scheduling method and tools, makes it difficult to accurately include updated availability of the required man-hours, machinery or budget for completing a planned task (Feng, Chen & Huang, 2010:347; Koo & Fischer, 2000:251). Thus, defining the cost of construction activities in the time schedule is difficult; the budget would be assigned to a work package which is a collection of tasks while scheduled activities are single tasks and more detailed (Yalcinkaya & Arditi, 2013:619). This issue can also be addressed by using a model where the time and cost are integrated based on the construction process. Adding the time to a 3D model and extending it to a 4D model, allows the planner to determine the construction period for any specific element of BIM model.

As discussed by Yalcinkaya and Arditi (Yalcinkaya & Arditi, 2013:619), visualization is a convenient tool to have a better understanding of the work and to provide a holistic view of the work. This tool is available through utilizing a BIM model (Russell, Chiu & Korde, 2009:1045).

Safety is another issue, which can be improved by applying BIM as it enables the designers to identify the risks and dangers while designing and mitigating them through passing useful information to the contractor (Lew & Lentz, 2010:37). The information provided allows the contractor to improve his safety plan to prevent hazards more efficiently. In this regard, an integrated procedure has been developed and examined by Hu et al. (2008:266) to analyse the safety benefits of utilizing a BIM model between the designer and constructors. Hu et al. find that this solution is more efficient than other methods which have been applied so far. Furthermore, linking the safety issue to the project planning can result in managing safety of work more effectively, as discussed by Sulankivi et al. (2010:117).

The role of BIM in enhancing the communication and improving site work efficiency as well as its usefulness in prefabrication and preassembly, has been stated by Kennedy, founder of the Birmingham, Alabama, firm BE&K (McGraw-Hill Construction, 2009). Additionally, Azhar et al (2012:15) identify the main benefits of implementing BIM at the construction phase of a projects to include checking the project status and progress, meetings and communication planning and uniting BIM model by RFIs, COs and punch list information.

2.2.5 Start-up and turnover phase

General expectation of the start-up and turnover phase:

Final testing of the project before commissioning and eventually handover of the completed facility to the owner is the last part of the project life cycle from the contractor’s perspective. This is the step where each project part which may run independently, would be tested on the same sequence as the facility performance work flow. If each part can perform its role properly, the project will run as it has been designed.

The project lifecycle however does not end when a final facility is handed over to the client by the contractor, but continues beyond the handover phase. The client will be responsible for managing the post-handover phases of the project lifecycle when they arise. During this phase documentation importance would be more apparent. Project documentation should be considered at the onset of the project all through to project completion by the contractor. It is necessary that project records be kept and updated and made accessible by the project owner. It is also critical that the latest updates be available to the owner for using in operation, maintenance and facility management.

The role of BIM in the start-up and turnover phase

The simulated model, developed all through the design process using BIM tools, is a valuable opportunity for checking if there might be any problem while commissioning the project. The model helps to test the whole concept and design as it is constructed. This ability is gained through the information flow in the backstage of the model which is modified, completed and updated during the project life cycle.

BIM is ideal with regard to project documentation because of its integrated features. It is often described as a united information backbone (Underwood, Isikdag & Global, 2010). The project life-cycle approach of BIM makes it powerful enough to handle this issue. The information gathered by the project team from the conceptual phase up to construction is of great value to the owner to enable efficient operation and maintenance as well as management of the facility. The availability and reliability of the information is not comparable with the traditional paper-based communication. The as-built drawings derived from BIM are accurate enough to be used for commissioning as they include all the changes that applied to the model. Any warranty or guarantee on the equipment is also included in this database to be made available to the owner for later use.

2.3 Advantages and risks in applying BIM

2.3.1 Most important advantages of BIM application in general

There are two general views on the relevance of BIM for the construction industry. Some industry stakeholders are of the view that BIM is complicated and does not possess the resilience to survive and help the industry through the complexities of the construction processes. The other view is the direct opposite of the first as some stakeholders consider BIM to be a cure-all to address all the challenges encountered by the industry.

The benefits of applying BIM on a construction project have been discussed from different perspectives. A large number of case studies and surveys have been carried out to investigate the benefits and advantages of BIM on construction projects. In 2009, a wide survey was conducted by Becerik-Gerber and Rice (210:185) within the construction industries in the USA. The survey showed considerable benefits of applying BIM amongst the respondents in which visualization, clash detection, building design and as-built model have been ranked the first top four. A similar study was carried out by Arayici et al (2011:7) which showed the competitive outcomes of using BIM through a case study. There are also researches confirming the benefits of BIM such as more accurate designs, earlier correction of the conflicts and improvement of project management within the project life cycle (Staub-French & Khanzode, 2007:38, Yan & Damian, 2008).

In the early stages of BIM technology application, the achievements of utilizing 3D and 4D modelling has been discussed by Staub-French and Khanzode (2007:381). Eastman et al. (2011:648) enumerate the BIM advantages in preconstruction, design process, construction and fabrication and post-construction, which are pointed out in section 2.2.

The significant benefit of BIM application is its truthful geometrical demonstration of different components of a building in a united data set (CRCC Innovation, 2007). In other words, it can be grouped mainly in simulated features and life-time information database, and other related advantages can be allocated to one of these main titles (Azhar, 2011:241).

Visualization and simulated model

- Providing a simulated model within the conceptual phase, can be a good evaluation tool for the owner to understand if the project is feasible within the allocated time and budget (Eastman, Teicholz, Sacks & Liston, 2011:648).
- Developing a virtual model before construction makes it tangible to see if the project is in an acceptable level of quality and sustainability. The ability of BIM models to connect to the energy analysing tools for optimizing the energy consumption and providing a sustainable design, can make it a preferred option for building companies.
- It also helps to better understand the design process as well as the construction work. This in turn can reduce errors in design and rework in construction. In other words, it is helpful for clash detection and identifying constructability issues. Also it improves individuals' creativity in design work by having the opportunity to check what-if questions which can be responded virtually.
- Fabrication and installation procedures are cleared through the simulated model. Therefore, supply and fabrication of the equipment can be well managed to decrease the storage and inventories as well as the lead-time (Sacks, 2004:301).
- Having a 4/5D model provides a comfortable situation for all the stakeholders to review and comment on the project, even if they are not able to spend much time investigating the project details (Eastman, Teicholz, Sacks & Liston, 2011:648). Studying 32 important projects which utilized BIM by Stanford University Centre for Integrated Facilities Engineering (CIFE), Gao & Fischer (2008) found that one of the main benefits of 3D models is its simplicity for communicating with nonprofessional stakeholders.

Information Database

- Gathering all the information about the project under the BIM umbrella, from the early steps of the project life cycle, facilitates the early and efficient collaboration among the project team members.
- Using parametric objects helps decreasing the human errors in calculation. As parametric objects are defined by parameters linked to the other related objects, BIM also expedites applying effects of any change on other objects which might be under its influence.
- Updated and accurate drawings of any section, part or view are extractable at any time. All these possibilities are achievable through a more productive design with less labour hours (Sacks, 2004:301).
- Providing a precise Bills of Quantity (BOQ) and Bills of Material (BOM) in a shorter time frame is another achievement of having all the data on a single model. This also allows easier cost estimation while design and construction are progressing. Meanwhile, all the related parties can be informed of the requirements of the specific construction stage (Shen & Issa, 2010; Staub-French & Khanzode, 2007:381).
- The information database of BIM tools is rich enough to be connected to energy analysis tools for assessing the sustainability and energy consumption of the constructed unit (Arayici, Coates, Koskela, Kagioglou, Usher & O'Reilly, 2011:7).
- In spite of conventional scheduling method where activities of the time schedule are defined based on abstract tasks, BIM allows the time to be allocated to the construction objects rather than a single project activity and task. This makes the time schedule more tangible and controllable (Staub-French & Khanzode, 2007:38).
- As the information is synchronized and updated regularly, the model would include the necessary information to provide an evaluation of the facility performance before it actually starts running (Staub-French & Khanzode, 2007:381).
- It also provides accurate as-built drawings of the project, which is of great value to the facility owner during the operation and maintenance phase (Becerik-Gerber & Rice, 2010:185).
- Allowing to put aside all the documents with unstructured formats, such as PDF, spreadsheets, emails and letters and keeping all the information in an integrated model which is accessible for all the project team members, is another benefit of such tools. This feature has been considered as the principle for developing a knowledge management database (Gao & Fischer, 2008).
- Chuang et al. (2011:144) enhanced BIM visualization and operation by designing a Graphical User Interface (GUI), which allows the users to obtain valid information via web. This new technology called Cloud-BIM provides access to the information and project status anytime

and anywhere as the users may need it. In turn, this eases the communication and data distribution for project team members when compared to normal BIM.

2.3.2 Advantages of BIM application for different parties

As different stakeholders in the project have various roles and responsibilities, there are some aspects of applying such a tool which sounds more attractive to them. The main achievements and gains of stakeholders can be extracted through some case studies, as described below.

BIM applications for Architects and engineers

The flexibility of the model developed with BIM, is one of the main fascinating features which attract architects and engineers. Using parametric objects makes it easier to apply changes on the model while different parties and disciplines have access to it. This makes BIM to be a highly demanded technology amongst the designers. It is mentioned as one of the main achievements of applying BIM in Aviva Stadium in the USA (Eastman, Teicholz, Sacks & Liston, 2011:648).

Another case study on a building in the University of Nebraska showed that Life Cycle Analysis (LCA) and evaluating the energy consumption during the building life cycle can be straightforward by linking BIM model to sustainable design analysis software. Owing to the parametric objects used in BIM model, the sensitivity analysis for LCA is much easier and BIM provides a useful platform for identifying required design changes to improve energy consumption performance (Wang, Shen & Barryman, 2011).

Decision making in design work is highly influenced by energy analysis which can be gained through an effective BIM tool. This was one of the advantages of early adoption of BIM by all the project parties in Helsinki Music Center project in Finland. The collaboration between the electrical engineers and HVAC engineers on the unique model, made it possible to prevent any clashes of services during the installation (Eastman, Teicholz, Sacks & Liston, 2011:648).

BIM applications for owners and facility managers

There is evidence of projects where the owner has been participating in the BIM implementation and gaining considerable benefits through it. For instance, the Sutter medical centre in California, USA, was constructed with a collaborative approach within all the project entities from the conceptual phase. Construction was started six month earlier than its original plan and completed under the target estimated cost. It is claimed that in this project which was delivered by the IPD method, no milestone was missed and all the team members were satisfied by the effective cooperation (Eastman, Teicholz, Sacks & Liston, 2011:648).

Decreasing the life cycle cost of the facility is an owner's main objective and includes the cost of the operation phase. The ability to connect early design information to the facility management documents makes BIM a desired tool for the owners and for facility management. It is also possible to see the travelling path through the designed BIM model and to identify any hazard which may occur later. Thus BIM is helpful for reducing the safety related issues (Wang, Wang, Wang, Yung & Jun, 2013). The same benefits in saving time and money were experienced in the One Island East project in Hong Kong due to early error correction and clash detection where all the stakeholders participated in BIM application from the first design steps (Eastman, Teicholz, Sacks & Liston, 2011:648).

In the Maryland general hospital project in the USA, despite utilizing BIM very late, it still helped to reduce the solid waste of the hospital in facilities management phase, improve the equipment life-time, enhance the preventive maintenance as well as to produce precise as-built drawings (Eastman, Teicholz, Sacks & Liston, 2011:648).

As described in Contructech magazine, in 2010, the USA General Services Administration was applying BIM in early stages of more than 70 capital projects for evaluating the possibility of rehabilitation of the buildings. In other words, the cost of renovation was calculated using BIM along with other software to provide a comparable analysis and evaluating the feasibility of the projects before it started. The cost calculation included pricing, energy and pro forma analysis as well as the 4D visualization (Constructech, 2010).

BIM applications for contractors, subcontractor and fabricators

It is important for the contractor to save time and cost while satisfying the owner and delivering the work at expected quality level. Designing the Blackfoot Crossing Historical Park in Alberta Canada was one of the BIM projects with perhaps no error. The contractor did not encounter changes or clashes during the construction phase. In this project, the contractor experienced improvement in the productivity by spending less labour hours with less errors and rework (Kaner, Sacks, Kassian & Quitt, 2008).

Enhancing the communication and interoperability is another feature which results in improving the quality of work as well as saving time and cost during the project. This is more important on the construction site and in the fabrication workshop as the shop-drawing and detailed design drawings should be interpreted correctly. The University Of Southern California School Of Cinematic Art was built utilizing a BIM model, where both the contractor and the fabricator found it quite helpful as they saved a considerable number of work days and man-hours (Luth, Schorer & Turkan, 2013:103).

2.3.3 Major risks and barriers in BIM application

In spite of identified advantages of utilizing BIM technology within a project, there would be also some risks involved in implementing it, which stop some organizations from adopting the BIM technology.

Human factors

Implementing a software based technology always needs acceptance by the users. Utilizing BIM needs both willingness and support of the project team members owing the comprehensive collaboration required for its successful implementation. So, if there is any party or group members who use traditional methods, it would be necessary to have the model on paper form and with sufficient information and data for planning, design or construction use.

Responses to a survey conducted by Yan and Damian in the UK and USA show that the time and human resource required for training is one of the obstacles for the companies (Yan & Damian, 2008). Wax (1997) argues that achieving business profit is the most important objectives of company owners. As such, they need some evidence to ascertain the future of such an investment. Results from a variety of case studies today provide sufficient proof and motivation for the owners in the AEC (Architecture, Engineering and Construction) industries. There is however, resistance to change and new technology which may explain why some of the key team members adhere to the old-style routines and ignore any benefits which can be gained by applying new technologies.

The other factor that is a key to BIM implementation criteria is accessibility of the information and the model to all team members for fulfilling their own part of the work process. This may need some change in the organizational culture as well as in the infrastructure. Compared to the traditional work flow, design and construction information are integrated into a shared model and at an early stage of a project. This requires more collaboration amongst all the stakeholders. Even in individual companies, a multidisciplinary approach is needed, thus, time and education would be required (Eastman, Teicholz, Sacks & Liston, 2011:648).

A lack of specialists either within the organization or project team is a difficulty for adopting BIM in some firms (Kashiwagi & Sullivan, 2012; Ku & Taiebat, 2011:175; Mayo, Giel & Issa, 2012:349, Johnson & Gunderson, 2010). The required cultural change in the organization may also present another stumbling block, which results in not having enough requests from the owners and investors for such a change (Birkeland, 2009:1; Brewer & Gajendran, 2010; Dawood & Iqbal, 2010; Denzer & Hedges, 2008).

Compatibility

Another challenge concerns the compatibility of data format when other project participants work with tools with data formats different from that of BIM. Industry Foundation Classes (IFC) has however, developed a data model to address this problem. The IFC data model provides a mechanism for interoperability between applications with different data formats (Eastman, Teicholz, Sacks & Liston, 2011:648, Johnson & Gunderson, 2010).

Legal Concerns

Regarding the responsibilities and division of labour, the conditions would differ when BIM is implemented in a project due to its integrated nature. This may affect the responsibilities and rules of the project team members. Although attempts have been made to resolve ambiguity by some professional groups, such as AIA and Associated General Contractors of America (AGC), there might still be some concern for companies to execute a project using BIM (Eastman, Teicholz, Sacks & Liston, 2011:648; Oluwole Alfred, 2011).

The copyright and possession of the database can be a controversial issue when using a shared model with an integrated database (Christensen, McNamara & O'Shea, 2007:191; Briggs & Brumpton, 2001:25, Johnson & Gunderson, 2010). Eadie et al. (2013:145) find that Intellectual Property (IP) and Professional Indemnity (PI) insurance are subjects to uncertainty and their ambiguity is an area of concern when applying BIM.

Value of BIM: Cost versus quality

Implementing any new tool is costly (Azhar, 2011:241), especially if there are not enough extra budgets for the new required infrastructure and for supporting its implementation (Bazjanac, 2004:58). Barlish and Sullivan suggested a methodology to measure BIM advantages and concluded that project size, the level of proficiency amongst project team members, the nature of team communication and other external factors influencing the organization, can affect the level of implementation of BIM (Barlish & Sullivan, 2012:149).

AIA and Autodesk define the Level of Development (LOD) specification as “a reference that enables practitioners in the AEC industry to specify and articulate with a high level of clarity, the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process”. The LOD system can vary from 100 for the conceptual phase to 500 for the as-built stage (see Table 2.1). There are some methods to control the LOD for the drawings, but Luth et al. (2013) is of the opinion that the LOD system is not measuring the quality of the drawing and therefore it cannot evaluate the effect of the drawings on constructability or time and cost saving (Luth, Schorer &

Turkan, 2013:103). The cost of implementing BIM is a function of project complexity and Level of Development (LOD) of the model (Hergunsel, 2011a).

In general, the cost of providing resources as well as training the project team is one of the major obstacles for implementing BIM in construction industries, especially because the benefits of applying BIM are not achievable immediately and take time to be noticed (Azhar, Carlton, Olsen & Ahmad, 2011:217; Crotty, 2011; Eadie, Browne, Odeyinka, McKeown & McNiff, 2013:145; Sebastian, 2010:166; Thompson & Miner, 2006; UK cabinet Office, 2011; Yan & Damian, 2008).

Table 2-1: Fundamental LOD

(AIA/AGC, Aug. 22, 2013)

LOD 100	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements
LOD 200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 300	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
LOD 400	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

2.4 Chapter synthesis

BIM started to be used within AEC industries for addressing disintegration of the information and for unifying data and dimensions for construction components. There are considerable advantages for applying BIM through the project life cycle, which include but are not limited to the following:

- Using the centralized information during project life cycle
- Saving considerable time and cost associated with reproducing the information as well as reconstructing and modifying
- Improving sustainable design
- Helping with proactive project risk management
- Early cost estimation in conceptual phase
- Linking schematic design to the time schedule and predicting the cost of drawings issuance and each square meter of the project in planning phase
- Providing integration and collaboration amongst all disciplines in design phase
- Identifying constructability issues and correcting them before starting construction in design phase
- Capturing cost and time schedules associated with the fabrication and assembly steps in construction phase
- Improving construction safety
- Optimizing the facility management process

There are also some barriers in implementing BIM that relate to human factors, compatibility, legal issues and cost of implementation.

Chapter 3 – BIM application in Industry

3.1 Chapter Introduction

Chapter 2 provided a background to BIM. This chapter gives an overview about BIM application in the industry. The worldwide business achievements of BIM as well as the trend of BIM adoption in some pioneer countries are provided. The current situation of BIM usage and guidelines and standards in these countries are discussed as well as a summary of the possible future of BIM. Also discussed in the chapter is the utilization of BIM in South Africa and maturity and the limitation in applying it. An outline of the topics covered in this chapter and section contents is illustrated in figure 3.1.

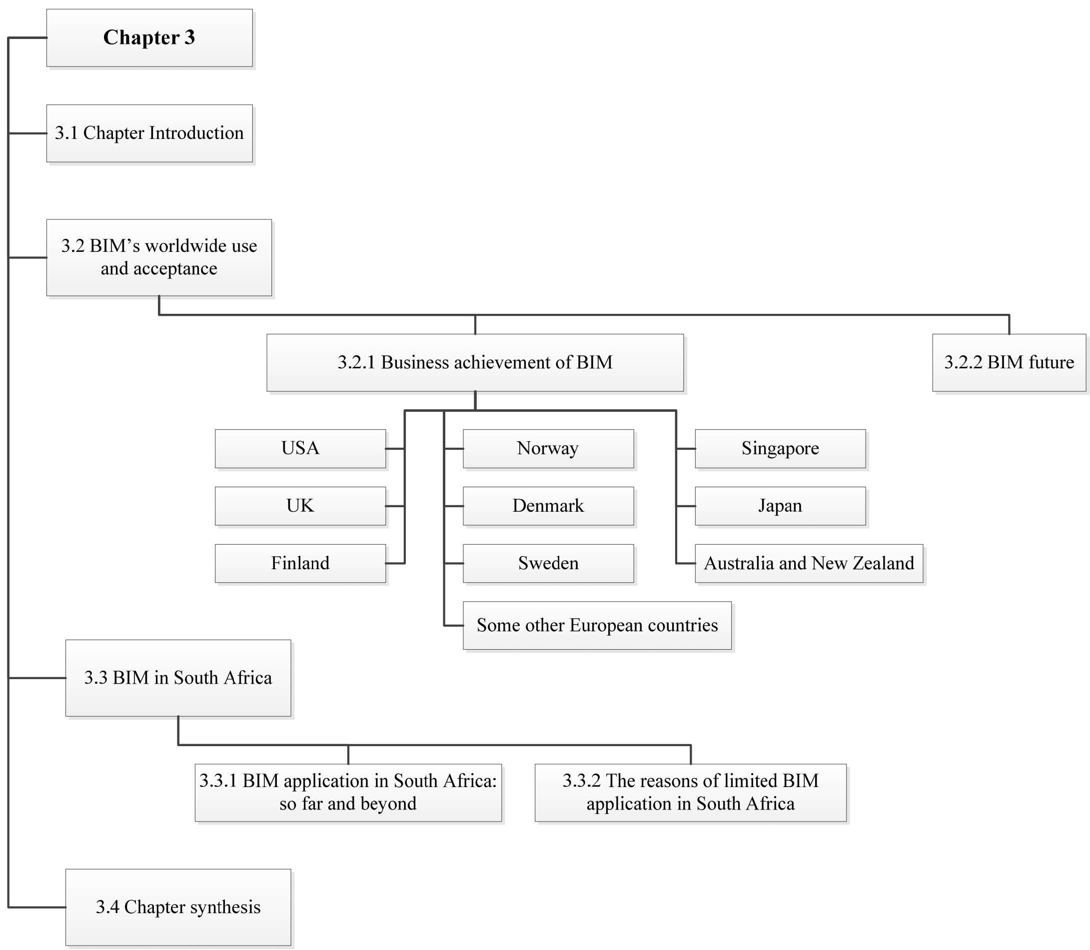

Figure 3.1: Chapter 3 Diagram

3.2 Worldwide use and acceptance of BIM

3.2.1 Business achievements of BIM

The McGraw-Hill construction report (2009) showed that the application of BIM has been quite impressive and with some measure of success. Two-thirds of BIM users in North America reported positive Return on Investments (ROI) on their overall investment in BIM while one-fifth of them achieved more than 50% returns. In the same report, reducing rework was ranked as the most important benefit of using BIM. The other top rated feature in the report is decreasing design clashes and changes during construction.

Fifty five percent of respondents who participated in the McGraw Hill survey acknowledged the impact of BIM in cutting project cost. Of this number, 39% believed that BIM could reduce cost by up to 25% (McGraw-Hill Construction, 2009).

A survey of 32 major projects in the USA showed that approximately 40% of undesired changes, for which no cost was allocated in the project cash flow, were eliminated by applying BIM. Furthermore, the respondents had experienced about 80% time reduction for generating the cost estimation and 3% claimed more precision in the cost estimation. Those surveyed believed that they saved around 10% of the contract value for early clash detection and up to 7% cut on the entire project duration (Azhar, 2011:241).

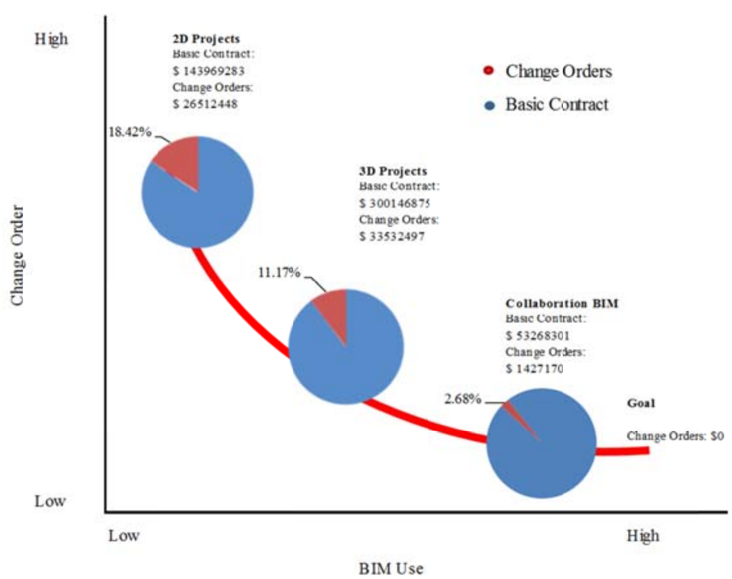

Figure 3.2: Saving through collaboration

(J.C. Cannistraro, 2009)

J.C. Cannistraro, a large mechanical construction firm in the USA that provides plumbing, HVAC, fire protection and facilities services for commercial and institutional projects, analyzed 408 projects they had executed. They concluded that the more BIM was applied on a project, the more saving was achieved on Change Orders (CO). Figure 3.2 shows that 18.24% of the entire project cost for COs was decreased to 2.68% by utilizing BIM (J.C. Cannistraro, 2009).

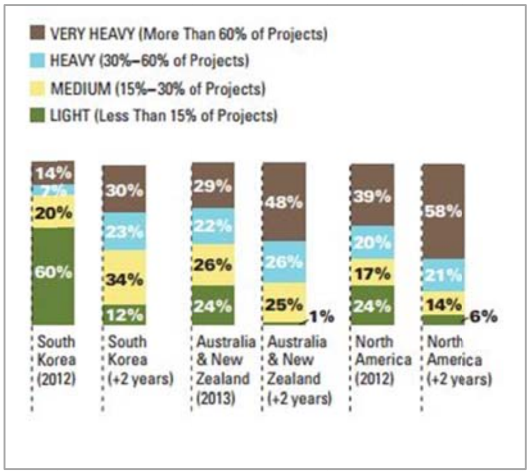

Figure 3.3: BIM Implementation Level in 2012 and forecasted for 2014

(McGraw-Hill Construction, 2014b)

Another report of McGraw Hill Construction (2014b) forecasted a remarkable shift in applying BIM in North America and South Korea in 2 years from 2012 as well as in Australia and New Zealand from 2013 (See Figure 3.3).

A more recent investigation of the construction industry in 10 countries in 2013 showed that the uptake of BIM utilization by contractors will double or increase even more by the year 2015 with the exception of Japan. Figure 3.4 shows the countries studied and the present and projected level of BIM utilization by contractors (McGraw-Hill Construction, 2014a).

The changes and pace of adoption of BIM by contractors can be regarded as a sign of coming changes in other project parties. Contractors adopting BIM, regardless of whether clients demand its utilization on their project, enhances the contractor's capacity to deploy BIM, thus improving the contractor's performance on a project. The spin off effect could be that the client may be convinced to apply this paradigm shift in his/her organization as well. However, if this movement starts from the public sector, it can even result in a faster adoption and commitment to BIM. The role of the private sector cannot be ignored, seeing that R&D works are mainly pushed by the public sector and supported by private sector and therefore have a strong influence on awareness and readiness for accepting the required changes (Wong, Wong & Nadeem, 2009).

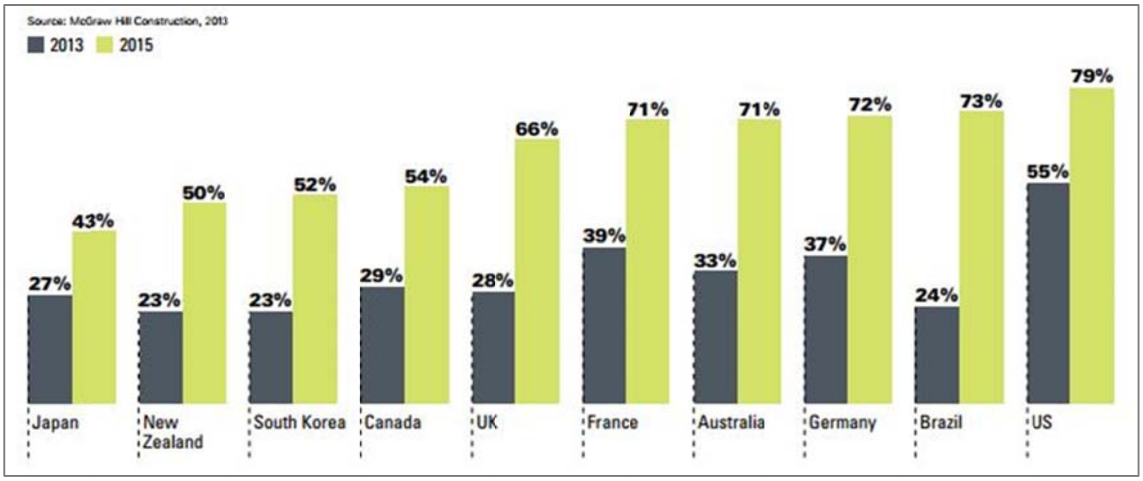

Figure 3.4: Forecasting the percentage of contractors at high/Very high BIM Implementation Level in 2015 compared to the ones in 2013

(McGraw-Hill Construction, 2014a)

Conclusions from these reports provide evidence which suggest that rate of uptake of BIM technology is different for each country as some countries are adopting BIM at a faster rate than others. The experience of some countries with regard to the level of BIM utilization is discussed below.

USA

About 71% of firms in the AEC industry in North America had adopted BIM as of 2012. There was an astronomical rise considering that only 17% and 49% of firms had adopted BIM in 2007 and 2009 respectively. It is worth mentioning that the rate of BIM adoption amongst contractors was around 74%, which was 4% more than architects and 7% more than engineers. The General Services Administration, that runs all the state buildings in the USA, requires that all public buildings be integrated to a 3D–4D BIM program (McGraw-Hill Construction, 2012).

There are quite a large number of guidelines and standards to support BIM application procedure in the USA. Some of them are published by a government related body or public sector while some are issued through the private sector. There are also a number of academic institutions who distribute their publications on BIM utilization (Broquetas, 2013; McGraw-Hill Construction, 2009). The most famous standard, which is quite popular in the USA, is National BIM Standard (NBIMS) whose third version was published by BuildingSMART Alliance in 2013. The base of NBIMS is IFC format for sharing information (McGraw-Hill Construction, 2014a; NIBS, 2008b; Broquetas, 2013). Table 3.1 presents a number of BIM guidelines or standards developed in the USA.

Table 3-1: BIM standards and guidelines in the USA, Adopted from CAD Addict forum (Adopted from Broquetas, 2013)

Institution	Published by	Document	Date
GSA (General Service Administration)	Government	BIM Guide Series	2012
Department of VA (Veterans Affair)	Government	The VA BIM Guide	2010
Air Force	Public sector	BIM Requirements	2011
Tricare	Public sector	DoD MHS Minimum BIM Requirements	2011
USACE (U.S. Army Corps of Engineers)	Public sector	BIM Requirements	2011
GSFIC (Georgia State Financing and Investment Commission)	Public sector	GSFIC BIM Guide	2011
Federal Aviation Administration	Public sector	Minimum BIM Requirements	2012
New York School Construction Authority	Public sector	BIM Guidelines and Standards	2013
New York City Department of Design and Construction	Public sector	DDC BIM Guidelines	2012
Port Authority of New York Engineering Department	Public sector	EAD BIM Standard Manual	2012
City of San Antonio	Public sector	CoSA BIM Standards	2011
Ohio DAS (Department of Administrative Services)	Public sector	Ohio BIM Protocol	2010
Texas Facilities Commission	Public sector	Guidelines - Standards (pp 48-72)	2008
Wisconsin DOA (Department of Administration)	Public sector	BIM Guidelines and Standards	2012
NIBS (National Institute of Building Sciences)	Private Sector	NBIMS-US™ V2	2012
AIA (American Institute of Architects)	Private Sector	BIM Protocol Exhibit	2008
AGC (The Associated of General Contractors)	Private Sector	Contractor's Guide to BIM 2nd Ed ($75)	2009
AGC (The Associated of General Contractors)	Private Sector	Contractor's Guide to BIM 1st Ed	2006
SDCCD (San Diego Community College District)	Higher Education Institute	BIM Standards for Architecture, Engineering & Construction	2013

Institution	Published by	Document	Date
Georgia Tech	Higher Education Institute	GT BIM Requirements for Arch. Eng. & Contr.	2011
MIT Department of Facilities	Higher Education Institute	MIT CAD and BIM Guidelines	2012
Los Angeles Community College	Higher Education Institute	BIM Standards	2009
Los Angeles Community College	Higher Education Institute	DB BIM Standards	2010
Los Angeles Community College	Higher Education Institute	DBB BIM Standards	2011
Pennsylvania State University	Higher Education Institute	BIM Project Execution Planning Guide v2.1	2010
Pennsylvania State University	Higher Education Institute	BIM Planning Guide for Facility Owners	2012
University of Southern California	Higher Education Institute	BIM Guidelines 1.6	2012
Indiana University	Higher Education Institute	IU BIM Guidelines and Standards	2012

UK

As reported in the 2014 edition of the UK National Building Specification (NBS), the level of BIM awareness and usage has jumped in UK industries as only 13% of the industries were practicing BIM in 2010 and this has increased to 54% in 2013. Furthermore, about 45% of the firms were neither aware nor using BIM in 2010; this has reduced to only 5% of them in 2013 (NBS, 2014).

Using BIM on refurbishment projects in the UK has been practiced and reported to be very beneficial for optimizing the design, enhancing information management and sustainability improvement (Kim & Park, 2013:765). In 2011, the UK Government Construction Client Group forced all public sector building projects to utilize BIM. Following this strategy, all the suppliers are required to have BIM technology to qualify for projects by 2016 (Baxter, 2013; UK cabinet Office, 2011). To support government in achieving this target, the business standards company of BSI (British Standards Institution) in the UK published PAS (Publicly Available Specification) 1192-2 for information management of the capital/delivery phase for construction projects in 2013. An earlier standard, which is also to be applied in the UK, was launched by AEC (UK) committee in 2012 and is called AEC (UK) BIM Protocol v2.0 (BSI, 2013; Broquetas, 2013).

Finland

The Finnegan state property services agency, Senate Properties, tried some pilot projects adopting BIM since 2001 and providing IFC compatible models for its project has been mandatory since 2007 (Wong, Wong & Nadeem, 2009; McGraw-Hill Construction, 2014a; Baxter, 2013). This was extended to other public sectors so that 20-30% of the clients required and used BIM by 2012. The growth was not at the same pace in the private sector as less than 10% of private clients had adopted BIM by the same year. This difference was also seen between large and small construction firms, as the larger companies were more open to move towards this new technology and used it in around 50% of their works. Comparably, smaller companies' adoption was barely up to 10% (Koppinen & Henttinen et al, 2012).

To define the steps of modelling in depth, a guideline has been developed in Finnish language which needs additional expansion to cover data exchange conditions (Wong, Wong & Nadeem, 2009). There are also several centres for research on BIM development or promoting its utilization and the government supports them by subsidizing the R&D projects (Juhola, 2011). For instance, Skanska Oy is carrying out research on the feasibility of integrating BIM models into an industrial construction procedure (Wong, Wong & Nadeem, 2009). VTT Technical Research Centre of Finland is investigating BIM solutions for sustainability and application in the built environment while also working on the research about cloud storage and real-time information access for BIM program (Permala, Kiviniemi, Sirkiä, Hiljanen, Granqvist & Lehtinen, 2008:66).

Norway

Almost 22% of Norwegian AEC/FM companies have already practiced or implemented BIM (Wong, Wong & Nadeem, 2009). The civil state client (Statsbygg) in Norway started using BIM in 2005 and by 2010, it had successfully implemented BIM for all its projects across the entire project lifecycle (Juhola, 2011, Baxter, 2013, McGraw-Hill Construction, 2014a). BIM got more popular among contractors because it is reputed to be a powerful way of integrated construction for habitations (Wong, Wong & Nadeem, 2009). There is also research being conducted in Norway focusing on BIM subjects, particularly focusing on optimizing design sustainability (Wong, Wong & Nadeem, 2009). Also, a Norwegian BIM guideline has been published which resonates with the NBIMS standard of the USA. Although this guideline, which is called BIM manual, was written for Statsbygg's project initially, it was subsequently adopted for use by other companies (Lê, Mohus, Kvarsvik & Lie, 2006:191; Wong, Wong & Nadeem, 2009). Furthermore, the Norwegian International Alliance for Interoperability (IAI) forum tried to classify the information exchange necessities which can optimize the information interchange for improving the business within a construction firm (Wong, Wong & Nadeem, 2009).

Denmark

The implementation of BIM in government projects has been mandated by the Danish government since 2007 (McGraw-Hill Construction, 2014a; Wong, Wong & Nadeem, 2009; Kiviniemi, 2008). However, one year before the mandate was issued, BIM was found to be utilized by approximately 50% of the architects, 29% of the owners and 40% of the engineers. The Palaces and Properties Agency, The Danish University and Property Agency and Defense Construction Service are some of examples of public sector BIM users (Wong, Wong & Nadeem, 2009). Although some of the rules, which should be considered while applying BIM, are part of the construction laws, there is no guideline specific to BIM utilization. However, Byggherrekravene laws, set by the Danish government, cover the main necessities of implementing BIM. Besides, 'Det Digitale Byggeri' (the Digital Construction) prescribes some methods and routines while working with digital tools. As of 2009, this guideline was still under experimentation and modified based on the specifications and condition of the projects. Guidelines for 3D CAD modelling have also been developed, consisting of: 3D CAD Manual 2006, 3D Working Method, 3D Working Methods and Layer and Object Structures 2006 (Hermund, 2009; Wong, Wong & Nadeem, 2009).

There are also some organizations which are leading or supporting R&D work in BIM. 'bips' is one of these organizations, which is leading IT practice in construction industry (Wong, Wong & Nadeem, 2009). The other organization is Rambøll which is mainly focusing on research in BIM (Wong, Wong & Nadeem, 2009).

Sweden

The demand for BIM in Sweden is similar to the trend observed in Finland and Norway. Its applications have been mainly in design and construction processes of major complicated infrastructure projects such as the Stockholm Bypass and the City Line in Stockholm (WSP Group, 2013a; McGraw-Hill Construction, 2014a). The application of BIM by clients has encouraged more designers and consultants to adopt BIM tools in their practice (Hooper & Ekholm, 2010). The Bygghandlingar 90 guideline is developed based on other Swedish standards for addressing administrative features of applying BIM. This guideline can satisfy standards and rules for utilizing BIM together with buildingSMART alliance's BIM Guide, which is published by BIM Project Execution Planning buildingSMART alliance™ Project (Hooper & Ekholm, 2010).

Some other European countries

From the year 2012, the Dutch Ministry of Interior "RGD" stipulated the use of BIM for large building maintenance projects to cover all the projects which were worth more than €10 Million. The RGD BIM Norm, the standard mostly applied in the Netherlands, was published by Ministry of Interior in 2011 and updated in 2012 (Baxter, 2013; BIM Journal, 2011).

The rate of adopting BIM in Germany and France was reported to be 36% and 38% respectively as of 2010. However, there was no public policy in France to mandate BIM adoption until 2013. A BIM guide was released in Germany by OBERMEYER Planen and Beraten & AEC3, which provides the main steps in BIM utilization as well as its requirements (Baxter, 2013; McGraw-Hill Construction, 2010; AEC3, 2013).

Singapore

3D Models, and later on BIM, have been applied in Singapore since 1997, mainly for building plan approval and fire safety procedures and certificates. Singapore pioneered the first BIM based permitting system for constructing a building through e-submission. More than 200 projects acceptance had been authorized until 2011 by submitting the BIM model electronically (McGraw-Hill Construction, 2014a; Wong, Wong & Nadeem, 2009). The use of BIM and IFC is one of the requirements of e-submission procedure and a variety of approvals such as construction plan and fire safety certificates would be issued by providing a BIM model only (Khemlani, 2005). The company in the forefront of providing this service, CORENET, has published Singapore's BIM guide, the first version of which was released in 2012. The BIM Guideline used in Singapore is called "Integrated plan checking" which is developed based on the IAI standards (Wong, Wong & Nadeem, 2009).

Japan

According to McGraw-Hill 2014, 23% of Japanese contractors were benefitting from BIM application in 2013 and this is expected to increase to 43% by 2015 (McGraw-Hill Construction, 2014a). The Ministry of Land, Infrastructure and Transport in Japan started adopting BIM on Building and maintenance pilot projects since 2010. Two years later, in 2012, the BIM guideline was published by Japan Institute of Architects (JIA), which discussed the achievements that can be expected from utilizing BIM by architects. Some research has also begun, commissioned by MLIT Government Building Department to look into BIM and its rules for Japanese construction firms (Shiokawa, 2013).

Australia and New Zealand

Although the governments of Australia and New Zealand are yet to mandate BIM application within industries, adopting BIM is growing fast in these countries. According to McGraw Hill Report (2014), 51% of companies started adopting BIM for about 30% of their projects, and this is predicted to reach to 74% in the next two years (McGraw-Hill Construction, 2014b).

Australian National BIM Guide was published in 2011 by NATSPEC, a non-profit organization. The main focus of this guide was to identifying BIM requirements at early stages of planning to avoid clashes and conflicts. As technical issues are not included in this guide, the standard of BIM-MEP^{AUS} (Minimum Energy Performance) is released by the Air Conditioning and Mechanical Contractors' Association (AMCA), which is more prescriptive to cover in detail aspects of the designing process (McGraw-Hill Construction, 2014b).

3.2.2 The future of BIM

BIM has influenced and changed the construction process and is positioned to be the preferred alternative to CAD systems. It has effectively changed/modified the way of design, construction, operation and management of the facility. The successful implementation of BIM can reduce the risks for all project stakeholders while enhancing their profitability and productivity. However, these may not be the only benefits that can be achieved by applying BIM as it is yet to develop by supporting new coming technologies.

Advancements in the development of mobile IT devices such as smartphones and tablets will provide the opportunity for online reporting and updating, which in turn results in more efficient decision making as well as communication. The cloud technology is developing rapidly providing the opportunities for sharing information over a network accessible to public or private bodies. These technologies can support BIM model accessibility and updating significantly (Azhar, Khalfan & Maqsood, 2012:15; Hardin, 2009).

The other complimentary application for BIM is 3D scanning which can be very helpful in maintenance and building repair, in particular. The current facility can precisely be scanned and compared to the last updated BIM model in order to identify the renovation and repair requirements. A semi-automated method for calculating the progress has been developed based on importing site digital photos to the BIM model, which can be helpful for the project manager (Zhang, Bakis, Lukins, et al., 2009:294). It also can help in equipment installation by importing the accurate scan of the equipment to the model to check any conflict or clash (Azhar, Khalfan & Maqsood, 2012:15).

Furthermore, 3D printers, which are very helpful for making prototypes of buildings for further study and investigation before actual construction of the building, are developing fast. This is going to replace the 3D model of the project which used to be made for providing a comprehensive view of the structure. This technology has improved the 3D visualization feature of BIM to a tangible and more practical model (Arayici, Coates, Koskela, Kagioglou, Usher & O'Reilly, 2011:7; Arayici, Egbu & Coates, 2012:75;Cesaretti, Dini, De Kestelier, Colla & Pambaguian, 2014:430). Thus, there is still the opportunity for BIM to grow and develop, which suggests that companies should consider taking the advantage of utilizing it as soon as they can.

3.3 BIM in South Africa

3.3.1 BIM application in South Africa: now and beyond

South Africa started adopting BIM applications since 2003, when A3 Architects used BIM for a $5.45 million project of the Glynnwood hospital. The design for this project was completed in three weeks by a 3D model including plans, sections and several elevations. A variety of residential projects, from a holiday house to a multi-unit complex, have also been designed by smaller firms using Building Information Modelling since 2004 (Rundell, Jul. 15, 2004).

The company Royal HaskoningDHV is utilizing Virtual Design and Construction (VDC). VDC is defined by Stanford University (s.a.) as "use of multi-disciplinary performance models of design-construction projects, including the Product, Work Processes and Organization of the design - construction - operation team in order to support business objectives". According to this definition, BIM is one of the tools for applying VDC. This technology has brought Royal HaskoningDHV significant savings in time and cost compared to the traditional methods which vary between 10 and 25%, depending on project size and complexity. The UNISA campus in Florida is one of the latest projects which have been constructed by this company, in which they have reduced the clashes to less than 50. They are also benefiting from this new technology in applying SANS standards (Charlton, 2014).

Besides the competitive feature of construction and the need to catch up with the world's fast pace in using new technology, there are also other motivations for South African firms to consider implementing BIM solution. From 2004, the Department of Minerals and Energy in South Africa aimed to save energy in buildings as a goal in its strategic plan. To achieving this target, two sets of standards were developed:

- Energy Efficiency in Naturally Ventilated Buildings – SANS 283
- Energy Efficiency in Artificially Controlled Buildings – SANS 204

These standards will be mandatory for incorporation into the South African National Building Regulations. This would lead BIM application to grow faster in South African industries as it allows them to fulfil the requirements of the Department of Energy for sustainable design while benefitting from other advantages that BIM can bring to their business (Department of Minerals and Energy, 2005).

One of the consultant companies who applied BIM for a project within South Africa is WSP. This company was the consultant for the Van Reenen's Pass project, which is a part of the N3 National route across the Drakensberg Mountains between Gauteng and Durban. WSP had been asked to plan and design the alternate route in 2007 and it is believed that transferring the design to BIM tools saved them significant time (WSP Group, 2013b; South African National Department of Transport, 2005). Civil and structural engineering consultants of BSM Baker, is another evidence of approaching 3D model technology and BIM on massive projects (CADEX, 2014).

In 2013, a significant BIM adoption growth was noted by Autodesk Gold Partner, CAD Corporation in the Gauteng province. It seemed that developing considerable amount of BIM-utilized projects by consultants provided the infrastructure for the construction firms to step towards BIM adoption (Kotze, Jun. 14, 2013).

Generally, it can be concluded that the movement towards utilizing BIM has started in South Africa. It is mainly adopted by consultant companies who experience the advantages of implementing BIM.

3.3.2 The reasons for limited BIM application in South Africa

There are some indicators showing that South African industries are not fully matured with regard to BIM application and BIM are yet to be adopted broadly. Strauss, the owner of Graphisoft South Africa, identified that there are several companies in South Africa who are applying BIM successfully from the design phase all through to the project delivery and facility management. He believes that the Southern African Development Community (SADC) already knows about BIM and its benefits for the first world countries. Strauss concludes that, the only reasons which may stop firms from turning to BIM application can be the lack of confidence in applying BIM project wide, and the lack of industry support from local suppliers to provide specifications of energy ratings on BIM models instead of 2D drawings (Strauss, 2012).

Booyens et al. (2013) in their study of BIM application in South Africa found that not a large number of contractor firms have the capacity to make use of BIM tools as it is quite costly for them to prepare the framework to utilize it. This also includes the cost of training as there are not enough BIM specialists for implementing BIM within a company. Larger South African construction companies such as WBHO, Murray & Roberts, Basil Read and Group Five have moved towards BIM adoption (Booyens, Bouwman & Burger, 2013). However, BIM is applied in a company on specific projects only and the usage is limited.

Referring to the study by Booyens et al. (2013), there are some local companies who are utilizing BIM in their international offices. However, despite experiencing its benefits, they still have doubt of using it for South African projects. The culture of sharing knowledge and information may need to be more widespread to prepare the background for accepting an integrated model (Booyens, Bouwman & Burger, 2013; Kotze, Jun. 14, 2013).

Moreover, clients are not convinced of paying or rather investing extra funds on BIM utilization and therefore engineers and contractors also avoid taking the risk of pioneering a new technology. There are some perceptions that BIM is not feasible in a country such as South Africa where the likelihood of strikes in the transport industry is high or where supply and demand of materials such as steel is not balanced (Booyens, Bouwman & Burger, 2013). However, this view is concluded from a limited number of interviews and might not be generalized. The assumption here is that, BIM is more applicable to first world countries where these issues are limited (Booyens, Bouwman & Burger, 2013). Thus, South African industries can be said to be in the early stages of BIM adoption, and training is a necessity to expedite this process (Booyens, Bouwman & Burger, 2013).

3.4 Chapter synthesis

The business impacts of BIM shows enhanced productivity in construction processes through cost cutting and time saving through efficient collaboration. There are many countries where companies in the AEC industry are exposed or even mandated by their governments to utilize BIM and report significant business achievements. South Africa has started applying BIM in some projects through a few companies. There are several BIM standards and guidelines published in different countries which are customized for their specific requirements in implementing BIM. The fast growth of IT, in terms of information and database management and cloud technology, will enhance and support BIM applications in the near future.

Chapter 4 - BIM Education

4.1 Chapter Introduction

This chapter provides an overview about BIM education. A brief history of BIM teaching is discussed and the current situation is provided of BIM programs in some pioneering countries. The strategies in BIM training are discussed as well as different methods of introducing BIM, including the variety of collaboration in the courses. The main challenges of teaching BIM are also highlighted. An overview of BIM teaching in South Africa is also provided. An outline of the topics provided in this chapter is illustrated in figure 4.1.

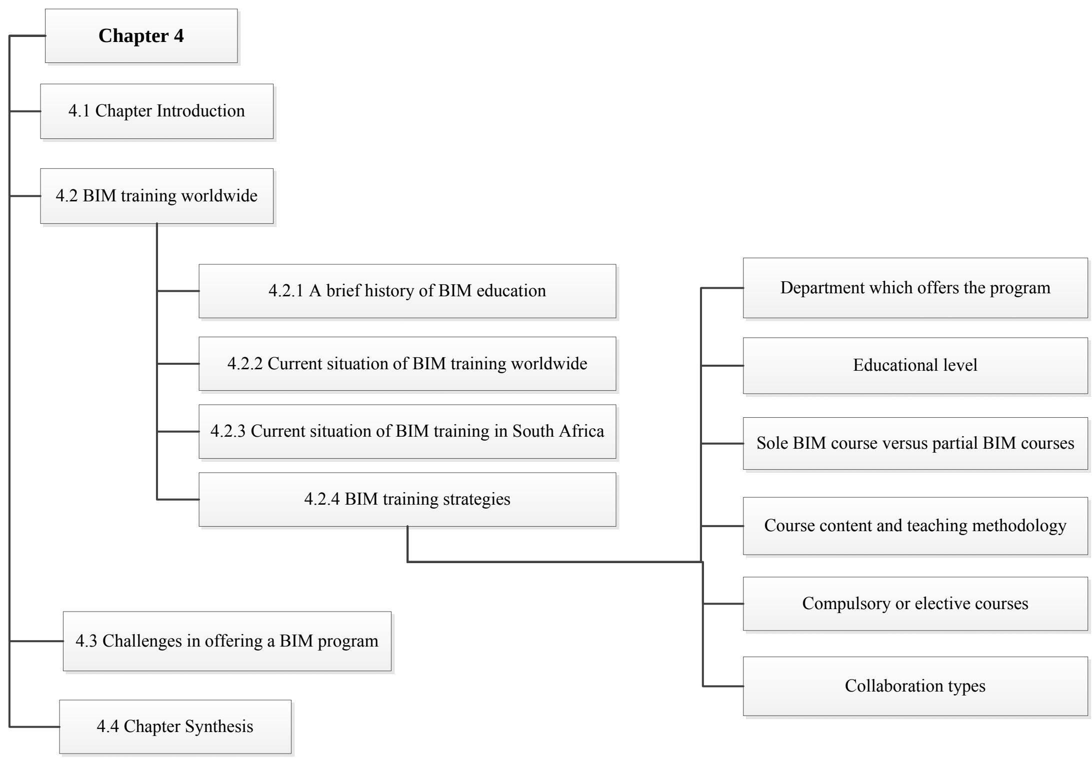

Figure 4.1: Chapter 4 Diagram

4.2 BIM training worldwide

4.2.1 A brief history of BIM education

Currently, a large number of universities and institutes around the world are exposing their students to BIM technology, with different methods, approaches and scopes. According to Barison & Santos (2010a), this process started quite a while back, as Georgia Institute of Technology is one of the pioneering institutes that considered BIM subject in their researches since the 90s. There were also some early bird programmes in some educational institutes in the USA that introduced BIM software to enhance students' technical skill, such as the college of Architecture at Texas A&M University. Other institutions in the USA however, only started exposing students to BIM within their programmes after 2003. The University of Minnesota, Madison Area Technical College and Worcester Polytechnic Institute are some examples of those who added some BIM subjects in their undergraduate or graduate programmes (Autodesk, 2007; Salazar, Mokbel & Aboulezz, 2006).

The California State University of Chico started their BIM teaching in 2004. One year later, Nevada University started to integrate teaching BIM in its curricula. According to the survey on 90 universities in the USA, only 19% of them had engineering graphics or graphical communication in their curricula in 2005 and 73% were demanding graphic communication and/ or surveying. The study showed that there was not much place for developing 3D models as a medium for communication (Russell & Stouffer, 2005:118). However, in 2006, Pennsylvania State University exposed students to an Integrated Design Studio by applying BIM while the University of Utah, Montana State University, Brigham Young University and New Jersey Technical Institute also started some changes in their curricula for their architecture schools. In 2007, after implementing a collaborative project amongst students, the Auburn University started requiring a BIM model to be handed in by undergraduate students in their culminating thesis project. Students at Wyoming University also had the opportunity to develop a collaborative model during their undergraduate studies (Barison & Santos, 2010a; Berwald, 2008:1; Deborah & Ryan, 2008; Hedges, 2008:311; Hu, 2007; Kymmell, 2008; Scheer, 2006:2006; Taylor, Liu & Hein, 2008:2; Önür, 2009).

The rate of BIM courses in universities grew rapidly. For example, at Texas Tech University a course on BIM required students to first pass a combined course of building technology and representation. The Oklahoma University offered a multidisciplinary course to teach the process and the use of the software. Also, a multidisciplinary course was introduced at Stanford University to enable students to be qualified for modelling and analysing (AIA, 2008; Barison & Santos, 2010a; Rex, Park and Kox, 2008).

While BIM was integrated as part of different courses in the University of Wisconsin- Milwaukie, the California Polytechnic State University introduced a single BIM course for architecture, engineering and construction management students (Barison & Santos, 2010a; Dong, 2009; Dong, Doerfler & Montoya, 2009:1). Barison & Santos (2010a) report that Pennsylvania State University, Georgia Tech, University of Southern California, Montana State University and University of Wyoming were the first to apply BIM teaching.

The Chinese Tongji University started offering a BIM program in 2005 by providing a collaborative environment for civil engineering students (Barison & Santos, 2010a). Also in 2008, BIM replaced 2D modelling in architectural science and technology course for architecture students at the Queensland University of Technology. The focus of this course was on enhancing students' knowledge about BIM processes and collaboration rather than on using the software (Nielsen, Fleming & Kumarasuriyar, 2009). Technion-Israel Institute of Technology also mandated the course of Communicating Engineering Information for all the civil engineering students, since 2008 (Sacks & Barak, 2009:30). The Norwegian University of Science and Technology (NTNU) considered providing BIM courses in their curricula since 2010. A variety of research topics were investigated on this subject (Wong, Wong & Nadeem, 2009).

4.2.2 Current situation of BIM training worldwide

While industries are considering adopting new technologies and tools, university graduates are expected to be knowledgeable in terms of the latest information technology and project delivery methods in addition to the latest aspects of construction such as sustainability and energy consumption (Johnson & Gunderson, 2010; Smit, Wall & Betts, 2005). It is common to assume that universities should motivate the industry for adopting changes and for updating the communication and integration methods (Becerik-Gerber, Gerber & Ku, 2011:411).

A survey carried out in the USA in 2011 on 101 programmes showed that almost 50% of them included BIM courses while a majority were planning to integrate BIM in their curriculum, even as one single course, within two years. The programmes in this survey consisted of architecture, architectural engineering, civil engineering, civil engineering technology, architectural engineering technology, construction engineering, construction engineering technology and construction management (Becerik-Gerber, Gerber & Ku, 2011:411).

Currently, there are quite a large number of academic courses or professional workshops on BIM provided by universities or institutes (Becerik-Gerber, Gerber & Ku, 2011:411). In some countries, BIM education is provided through universities during a degree programme while in others it is provided through short courses and workshops to enhance BIM awareness for the individuals. Some companies prefer in-house training for their employees in order to improve their BIM knowledge and productivity (Taylor, Liu & Hein, 2008:2; Poerschke, Holland, Messner & Pihlak, 2010:575). Tables 4.1 and 4.2 show some of the universities around the world that are facilitating BIM courses for their students, for postgraduate and undergraduate programmes respectively (Barison & Santos, 2010b:1; Becerik-Gerber, Gerber & Ku, 2011:411; Georgia Tech, s.a.; Montana State University, s.a.; Pennsylvania State University, 2008; Poerschke, Holland, Messner & Pihlak, 2010:575; Sacks & Barak, 2009:30; Sacks & Pikas, 2013; Taylor, Liu & Hein, 2008:2; University of Southern California, 2013a; University of Southern California, 2013b; University of Stanford, 2014a; University of Stanford, 2014b; University of Wyoming, s.a.; George Mason University, s.a.; Luleå University of Technology, s.a.; Milwaukee School of Engineering, s.a.; MIT, s.a.; NYC Polytechnic School of Engineering, s.a.(a) ; NYC Polytechnic School of Engineering, s.a.(b) ; Purdue University,s.a ; Technion, 2014a; Technion, 2014b; University of New South Wales, 2013; University of Washington, 2014).

These universities are either ranked as pioneer universities in BIM education in Barison & Santos (2010b:1), or the universities have published their work in appropriate journals (Sacks & Pikas, 2013) or are mentioned in Sacks and Barak's paper (Sacks & Barak, 2009:30).

Table 4-1: Sample of universities offering BIM courses for postgraduate programme

University	Course	Course Definition by the department	Department
Pennsylvania State University (USA)	AE 597G: Building Information Modelling Execution Planning	"The application of BIM on AEC projects and within AEC companies"	Architectural Engineering
Georgia Tech (USA)	COA 8901: Building Information Modelling: Case Studies	"BIM, from a technology and design and building practice perspective, by reviewing some case studies to understand better the impact of BIM and developing new case studies to add to the current literature"	Architecture
Technion (Israel)	019627: Advanced BIM	"Principles of building information capturing parametric, object-oriented modelling, capturing design intent, visualization, engineering analyses, fabrication detailing and automation, interoperability and model servers, IPD"	Architecture, Engineering, Construction
NYC Polytechnic School of Engineering (USA)	CE 8243: Construction Modelling Techniques	"Development of 2D and 3D design documents, BIM and their associated databases, using state-of-the-art design and management systems"	Civil Engineering

University	Course	Course Definition by the department	Department
NYC Polytechnic School of Engineering (USA)	CE 8303: Information Systems in Project Management	"Information management over the life of a project by applying 3D BIM model and 4D and fully integrated and automated-project processes (FIAPP) that integrate 3D computer models, simulation, cost estimating, scheduling, procurement and information technology"	Civil Engineering
University of Washington (USA)	CM 515: Advanced Project Management Concepts	"Examination of innovative techniques for planning and managing construction projects including use of time-phased, 3D BIM Models; sustainable construction techniques; and web-based project management tools"	Built Environments Construction Management
Luleå University of Technology (Sweden)	ITC Euromaster: Virtual Construction	"Implement model based quantity take-off from a BIM model and deliver a net cost estimate of the construction project to plan the construction project"	Civil and Environmenta l Engineering

Table 4-2: Sample of universities offering BIM courses in an undergraduate programme

University	Course	Course Goal as defined by the department	Department
University of Southern California (USA)	CE 470: BIM and Integrated Practices	"Coordination of design and construction; information management throughout building lifecycle; project delivery systems and technologies for integrated practice"	Civil Engineering
University of Southern California (USA)	CE 570: BIM for Collaborative Construction Management	"Multidisciplinary and geographically distributed virtual project teams used to simulate engineering and construction problems for projects selected in collaboration with industry partner"	Civil Engineering
Montana State University (USA)	DDSN166: REVIT 1, DDSN266: REVIT 2	"Introducing Parametric Design and BIM"	Civil Engineering
Technion (Israel)	014008: Graphic Engineering Information	"Develop understanding and capability in representation and communication of engineering information in order to establish civil engineering projects."	Civil and Environmental Engineering

University	Course	Course Goal as defined by the department	Department
University of Wyoming (USA)	5600: Collaborative BIM Design	"An advanced building design course integrating architectural and engineering skills, using BIM software and simulating a professional IPD experience by collaborating with a practicing architect on a real-world project"	Architectural Engineering
University of Stanford (USA)	CEE 110/210: Building Information Modelling	"Creation, management, and application of BIM, Process and tools available for 2D and 3D representations of building components and geometries. Organizing and operating on models to produce architectural views and construction documents, renderings and animations, and interface with analysis tools"	Civil & Environmental Engineering
Technion (Israel)	014008: Graphic Engineering Information	"Develop understanding and capability in representation and communication of engineering information in order to establish civil engineering projects."	Civil and Environmental Engineering
University of New South Wales (Australia)	BENV7151: Parametric Design Using BIM	"Developing a deeper understanding of the technology of BIM with particular emphasis on modelling parametric building components"	Built Environment (Architecture Programme)
MIT (USA)	4.501: Architectural Construction and Computation	"Investigating the use of computers in architectural design and construction, beginning with a pre-prepared design computer model, which is used for testing and process investigation in construction; Exploring the process of construction from all sides of the practice."	Architecture
Purdue University (USA)	CGT 460: Building Information Modelling for Commercial Construction	"The study of commercial jobsite planning and coordination, emphasizing on trade coordination, visualization, and communication and including collision detection reports, construction animations, and professional presentations."	Computer Graphics Technology

University	Course	Course Goal as defined by the department	Department
George Mason University (USA)	290: Engineering Computation and Design;	"Introducing civil engineering design process, including methods, technologies for spatial data acquisition, emphasizing land measurements, mapping, and surveying, 2D and 3D computer-aided design techniques and application of digital computation"	Civil and Infrastructure Engineering
Milwaukee School of Engineering (USA)	AE-1312: Introduction to Building Information Modelling I	"The basics of CAD drafting and BIM including basic drawing and editing of details in AutoCAD, 3D building modelling, and an introduction to the concept of utilizing REVIT Building to produce estimates"	Architectural Engineering and Construction Management

4.2.3 Current situation of BIM training in South Africa

In South Africa, there are some efforts from universities to introduce BIM to students of architecture, civil engineering and construction management. Often, this appears to be ad hoc and on an informal basis (ICE-SA, 2014; University of Pretoria, 2014). The University of Witwatersrand has recently considered including BIM in their degree programmes including BSc in Construction Studies, BSc Honours in Quantity Surveying and BSc Honours in Construction Management (University of the Witwatersrand, 2014).

Universities are yet to provide graduated engineers with a capability of applying BIM. Very often companies that apply BIM provide in-house training for their employees. For instance, Royal HaskoningDHV train their staff through modules offered by Stanford University for applying VDC solution, which includes using BIM as one of its tools (Charlton, 2014). However, if the BIM utilization of the company is not highly matured or broad enough, individuals will use some online courses or videos to learn more about it (Niemandt, 2014).

4.2.4 BIM training strategies

The benefits and advantages of a technology can be achieved only if specialists are available to apply it. The rapid spreading of Building Information Modelling has meaningfully increased the demand for skilful BIM users around the world. Therefore, the facility to train experts in BIM application is important in professional education (Barison & Santos, 2010a; Nejat, Darwish & Ghebrab, 2012; Sacks & Barak, 2009:30; Salazar, Mokbel & Aboulezz, 2006; Fox & Hietanen, 2007:289; Hartmann

& Fischer, 2008; Young, Jones & Bernstein, 2008). A number of researches (e.g. Becerik-Gerber, Gerber & Ku, 2011:411; Johnson & Gunderson, 2010; Lang, Cruse, McVey & McMasters, 1999:43) have reported that students' readiness for carrying professional responsibilities is dependent on the following three major factors:

- Collaboration capability and efficient communication skills for working as a team member
- Holistic awareness about their work including social, environmental and economic aspects of their career
- Practical skills for using appropriate technologies

Tatum (2010) is of the opinion that there are four attributes that any construction engineering programme offered by universities should encompass, namely (i) technical fundamentals, (ii) materials of construction, (iii) construction-applied resources, and (iv) field operations. These elements in structured programmes would result in a reasonable coverage of construction management topics in construction engineering courses (Tatum, 2010). Bearing in mind that sufficiently-matured BIM tools can be an alternative to current construction management tools (Moon et al., 2012:67), these key features should be covered in any of the eight methods that introduce BIM. Two of these features focus on technical aspects while the other two are more practical (Tatum, 2010). Introducing BIM while exposing students to the construction processes can satisfy all these attributes. In addition, teaching students about the software and how to apply the acquired knowledge into a virtual model is significant for such a programme.

Since BIM provides a collaborative environment that influences the whole project team, training is needed in the company or university (Lang, Cruse, McVey & McMasters, 1999:43). Hietanen et al. (2008) are of the opinion that learning the concept of BIM comes prior to becoming proficient in its application. Kymmell identifies collaboration as the most vital part of learning BIM concepts (Hietanen & Drogemuller, 2008:24; Kymmell, 2008). Civil engineering students in particular need to be prepared through undergraduate curricula in order to show their knowledge when communicating and collaborating via 3D models (Sacks & Barak, 2009:30).

According to a study by Dean (2007), teaching BIM is mandatory for construction management students considering that around 70% of the companies who participated in his survey were either adopting or planning to apply BIM. 75% of the surveyed companies preferred employing individuals with BIM expertise (Dean, 2007). Woo (2006:12) states that ability and knowledge of the students regarding BIM and its application is necessary for their future profession. Currently, almost 45% of contractors in the USA are investing in BIM training while 41% of them spend money for the software to apply BIM. Furthermore, BIM training was ranked second for investment by contractors into BIM development plans. This shows the high level of demand for BIM specialists (McGraw-Hill Construction, 2014a).

Becerik-Gerber et al. (2011:411) investigation of 101 programmes in the USA found that around 52% of respondents in engineering schools have a specific BIM course while nearly 76% of respondents were learning using BIM on projects in classes.

There are 20 educational principles verified by the BIM education working group of the Australian Institute of Architects and Consult Australia (2012), as listed in table 4.3.

Table 4-3: educational principles verified by the BIM education working group of the Australian Institute of Architects and Consult Australia (2012)

No.	Educational Principles
EP1	BIM Education is the shared responsibility of academia and industry.
EP2	BIM Education addresses the requirements of current professionals (irrespective of formal qualification), future professionals (students) and their teachers/trainers.
EP3	BIM Education encompasses all modes of BIM Learning (tertiary courses, industry workshops, online media and on-the-job training).
EP4	BIM Education ranges from spreading awareness to developing highly specialised skills.
EP5	BIM Education should be made available to all those who need it in formats which are mindful of their respective disciplines, specialties, roles, education and experience levels.
EP6	Collaborative BIM Education should be developed and delivered collaboratively.
EP7	Every individual within the construction industry is a potential BIM Learner, and every BIM Learner is a potential BIM Learning Provider.
EP8	BIM adoption within industry and academia is a significant change process (technical, procedural, cultural) which requires a significant investment in systems and people.
EP9	Accreditation and professional associations should engage with universities to develop new collaborative BIM courses or to integrate the principles and technologies of multidisciplinary collaboration into their existing curricula.

No.	Educational Principles
EP10	Tradespeople and para-professionals stand to benefit and contribute to BIM and its wide-ranging effect on project lifecycle phases and construction supply chains. The VET sector should incorporate data-rich models and multi-party collaborative workflows into educational curricula and delivery strategies.
EP11	There is need to de-mystify the BIM process and develop integrated, coordinated and viable BIM training modules delivered via professional associations. These training modules should align with university/TAFE curricular and tightly complement their educational deliverables.
EP12	There is a need for BIM-ready graduates. Availability of adequately prepared graduates will minimize (or at least refocus) the training delivered by AEC organisations.
EP13	There is a need for regular BIM Learning opportunities and non-technical BIM learning materials, specifically tailored for senior and executive staff.
EP14	There is a need to consider how to assess and improve the BIM knowledge, skill and experience of current professionals, para-professionals and tradespeople.
EP15	There are many BIM competencies which need to be learned by individuals involved in the design, construction and operation of facilities
EP16	A collaborative CPD programme is an integral part of the Collaborative BIM Education Framework.
EP17	A web-hosted, socially connected BIM Learning Hub at the core of the Collaborative BIM Education Framework is needed.
EP18	A BIM Learning Module is a collection of BIM topics, customised for a target audience, and delivered at a defined level of difficulty.
EP19	An academic framework informed by research, discipline professionals and other industry stakeholders is a pre-requisite for delivering Collaborative BIM Education within tertiary institutions.
EP20	The establishment of a well-structured and well-funded BIM institution is essential to facilitate the development and delivery of Collaborative BIM Education across the construction industry.

The main principles for teaching BIM can be summarized as i) the necessity of involving the professional community into the courses and bringing industries practical experiments and needs to the curricula,; and ii) clarifying the ambiguities within the BIM process to introduce the integrated and collaborative features of it by engaging professional associations (NATSPEC , 2014).

According to Barison & Santos (2010a), there are eight main ways for teaching BIM through which students will be exposed to its application, namely: Digital Graphic Representation (DGR), Workshop (short duration courses), Design Studio, a BIM course, Building technology, Construction management, Thesis projects and internships. Sometimes the programme might be a mixture of these means. According to Barsin's survey (Barison & Santos, 2010a), Design Studio was the most popular course for introducing BIM to architects, followed by DGR and a BIM course while a particular BIM course was the most common way of exposing civil engineering, architectural engineering and construction management students to BIM. Design Studio and DGR were ranked second and third options for engineering students.

The programmes may vary considerably in that some of these features can be combined to provide a better structured programme. Kymmell (2008) offered to improve modelling and analysing skills of the students in the first two years by focusing more on technical aspects, while in the next years the emphasis would be more on developing team work and multidisciplinary skill by considering a collaborative approach. In the final year, students should have the opportunity to work on a real construction project while collaborating with a company (Barison et al.; 2010b).

The main differences in the programmes would be related to issues such as the department which is facilitating the programme, education level of the students, offering a single BIM course or some limited focus BIM courses, being an elective or mandatory course, and the methods of collaboration. A discussion of these features is presented in the sections that follow.

Department which offers the module

The department which is promoting BIM-enabled courses can be architecture, engineering or construction management. Note that collaboration may be arranged amongst different disciplines and departments. In this study, the main focus is on civil engineering and construction management departments. The course focus can be either on modelling aspects or on the construction phase, which is likely to be dependent on the department providing the programme (Nejat, Darwish & Ghebrab, 2012). The objective of the programme for undergraduate civil engineering students, as provided for some of the universities in table 4.2, include: better understanding of design process and construction through the project life cycle; managing the information in a multidisciplinary environment; practicing integrated and collaborated team work; and, developing verbal, graphical and online communication capabilities of the students. Enhancing the technical skills by introducing parametric models and the use of software for creating models are other aspects of some of these courses. In general, students should learn how to use a BIM model for understanding, analysing and improving construction processes (Mutai et al., 2010; Barison & Santos, 2010b:1).

Enhancing students' opportunity to communicate with industry and for working on a real-world model in collaboration with companies should also be considered (Kymmell, 2008; Barison & Santos, 2010b:1).

Education Level

The academic levels of the students who benefit from the course would be varied from undergraduate level to Master of Engineering/Science or even Ph.D. Also, there are some specific programmes for professionals from industry called Continuing Professional Development/ Education (CPD/CPE) for enhancing the BIM knowledge of experienced engineers or architects. According to a survey by Johnson et al. (2010) on 43 programmes of the Associated Schools of Construction (ASC), more than 30 programmes were offered at undergraduate level. The goal of a graduate programme may vary due to different undergraduate backgrounds.

Stand-alone BIM course modules versus BIM integrated into other course modules

The module can be offered as a dedicated BIM or as course with a BIM core unit, which collaborates effectively and gradually provides a comprehensive attitude towards BIM (Techel & Nassar, 2007; Hietanen & Drogemuller, 2008:24; Barison & Santos, 2010b:1). Camps states that all the disciplines should try adding BIM in their courses and integrating it with other disciplines courses (NIBS, 2008c). Johnson et al. (2010) in a study of 43 programmes of ASC associates finds that, three different approaches can be considered for adding BIM into a programme, namely stand- alone BIM courses, partial focus on BIM courses by integrating into other courses or a combination of both in a single programme. 22 of 43 programmes studied by Johnson offered courses with limited focus on BIM.

Course content and teaching methodology

As discussed by Sacks and Barak (2010) teaching BIM should be started early in civil engineering teaching to provide students an understanding of the information used for designing. Therefore, regardless of the tool which is applied, BIM should be applied in any design course. Sacks and Barak find that, implementing such a foundation for students would provide them with some fundamental knowledge in the field.

It is logical to start with the main concepts of BIM and then using case studies while the students are part of a team to have the opportunity for collaborating and interacting as suggested by Becerik-

Gerber (2008). Hietanen & Drogemuller (2008) observe that working on a real-world model would make better sense and would enrich the understanding of the students (Barison & Santos, 2010b:1).

Table 4-4: Main topics and concepts in some of the BIM courses

Category	Main Topic	Offered course code and name
Engineering graphics and drawings	• Visualization skill • Practical working with 3D CAD tools • Providing isometric and sectional views • Understanding the background of physical component of the model • Understanding geometry and spatial relationships	5600: Collaborative BIM Design CEE 110/210: Building Information Modelling 290: Engineering Computation and Design; AE-1312: Introduction to Building Information Modelling I CEE 110/210: Building Information Modelling 014008: Graphic Engineering Information
Basic concepts of BIM	• Understanding parametric model and object modelling • Understanding graphical user interface technology • Understanding relational database technology and database processing techniques • Understanding the analytical mode • Basic building and structural objects and quantity take-off	DDSN166: REVIT 1, DDSN266: REVIT 2 CEE 110/210: Building Information Modelling 014008: Graphic Engineering Information BENV7151: Parametric Design Using BIM 4.501: Architectural Construction and Computation AE-1312: Introduction to Building Information Modelling I
Engineering management	• Understanding the properties linked to the building components and information management • Coordinating design and construction • Quality control of the model and updating it throughout project life cycle	CE 470: BIM and Integrated Practices 014008: Graphic Engineering Information CEE 110/210: Building Information Modelling 014008: Graphic Engineering Information 4.501: Architectural Construction and Computation CGT 460: Building Information Modelling for Commercial Construction
Collaboration	• Understanding other disciplines requirements while Mechanical, Electrical and plumbing information are added to the model • Managing to avoid the clashes and overlaps • Understanding project delivery system and techniques for integrated practice	CE 470: BIM and Integrated Practices CE 570: BIM for Collaborative Construction Management 014008: Graphic Engineering Information CEE 110/210: Building Information Modelling 5600: Collaborative BIM Design CGT 460: Building Information Modelling for Commercial Construction

There are common concepts which some universities aim to convey to students with the 12 courses shown in table 4.2. These concepts can be categorized into four main groups as shown in table 4.4. Each of these categories satisfies specific requirements and goals of a BIM course in at least half of the courses listed in table 4.2. Some courses are more focused on engineering graphics and drawings to introduce BIM as a tool, while some of them concentrate on enhancing knowledge of construction processes by applying BIM. There are courses with specific topics on basic concepts of BIM, while other courses convey these concepts through collaboration or management topics.

As stated in table 4.5, there are some schools where case studies are the main core of the course while others are based on lectures and laboratory activities. The project or case study in some universities is done in a group to enhance collaboration ability, although, some prefer individual assignments at least for the first part of the programme (Georgia Tech, s.a.; Pennsylvania State University, 2010; University of Southern California, s.a. (a); University of Southern California, s.a. (b); Luleå University of Technology, s.a.; Milwaukee School of Engineering, 2013; MIT, s.a.; Technion, 2014c; Technion, 2014d; University of New South Wales, 2013).

Table 4-5: Teaching Methodology in some of the pioneer universities

University	Module Code/ Name	Methodology of Teaching
Pennsylvania State University (USA)	AE 597G: Building Information Modelling Execution Planning	• Lectures, demonstrations, in class discussion, project presentations • Individual assignment to explore a specific use of BIM • Group assignment to investigate in detail the implementation of BIM on a particular project • Final group project to implement the BIM Execution Planning Guide on a specific project or explore a BIM implementation strategy within a company
Georgia Tech (USA)	COA 8901: Building Information Modelling: Case Studies	• Reading and discussion • Group case study on BIM effects on design processes, construction, or building procurement and commissioning; collaboration with engineering consultants, and others

University	Module Code/ Name	Methodology of Teaching
Technion (Israel)	019627: Advanced BIM	• Formal lectures • Hands-on group projects
Technion (Israel)	014008: Graphic Engineering Information	• Theoretical content • Discussions • Class exercises
Luleå University of Technology (Sweden)	ITC Euromaster: Virtual Construction	• Theoretical lectures • Individual practical exercises in a computer environment • Group project to apply knowledge from the first part in a project
University of Southern California (USA)	CE 470: BIM and Integrated Practices	• A combination of lectures hands on software training experiments with new technologies and discussions
University of Southern California (USA)	CE 570: BIM for Collaborative Construction Management	• A combination of software tutorials, lectures, case studies, peer-to-peer learning and discussions
University of New South Wales (Australia)	BENV7151: Parametric Design Using BIM	• Lectures • Computer lab classes • Practical exercises using a range of BIM tools
MIT (USA)	4.501: Architectural Construction and Computation	• Lectures • Group Assignments • Group Final Presentation
Milwaukee School of Engineering (USA)	AE-1312: Introduction to Building Information Modelling I	• Lecture • A laboratory exercise to reinforce the principles presented in lecture

Compulsory or elective courses

Another option to be considered is whether the course should be made mandatory or elective for the students. As reported by Johnson et al. (2010), for almost half of 43 programmes (N=21) of ASC members, BIM courses were mandatory while the other half were elective courses.

Collaboration types

Collaboration options for the programme may vary from single discipline to multidisciplinary approach which is discussed in more detail in the following section.

Barison & Santos (2010a) investigation of 103 universities found that the introductory BIM course was offered as an interdisciplinary course amongst 90% of them while a multidisciplinary course was yet to be developed. The course was taught either to architecture, engineering or construction management students, exclusively. For instance, Tongji University implemented such a facility for construction management undergraduate students and Queensland University of Technology had a programme for graduate architecture students. In both of these examples, students developed a simulated model, and collaborated with other students from the same discipline (Hu, 2007, Nielsen, Fleming & Kumarasuriyar, 2009).

Programmes offered in some universities such as Pennsylvania State University, Oklahoma University, Auburn University, California Polytechnic State University, Texas A&M University, Georgia Tech and University of Maryland, were based on a multidisciplinary approach. Thus, they provided an opportunity for the students to develop models through real collaboration with at least one student from another field (Hietanen & Drogemuller, 2008:24). A different approach of a multidisciplinary course was pioneered by University of New South Wales in Australia where students developed a shared model from some courses using the IFC standard model (Barison & Santos, 2010a; Plume & Mitchell, 2007:28).

Another practical innovative way of teaching students to build a collaborative model is through distance collaboration. This happened amongst University of Nebraska-Lincoln, Montana State University and the University of Wiyoming. Through this programme, architecture and engineering students collaborated effectively to address an architectural problem.(Hedges, 2008:311) Also, the Ferris State University and Oklahoma University were aiming to have a distance collaboration BIM programme as a cross university course (Dilg, 2010).

As discussed by Heitanen et al. (2008:24), it is more practical to introduce BIM concepts and principles first, and then extend it to interdisciplinary application and collaboration. Undergraduate students can thus master the tools, in first and second year, and get to know more about practical teamwork and collaboration in last two years (Kymmell, 2008). This also has been experienced in the

Pennsylvania State University where assignments are defined for students from different disciplines (architecture, landscape architecture, construction, structural, mechanical and electrical department) to modify the design of a school building through a unique BIM model. This task, which was defined to get done through Design Studio, resulted in a centralized collaboration at both undergraduate and postgraduate levels. It also helped the faculty to observe the concept of BIM and its likely benefits (Poerschke, Holland, Messner & Pihlak, 2010:575).

4.3 Challenges in offering a BIM programme or module

Due to the holistic approach of BIM, it can be introduced through a variety of courses rather than through a single course. The decision making for adding BIM to a current curriculum can thus be complicated and one of the most challenging trends for construction management programmes (Johnson & Gunderson, 2010). According to the participants' discussion in III BIM workshop in 2007 (Bronet, Cheng, Eastman, et al., 2007, Barison & Santos, 2010a), there are some challenges regarding teaching BIM due to the method, software and organizing content of the lessons (Barison & Santos, 2010a; Taylor, Liu & Hein, 2008:2). Kymmell (2008) identifies the root of these challenges to be three main issues relating to software usage, BIM process understanding or the circumstances of the academic environment (Barison & Santos, 2010a; Bronet, Cheng, Eastman, et al., 2007).

Guidera (2007) through a survey of 22 institutions in the USA reports that in 2007, the development of BIM courses in their curriculum was not widespread (Barison & Santos, 2010a). Although there are universities that have yet to adopt interdisciplinary BIM courses, Scheer (2006) is of the opinion that having such a programme in the academia would be imperative soon. However, the lack of collaborative courses for programmes which need this interdisciplinary communication is another barrier that needs to be addressed before integrating BIM into degree programmes (Johnson et al., 2010).

The BIM education working group of the Australian Institute of Architects and Consult Australia finds that adding BIM to the curricula in the universities is not a simple matter and requires significant changes which are likely to be resisted ((NATSPEC) Rooney, 2014). The main challenges identified by this group include:

- Adding a new subject in a curriculum which is already full and compressed
- Not having instructors with enough BIM knowledge and experience
- Changing instructors' curricula while some of them prefer to keep their traditional way of teaching or are reluctant to being trained for new subjects
- Being incapable of linking the old-style teaching method to collaborative courses

The second barrier, in addition to the shortage of educational resources, funding and administration support are the main obstacles in BIM integration into curricula (Becerick-Geber et al., 2011:411, Johnson et al., 2010). Becerick-Geber et al. (2011:411) also find that not having a formal and accredited BIM course, made it more difficult to adopt BIM in curricula.

The difficulty and complexity of software and tools can be another reason for academia to avoid offering courses in BIM (Johnson et al., 2010).

4.4 Chapter synthesis

As the demand for BIM specialists has increased significantly, there are a large number of universities and institutes around the world that are exposing their students to BIM. BIM training was started in Georgia Institute of Technology since 90s, which is one of the pioneering institutes that considered BIM subject in their researches.

Programmes are offered in different academic levels and departments based on several methodologies. Some of the courses are more focused on technical concepts of BIM, while others consider a practical construction approach. As BIM implementation is going to spread more in the AEC industry, there will be more demand to train students in its application.

Chapter 5 - Methodology of the research

5.1 Chapter Introduction

This chapter provides the methodology employed in executing this study. An outline of the topics provided in this chapter is provided in figure 5.1.

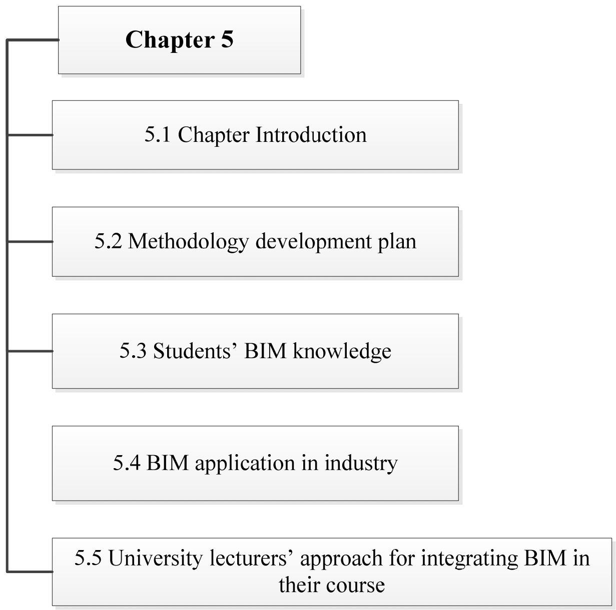

Figure 5.1: Chapter 5 diagram

5.2 Methodology development plan

For the purpose of this study, four consecutive approaches were required. First an extensive review of the literature was done to identify the main advantages which can be brought to the construction process by implementing BIM, and to identify barriers in adopting this innovative technology. A wide range of resources were studied on BIM integration in university courses and programmes to define strategies and principles of teaching BIM.

A review of literature gave pointers to the current BIM status in practice as well as the role universities have played in training BIM professions. To understand how construction processes can be improved by teaching BIM to the students, an understanding of the current situation of BIM usage in South Africa was required. It was necessary to establish the current status of teaching at academic institutions in order to address industry needs. Also, the attitude of academic staff was one of the principle concerns for integrating BIM into the current curricula. These issues formed the foundation for developing the survey data to collect three different sets of data. The questionnaire and data collection procedures are discussed in sections 5.1, 5.2 and 5.3 for each of these three surveys. Finally, the survey results are discussed after which proposals are made toward enhancing students' awareness of improving the construction processes by applying BIM.

5.3 Students' BIM knowledge

To evaluate the level of awareness and application of BIM amongst South African students, an online survey instrument was used. Considering the fact that the questions were not very detailed and only general knowledge of the students was targeted, the questionnaire was deemed to be more appropriate than interviews or other surveying tools. The questionnaire consisted of four sections:

- The university name and field of study (2 questions)
- The students' knowledge of Computer Aided Design (CAD) tools in general and BIM in particular (11 questions)
- The students' ability for interpretation of the software output and understanding of the interfaces (8 questions)
- The students' general knowledge regarding BIM (7 questions)

The questions were formulated based on the output of BIM courses and defined goals of BIM software programs as showed in tables 4.1 and 4.2, in addition to the course descriptions by Sacks and Barak (2009:30). A cover letter and invitation to distribute the survey amongst the 4th year students was sent via email to the heads of departments for civil engineering, construction management and quantity surveying from six universities in South Africa, including: Nelson Mandela Metropolitan University, University of Cape Town, University of Pretoria, University of the Witwatersrand, University of Johannesburg and Stellenbosch University. It is worth mentioning that the quantity surveying department of the University of Cape Town did not contribute in the survey. Nelson Mandela Metropolitan University has only a department of construction and management.

The cover letter included a link to the online survey administrated through a web based service (CheckBox). The invitation and subsequent reminder email were sent to the heads of departments within a four week period and a total of 195 responses were received. 28 responses were incomplete and skipped one or two sections, which were excluded from the analysis. Besides, 4 responses were from architecture and/or urban planning departments which were not targeted in the survey. The questions allowed respondents (except the first section) to make appropriate choices and, respondents could choose their responses from four potential options: “I am fully aware of it”, “I am familiar with the concept”, “I have heard about it; but have not personally experienced it”, and “I have not heard about it”. There were 2 responses where only “I have not heard about it” option was chosen for all the questions, which were ignored in the calculation, as it seems not to be a reliable response. Finally, 161 responses were considered in the survey analysis.

Data from the survey was downloaded, and exported to Microsoft Excel for further analysis. Due to the nature of the questionnaire, descriptive statistics were mostly used for analysing the survey data. As the responses were anonymous, it was checked through Response Guide of the online tool, to make sure there were no duplicate respondents.

5.4 BIM application in industry

To evaluate the gap between the requirement of industry and academic programmes, it was necessary to understand the extent to which South African industries are adopting BIM or the reasons for not taking this step towards this new technology. As there were specific questions that had to be answered, and because a large population would provide a better result than a small sample through interviews, an online questionnaire was chosen for this survey. The questions were grouped into three categories, namely:

- Company background (7 questions)
- Respondents background (in 3 brief questions)
- Company's BIM experience and expectations (two sets of questions, 4 and 6 questions respectively)

Under company background, beside some question to identify the nature of the work and size of the company, it was important to determine if the company was applying BIM technology or not. The last category (Company's BIM experience and expectations) was different for companies with BIM experience and those that were not exposed to BIM. The interviewee background was for validating the respondent and to verify if he/she was qualified to respond to the questionnaire.

The questionnaire was structured based on similar surveys (Nejat, Darwish & Ghebrab, 2012; Taiebat & Ku, 2010) and was tailored for the specific needs of this research. A cover letter and invitation to participate was electronically sent to a list of individuals in almost 30 companies who attended short courses at Stellenbosch University. A link was provided to the survey in the cover letter. The survey was managed by an electronic survey provider (CheckBox). After sending a reminder after four weeks, only 11 responses had been received. For extending the population, another approach was followed. The main idea behind the survey was to identify the gap between industry needs and academic outputs. Thus companies that applied BIM and experienced barriers in implementing BIM could be a qualified target group for the questionnaire. A cover letter was thus sent via email to the main South African distributers of BIM software including Tekla, Revit, ArchiCAD and Graphisoft. These companies were requested to distribute the e-survey amongst their clients. The Tekla reseller in South Africa, CADEX, helped with this request, which increased the number of responses to 93 within 3 weeks. However, only 74 responses were complete and the other 19 participants withdrew before finalizing the questionnaire and were therefore omitted from the analysis. Survey data was collected from the electronic instrument and transferred to Microsoft Excel for analysis. A field for the company name was provided in the company background section to identify duplicate responses from a single company. This field was completed by 45 respondents as it was not mandatory. This field also helped to identify three companies with multiple responses, and the response of the most qualified participants, based on their role in the company and personal experience, were then considered from each company for data analysis. For the remaining 29 participants, the Response Guide field of the online instrument was used to avoid duplicate responses as far as possible. 67 responses were validated for analysis.

5.5 University lecturers' approach for integrating BIM in their course

The results of the first two surveys were merged to help define the supplementary areas that can be added to the current academic curricula to extend scholars' awareness of applying BIM. As already discussed in section 4.3 on the difficulties in offering BIM courses, the main challenges were related to adding a new subject to the current full and compressed curricula as well as the lecturers' preference for keeping their traditional approach. It was thus important to determine the willingness of lecturers to include such aspects in their courses. For this reason, another survey was conducted among lecturers at Stellenbosch University, as a sample. Therefore, the detail of the courses and modules of the civil engineering undergraduate degree was studied to determine the relevance of the course to any of the identified areas of concern from the first two surveys. A short questionnaire comprising five main questions was used to evaluate the personal awareness and experience of the lecturers regarding BIM as well as their enthusiasm for integrating BIM into their courses. As it was important to know their specific preferences, comments and attitude for including a new subject in their courses, interviews were preferred for collecting the data. Thus, 6 lecturers were interviewed and the results were recorded and their transcript is presented in Appendix E.

Chapter 6 – Findings, results and analysis

6.1 Chapter Introduction

This chapter provides the result of the three surveys. The results of the survey amongst students are provided in four sections after which an overall outcome of the survey is presented. The questionnaire amongst industry practitioners is discussed in the same three main parts as the survey questions while the last section is provided separately based on the application of BIM in the companies. An overall conclusion of the results from the survey amongst companies is provided. The results of interviews with lecturers are also provided. An outline of the topics provided in this chapter is shown in figure 6.1.

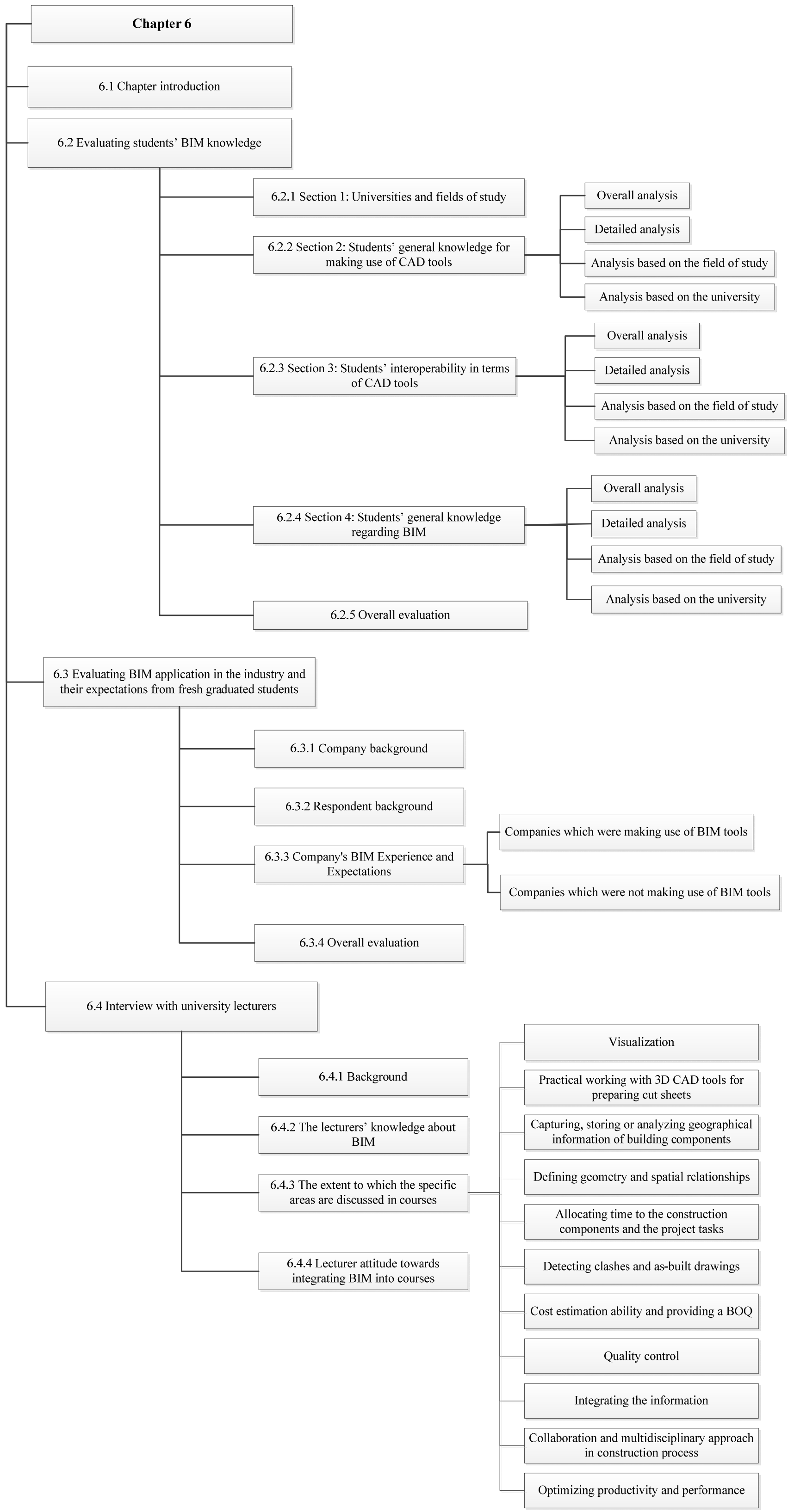

Figure 6.1: Chapter 6 diagram

6.2 Evaluating BIM knowledge of students

6.2.1 Section 1: Universities and fields of study

The first section of the questions was to identify the university contribution as well as the students' field of study to classify the responses. As shown in figure 6.2, the least contribution was 5 responses from the University of Cape Town and the University of the Witwatersrand, while the University of Pretoria had the most respondents.

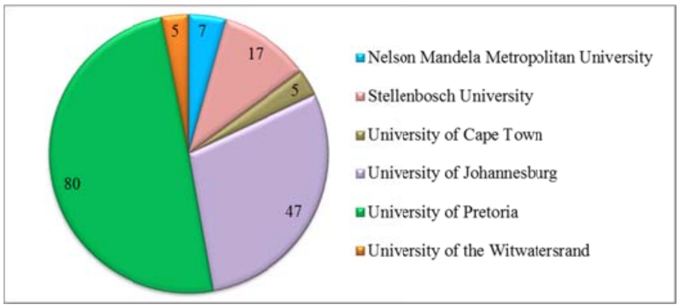

Figure 6.2: Universities contribution in the online survey

The number of responses differed greatly from the six universities and the Standard Deviation for these samples would be around 31, as calculated using equation 1. A larger sample size from a university could define the general level of awareness regarding BIM amongst the university students. But in the small size sample, the responses could be assumed to be the knowledge of individuals only and cannot be necessarily related to the university curricula. This means that analysis and comparison of the students' knowledge is not necessarily due to the impact of universities curricula for all the universities that contributed in the survey. However, in the case of the University of Pretoria, University of Johannesburg and Stellenbosch University, the results can show the effect of university programmes on the students' awareness, due to the larger sample size. For this reason, only these three universities with larger sample size are discussed under the topic of "analysis based on the university" in the sections that follow.

$$\boldsymbol{\sigma} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \ , \qquad \textbf{(Equation 1)}$$

Where:

$\sigma = Standard\ Deviation\ , x = sample\ size\ , N = number\ of\ samples,$

$\mu = Average\ of\ the\ sample, \ \ \mu = \frac{1}{N}\sum_{i=1}^{N} x_i$

As shown in figure 6.3, approximately 62% of the respondents were civil engineering (CE) students, followed by 32% quantity surveying (QS). A few students from construction engineering and management (CM) also responded to the questionnaire.

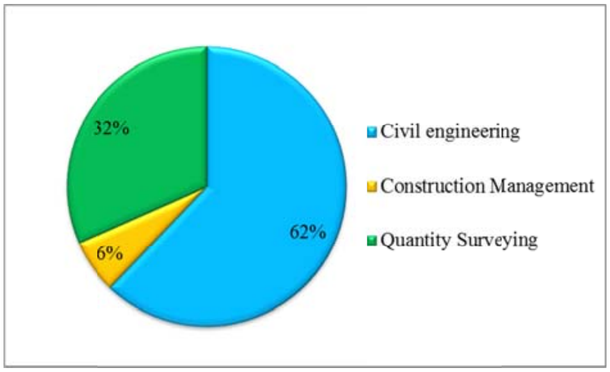

Figure 6.3: Study field of the survey respondents

6.2.2 Section 2: Students' general knowledge for making use of CAD tools

Overall analysis

The first 11 questions were structured to evaluate students' knowledge of Computer Aided Design (CAD) tools in general and of BIM in particular. As shown in figure 6.4, there were only a few students, (8%), who reported they have a comprehensive understanding about setting up a 2D/3D model or working with CAD tools and about half of them had not used it in person. 14% of the students had never been exposed to the applications of CAD tools stated and discussed in the first section of the questionnaire.

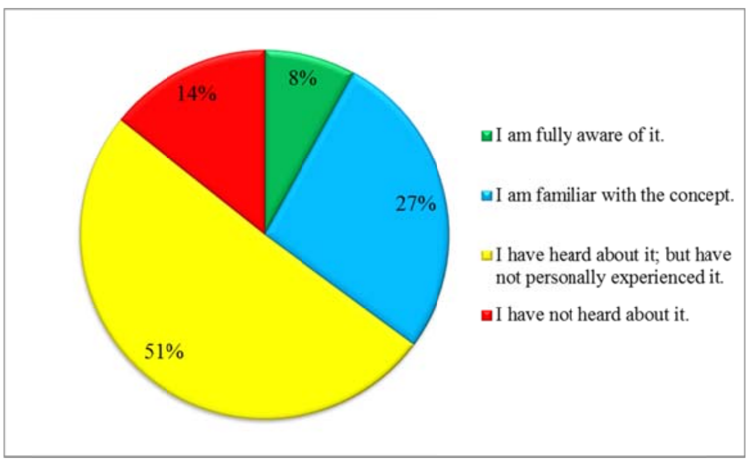

Figure 6.4: Students' cumulative responses for the first series of questions regarding making use of CAD tools

Detailed analysis

Reviewing the details of the responses, as illustrated in figure 6.5, students with experience in 2D models were more than double the ones with experience in 3D models (Question 2 compare to Question 3). The results confirm that not enough opportunity is given to the students to practice 3D modelling at the university.

Three areas, which were completely unfamiliar to the students, were defined as:

- Practical application of CAD tools in preparing sectional views and cut sheets for providing information such as quantity, sizes, lengths, and shapes of the reinforcing bar (Question No. 8)
- Capturing, storing or analysing geographical information of building components (Question No. 5)
- Defining geometry and spatial relationships such as identifying overlaps or whether one component contains or crosses the others (Question No. 4)

Only a few students had enough knowledge and experience about using CAD tools for 3D modelling (Question No. 3), analysing conceptual design and extending it to the detail design plans, which can also include calculating stresses on the components (Question No.7) and depicting profiles to display an existing ground section view (Question No. 10).

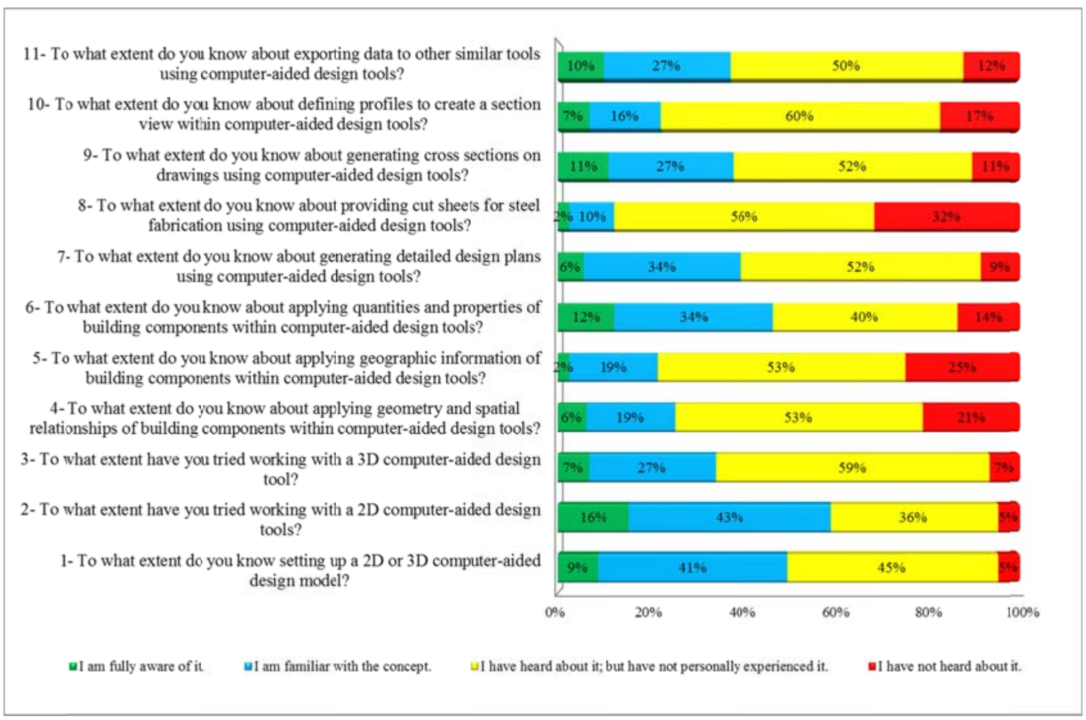

Figure 6.5: Students' detailed responses to the first set of questions regarding use of CAD tools

Analysis based on the field of study

The percentage of civil engineering students who were fully aware of CAD tools and its applications were more than the same group of the students in CM, which in its turn was double the number of the QS students, as displayed in figure 6.6. The proportion of CE students who were not familiar with this concept (13%) was less than CM (18%) and QS students (17%) who had almost no background regarding this subject. Considering the remarkable difference between proportions of CE students who were familiar with the concept (31%), in comparison with CM (11%) and QS students (23%), it is concluded that CE programmes may expose students more to the basic applications of CAD tools. CM students who were theoretically familiar with CAD tools were slightly more than QS students.

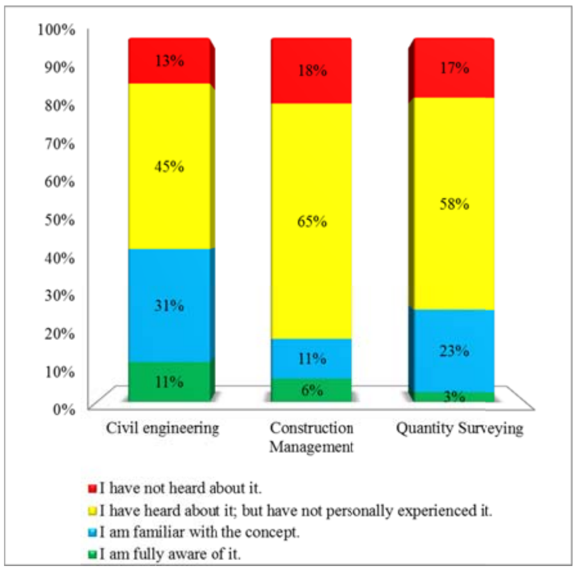

Figure 6.6: Students' responses to the first set of questions regarding use of CAD tools as per discipline

Analysis based on the university

As shown in figure 6.7, 67% of the students at Stellenbosch University reported they are either fully or fairly aware of CAD tools and their application. Top ranking ratios of the students with more theoretical knowledge and almost no practical experience, were in the University of Johannesburg (52%) and the University of Pretoria (54%). As it is explained in the first section of the survey results (6.1.1), for these two universities and Stellenbosch University, it can be concluded that the main focus of their programmes are on theoretical knowledge development whilst the practical skill for introducing CAD tools to the students may be a second priority.

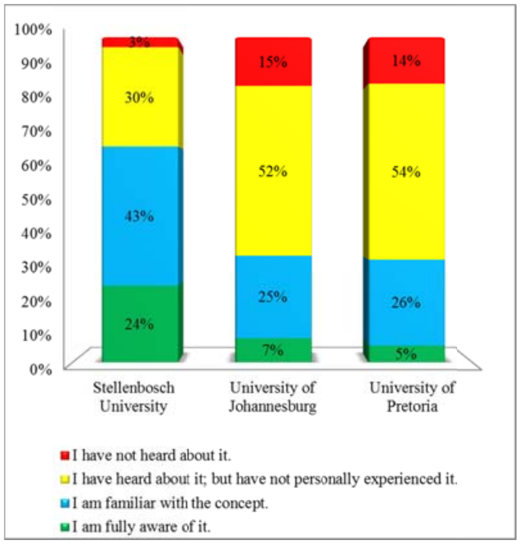

Figure 6.7: Students' responses to the first set of questions regarding use of CAD tools as per University

6.2.3 Section 3: Students' interoperability in terms of CAD tools

Overall analysis

Questions 12 to 19 of the questionnaire focused on the extent to which students can understand the set models and interpret information in terms of construction processes and the ability to communicate with other project disciplines. As figure 6.8 illustrates, almost a quarter of the students reported their lack of awareness regarding interoperability and understanding the tools while 13% of them were fully knowledgeable and able to understand the outputs of the software.

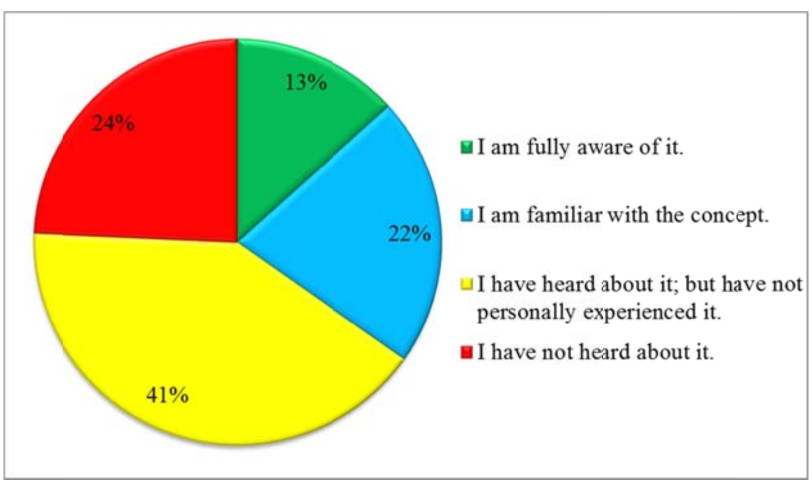

Figure 6.8: Students' cumulative responses for the second series of questions regarding tools interpretation

Detailed analysis

The conclusion drawn from these results, as shown in figure 6.9, is that a considerable part of the students were either expert or rather skilful in reading three orthogonal views and developing isometric views (34% and 25% respectively). Compared to the proportion of the students who were able to implement 2D (16%) and 3D (7%) models in the first section (question 2 and 3 in figure 6.5), it is apparent that in question 12 and 13 of section two, students are mainly reporting their paper-based ability for developing the drawings.

While 16% of the students are completely aware about the symbols of different engineering disciplines and 43% are moderately familiar with them, there is a lack of knowledge in four other areas, in terms of multi-dimensional models:

- Allocating time to the construction components and the project tasks
- Being aware of the possibility and the ways of detecting clashes between the components
- Providing as-built information for the facility
- Defining cost for the project elements

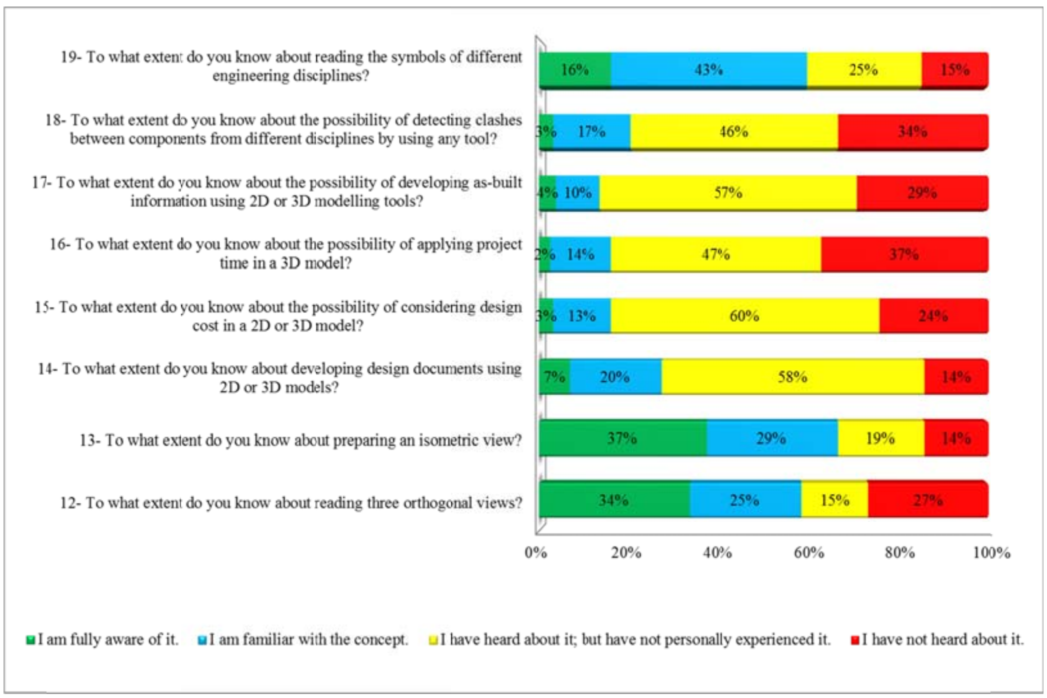

Figure 6.9: Students' detailed responses to the second set of questions regarding tools interpretation

In other words, their ability to interpret CAD tools as a media for the project information is very low and there are potential areas in which their knowledge and ability should be enhanced. Focusing on the first three discussed issues, managing time and cost as well as checking the constructability, which also results in saving time and cost, are vital for an efficient project management. The last two issues, which consist of generating reliable as-built drawing and fulfilling design requirements via a 2D/3D model, are more technical and practical skills which also need to be improved.

Analysis based on the field of study

A remarkable part of the students, who were completely knowledgeable in understanding the tools output and analysis, were studying CE (16%). The number of students with similar ability in CM (3%) and QS (5%) were considerably less than CE students, as can be observed from figure 6.10. However, there was no such a gap in students from different disciplines, who were fairly aware of interpretation of the tools; 24% of CE students were quite familiar with this concept while 19% and 18% from QS and CM students respectively, were categorized in the same situation. The higher percentage of the students with lack of knowledge in terms of understanding the output and interpreting it were amongst CM students (30%), followed by the QS students (24%) (as shown in figure 6.10). However, it is only marginally more than CE students.

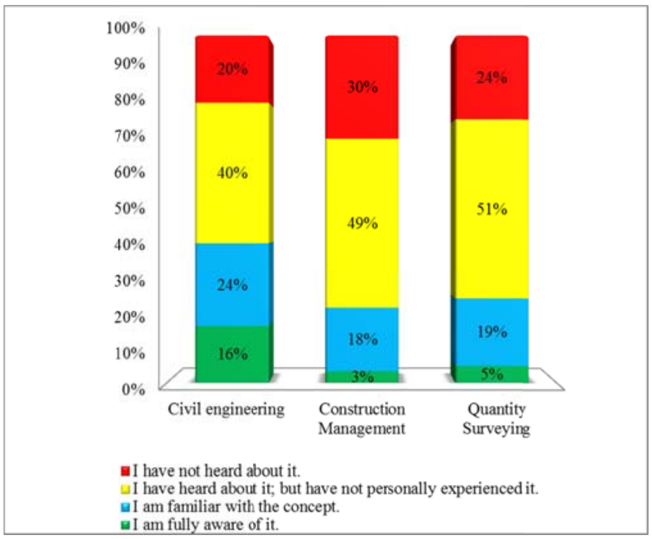

Figure 6.10: Students' responses to the second set of questions regarding tools interpretation as per discipline

Analysis based on the university

As illustrated in figure 6.11, the proportion of students knowledgeable in interpretation and communication with other disciplines via tools, was higher at Stellenbosch University (24%) and the University of Johannesburg (15%). The lack of knowledge regarding tools interpretation was more amongst the students of the University of Pretoria (23%) which was slightly higher than the same group of students at University of Johannesburg (21%). However, only 13% of the students from Stellenbosch University lacked enough information in this regard. Also, the percentage of the students who were familiar with the concept with no practical experience was very close in the University of Pretoria (48%) and the University of Johannesburg (44%). This gap was even less amongst the fairly aware students of these two universities (21% and 20% respectively).

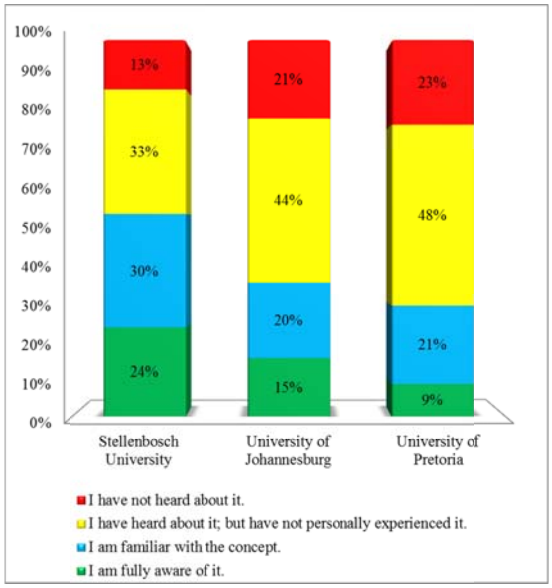

Figure 6.11: Students' responses to the second set of questions regarding tools interpretation as per university

6.2.4 Section 4: Students' general knowledge regarding BIM

Overall analysis

The last 7 questions of the questionnaire focused on the main benefits which can be achieved through implementing BIM, to evaluate students' fundamental awareness regarding BIM in particular. The first three questions aimed at establishing if students knew the advantages of this innovative technology, as discussed in sections 2.3.1 and 2.3.2 of this study. Respondents were then asked if they were aware of any tools for achieving these advantages. In the last question, students were asked if they had an idea of what BIM is.

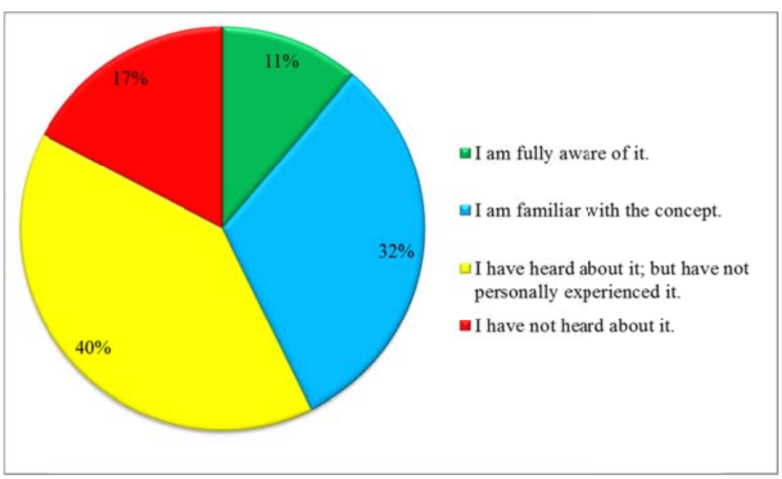

Figure 6.12: Students' cumulative responses to the third set of questions regarding BIM general knowledge

As displayed in figure 6.12, 11% of the students were completely aware of the main subjects that can be supported through applying BIM with 32% also having experienced these features adequately. While 17% of the students did not have any idea about the advantages that is achievable by BIM utilization, around 40% had been informed but did not have the opportunity to experience it.

Detailed analysis

Around 22% of the students stated that they were quite knowledgeable about collaboration in a construction project, as illustrated in figure 6.13. However, a smaller percentage was completely aware about other areas of concerns in a project which can be also addressed by BIM tools, consisting of saving, updating and also integrating project information. Only 3% of the students mentioned they knew BIM well. So, even if they had been informed about the main issues relating to integrating the information and models as well as collaboration and a multidisciplinary approach, a large number did not recognize that BIM is a tool for addressing these issues, as they have not been exposed to it. The concept of BIM was completely unfamiliar to about 33% of the students, as shown in figure 6.13.

Between 42 to 43% of the students were just aware of the existence of tools which can support interdisciplinary integration, information centralization and managing data and information as well as communication in the projects (questions no.23 to 25), as illustrated in figure 6.13.

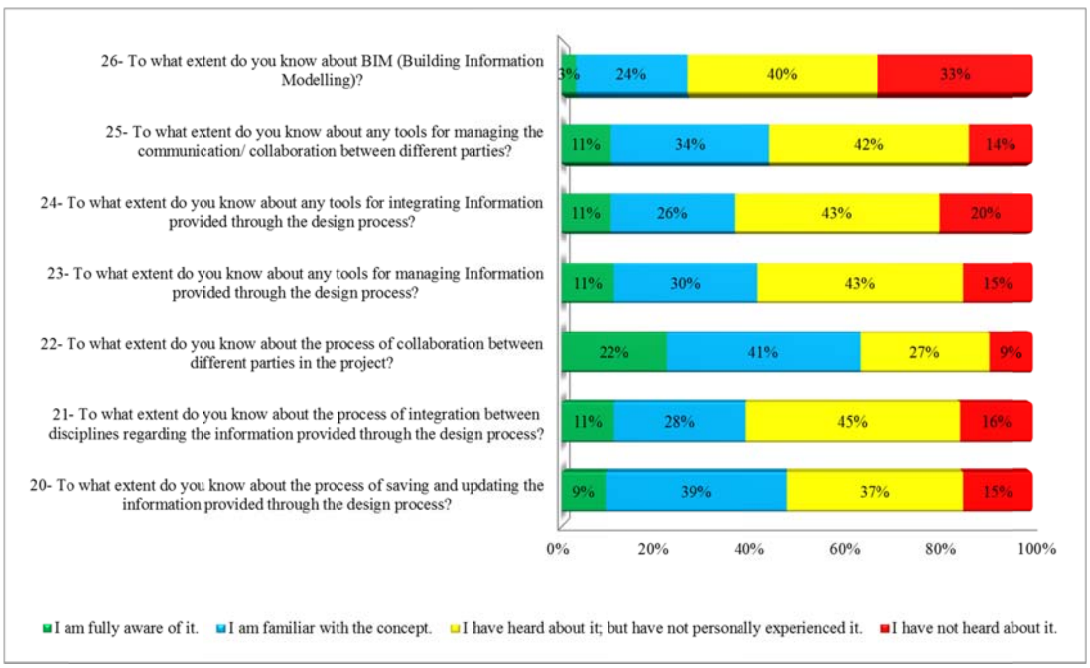

Figure 6.13: Students' detailed responses to the third set of the questions regarding BIM general knowledge

Analysis based on the field of study

Again, the proportion of the fully informed respondents in the CE departments was more than the students in CM and QS fields, which is shown in figure 6.14. The percentage of the students with no awareness was slightly less in CE group in comparison to CM and QS departments. The result did not show a significant difference between CM and QS students who are theoretically aware of some solutions for addressing integration and collaboration. Almost a quarter of QS students were fairly knowledgeable regarding tools and techniques which are helpful for information centralization and management. This percentage was very close to the same group of CE students (28%) and marginally more than CM students (19%).

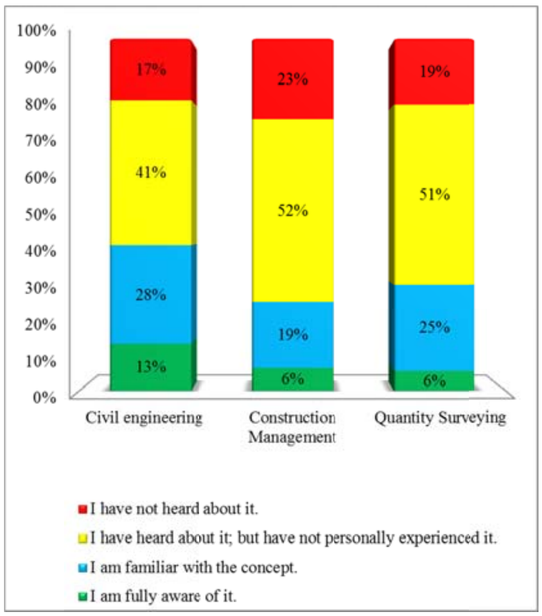

Figure 6.14: Students' responses to the third set of questions regarding BIM general knowledge as per discipline

Analysis based on the university

As shown in figure 6.15, the level of awareness in terms of BIM general knowledge was reported to be high for 20% of the students at Stellenbosch University. The next top ranked were the students of the University of Johannesburg at 12%. The proportion of the students who were adequately familiar with the basic concept and techniques of the integration and efficient collaboration tools was higher at the Stellenbosch University (32%). The percentage of the students who were not familiar with these concepts was very close in the universities of Pretoria (18%) and Johannesburg (19%) while only 9% of the students from Stellenbosch University were categorized in this group. The percentage of students with only theoretic understanding of BIM with no practical experience was very close in two universities of Pretoria and Johannesburg (48 and 44% respectively). The university of Pretoria and university of Johannesburg also had very similar result for the fairly-familiar students (26 and 25% respectively)

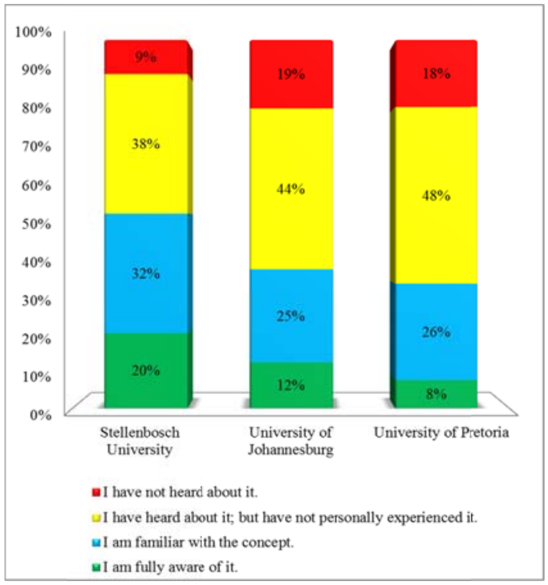

Figure 6.15: Students' responses to the third set of questions regarding BIM general knowledge as per university

6.2.5 Overall evaluation

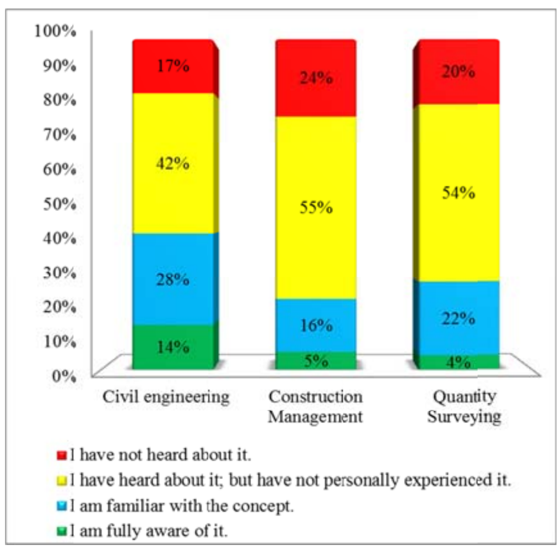

Figure 6.16: Overall students' responses as per discipline

The survey conducted among 161 students in civil engineering, construction management and quantity surveying showed that a considerable percentage of students in these disciplines need to extend their knowledge regarding BIM technology and its application. As shown in figure 6.16, an overall view of the students' level of awareness as per discipline defined that, the ratio of the students who have a comprehensive understanding of BIM in addition to those who are fairly familiar, is less than 50% in each discipline. 42% of CE students did not practice working with relevant software and need to learn it in their programmes. 17% were not exposed to the fundamental and theoretical knowledge regarding BIM, which should be included in their programme. The same requirements should be applied to CM and QS students in a larger scale as they have larger proportion of the students in these categories.

There are some areas that required more focus when developing a course content to enhance students' awareness about BIM. These include:

- Practical working with 3D CAD tools especially in preparing sectional views and cut sheets for providing information such as quantity, sizes, lengths, and shapes of the reinforcing bar
- Capturing, storing or analysing geographical information of building components
- Defining geometry and spatial relationships such as identifying overlaps or whether one component contains or crosses the others
- Allocating time to the construction components and the project tasks
- Detecting clashes between the components
- Providing as-built information for the facility
- Defining cost for the project elements
- Integrating the information and models
- Collaboration and multidisciplinary approach in construction process

As shown in figures 6.17 to 6.19, these areas were also unfamiliar to CE students. In other words, the same areas needed more focus while providing course content for CE students in particular.

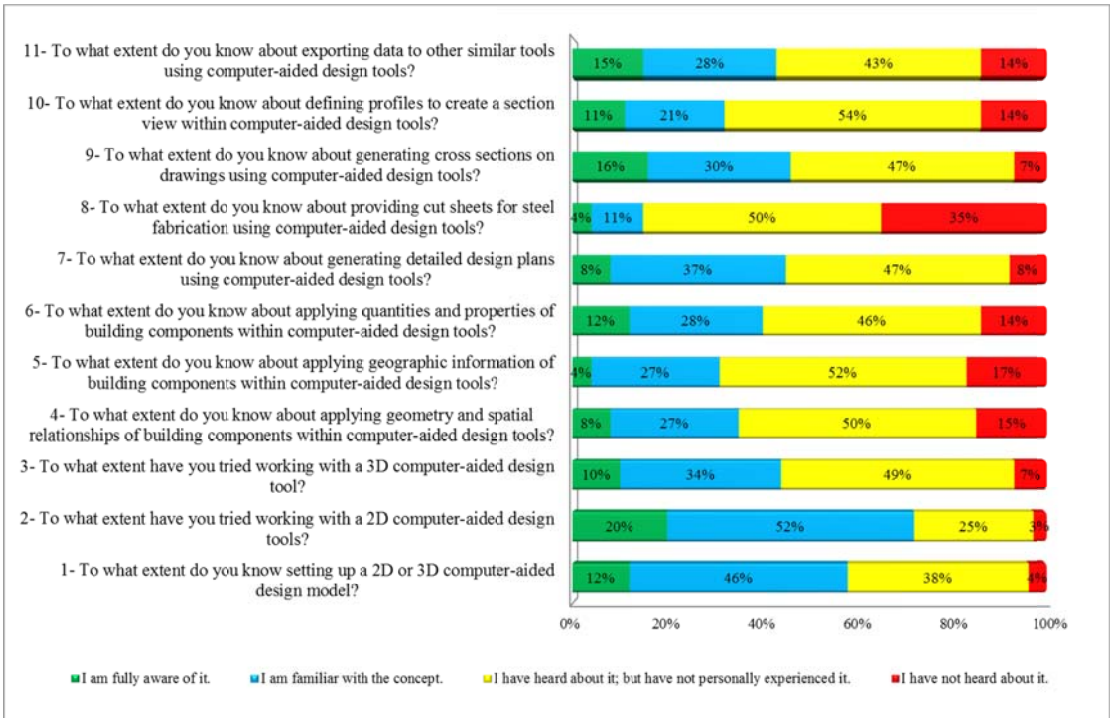

Figure 6.17: CE Students' detailed responses to the second set of questions regarding tools interpretation

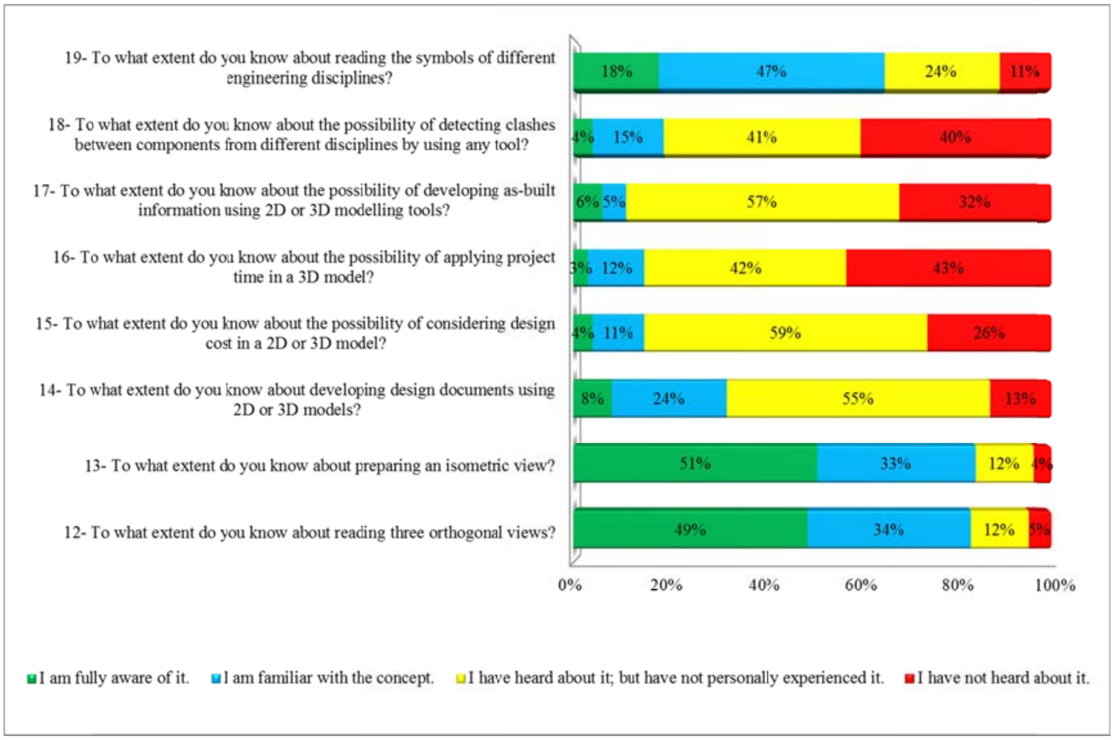

Figure 6.18: CE Students' detailed responses to the second set of questions regarding tools interpretation

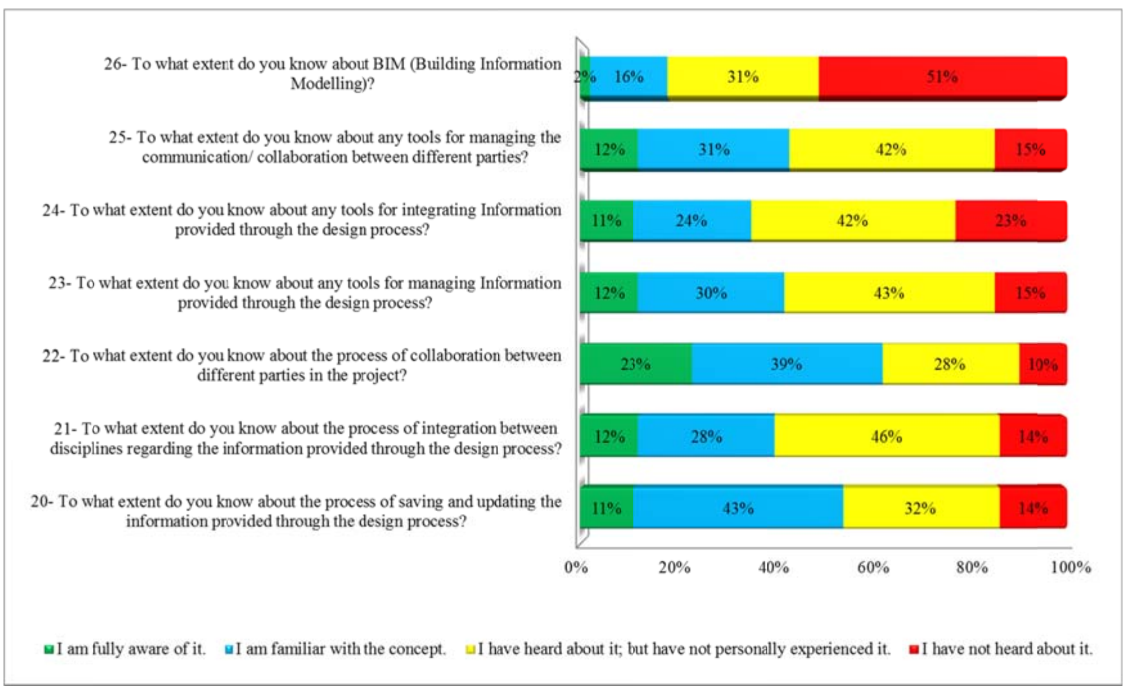

Figure 6.19: CE Students' detailed responses to the third set of the questions regarding BIM general knowledge

This is also confirmed through calculating the arithmetic mean and Standard Deviation (SD) for the level of awareness amongst CE students, as shown in table 6.1. It is found that, the lowest arithmetic mean is for the "fully aware" group and the highest is for the group of students who have not experience about BIM application in person.

Table 6-1: Arithmetic mean and SD for the level of awareness amongst CE students

Level Of awareness amongst CE students	Arithmetic mean	SD
Fully aware	13.3	12.0
Familiar with the concept	28.2	11.9
Just heard about it, with no personal experience	41.0	12.6
Not heard about it	17.5	12.9

6.3 Evaluating BIM application in industry and their expectation from young graduate students

6.3.1 Company background

The first section of the questionnaire comprise of 6 questions on the background of the company. The company's contractual role was the first information to obtain. This could be general contractor, sub-contractor, construction manager, consultant/engineer, Design-Build company, client/ owner and there was also an open-end field of "others" to be completed where the company role was not listed in the options.

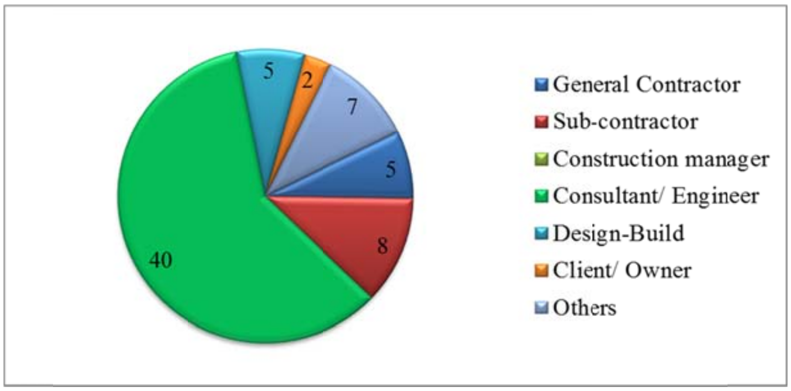

Figure 6.20: Diversities of companies' contractual role

As illustrated in figure 6.20, a considerable number of the respondents worked in consultant/engineer companies (40). There were only 2 client companies among the respondents and 5 companies with general contractor role. There were 8 sub-contractors that took part in the survey and 5 companies who were mostly doing Design-Build contracts. There was an open-field for the respondents who chose "Others" for the companies' role. None of the 7 respondents in "Others" group explained their companies' specific role in the open-end field, which could be because of having different contractual roles in various situations.

The companies were asked to categorize themselves based on the project type they are involved in. Respondents had multiple choices and the results are shown in figure 6.21.

It followed from the results that most of the respondents were representatives of companies involved in structural projects with almost a half also specializing in civil projects. 20 companies were implementing project management while 20 others were multidisciplinary. A considerable number of the respondents defined their companies' work as building services.

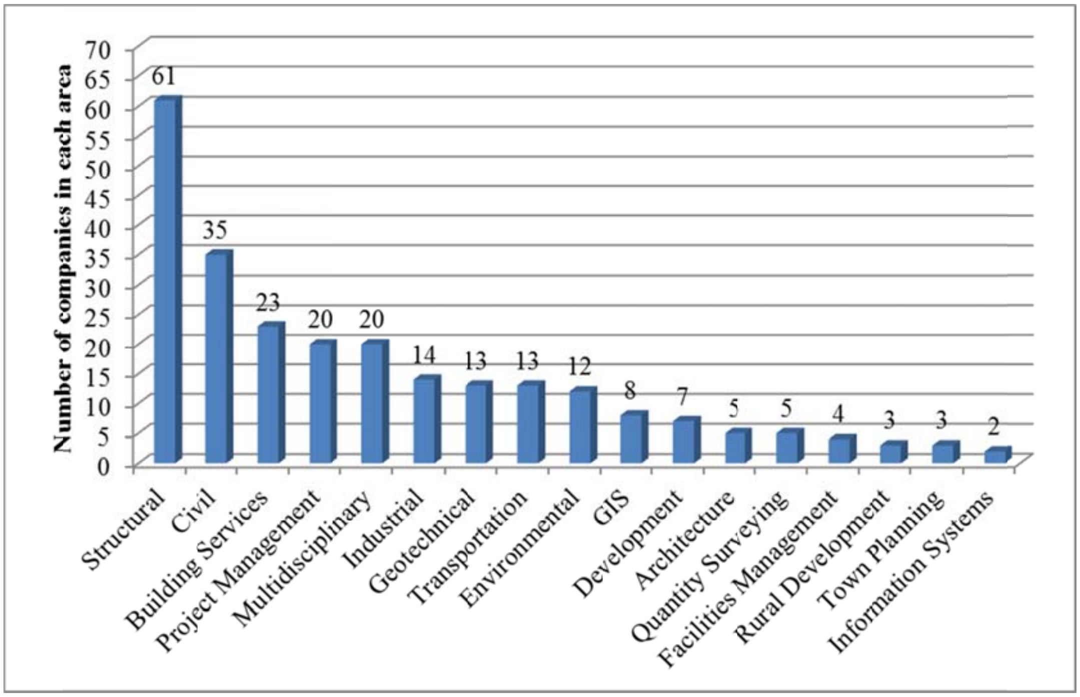

Figure 6.21: Distribution of company specializations

To obtain information on the size and the approximate annual revenue of the company, the number of employees and the geographical distribution of the company were required. The results are shown in figure 6.22 to 6.24.

While the annual revenue of 19 companies were not provided, 52% of the remaining 48 (N= 25) reported theirs to be less than 50 million Rand. As shown in figure 6.22, 31% of the companies (N= 15) were in the second category of between 50 million to 1 billion Rand, while the remaining 8 companies (17% of the respondents) had revenues of more than 1 billion Rand per year.

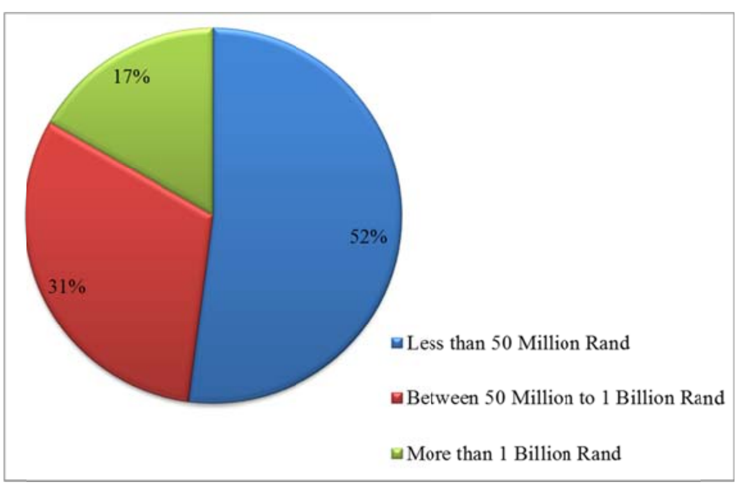

Figure 6.22: Diversity of companies based on their annual revenue

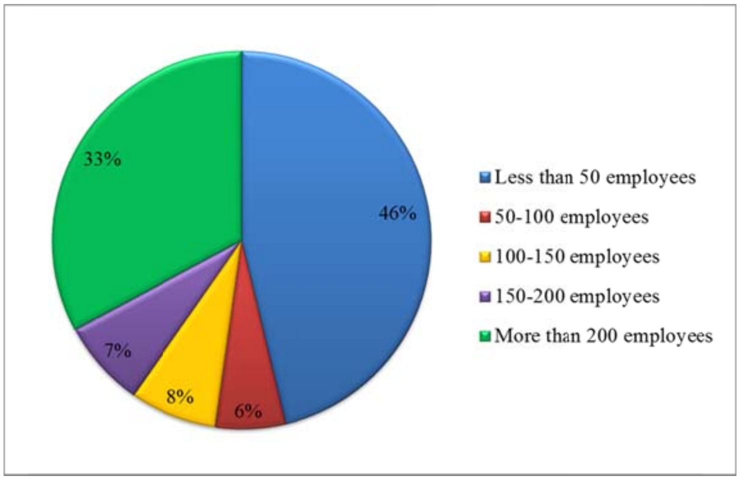

Figure 6.23: Diversity of companies based on their number of employees

The results showed that 46% of the respondents were representative of small companies with less than 50 employees while 33% were from large companies with more than 200 employees. A total of 21% medium size companies with more than 50 employees and less than 200 contributed in the survey (See figure 6.23).

As shown in figure 6.24, 43% of the companies had offices in less than three South African provinces, 28% were working internationally and 19% had projects in other African countries.

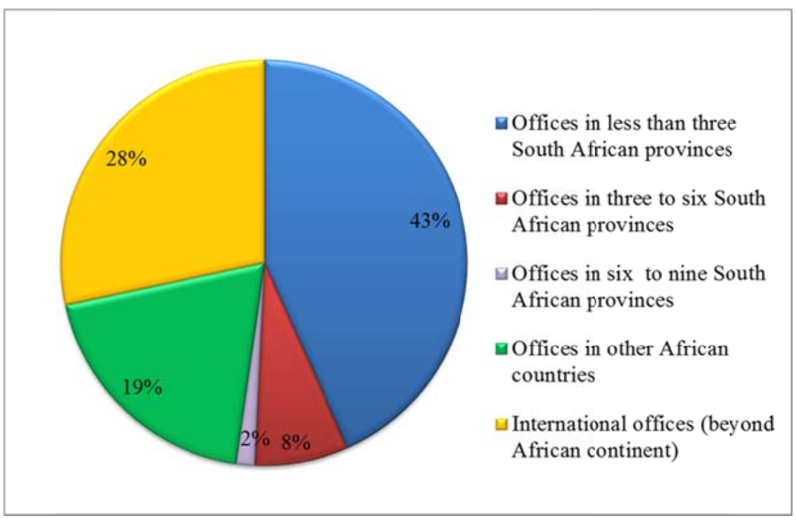

Figure 6.24: Geographical spread of the companies

In general, the variety of the companies that contributed to the survey was quite extensive and made the survey to be representative of the South African industry.

The last question in this section was to identify whether the company was making use of BIM. The response affected the subsequent questions. The number of companies that were making use of BIM was 38 (almost 57% of the respondents).

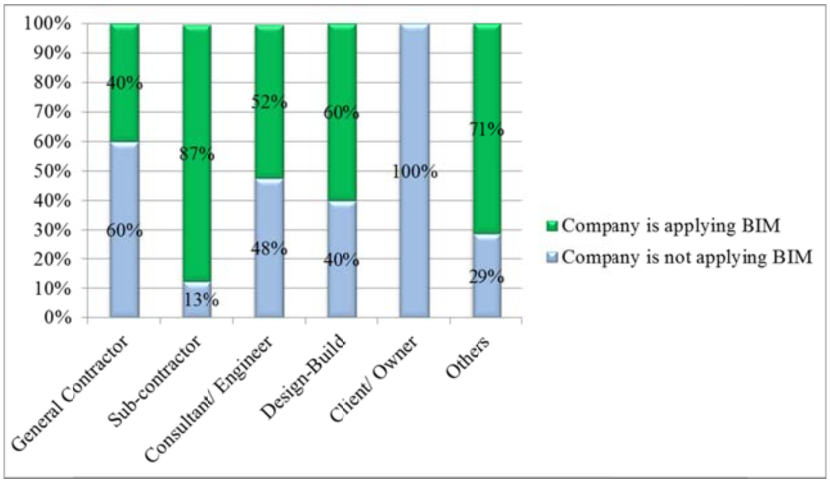

Figure 6.25: The rate of BIM application based on the company contractual role

Figure 6.25 presents the diversity of the contractual role of companies where BIM was applied or not. While none of the client firms that participated in the survey was using BIM, 88% of the sub-contractors were making use of it. A remarkable part of the companies that categorized their contractual role as others stated that BIM is implemented in their company. As discussed at the beginning of this chapter, these companies might choose the category of "others" for their contractual role, due to differing contractual roles in various projects. 60% of the Design-Build companies and 53% of the consultant firms reported that they have utilized BIM. After the client, the general contractor had the least ratio of BIM application at 40%.

6.3.2 Respondent background

Validation of the responses brought the need to determine whether the right person was completing the survey. For this reason, respondents were asked to provide their highest academic degree as well as their role in the company. Respondents were also asked to provide their personal involvement with BIM from a list that comprised "No or limited exposure", "Basic understanding of BIM", "Advanced knowledge about BIM", and "Supervise/lead/manage BIM implementation".

The distribution of the respondents on these three aspects is summarized in table 6.2 and 6.3 for companies where BIM was already applied and companies which were not implementing BIM respectively. The result showed that the majority of respondents can be considered reliable for their responses. The respondents were mostly from an academic background that would understand BIM concepts. Furthermore, their positions in their respective companies allowed them to understand the extent to which this technology was implemented. Their personal level of involvement with BIM application, in particular for the companies where BIM is utilized, was reliable for responding to such a questionnaire. It is worth mentioning that amongst the companies that were using BIM, only one of the respondents had limited knowledge and experience of BIM.

Table 6-2: Respondents diversity in companies where BIM was implemented

In companies where BIM was implemented (38 respondents)					
Highest academic degree distribution		**Interviewees' position distribution**		**Distribution of the personal level of involvement with BIM**	
PhD	9	Associate Engineer	12	Basic understanding of BIM	19
MSc Eng.	8	Function/ Project/ Executive Manager	8	Supervise/ lead/ manage BIM implementation	11
MBA	5	Director	6	Advanced knowledge about BIM	7
MSc	4	Owner	4	No or limited exposure	1
BSc. (Hons)	3	Detailer	3		
BSc. Eng.	3	Partner	2		
BSc	2	Draftsman	2		
B Tech	1	Technician	1		
Higher National Diploma	1				
M Dip Tech	1				
Graduate Diploma	1				

Table 6-3: Respondents diversity in companies where BIM was not implemented

In companies where BIM was not implemented (29 respondents)					
Highest academic degree distribution		**Interviewees' position distribution**		**Distribution of the personal level of involvement with BIM**	
PhD	1	Associate Engineer	15	Advanced knowledge about BIM	1
MSc Eng.	10	Director	7	Basic understanding of BIM	12
MBA	1	Administration	1	No or limited exposure	16
MSc	1	Partner	1		
BSc. (Hons)	3	Technician	1		
BSc. Eng.	1	Draftsman	1		
BSc	5	Detailer	1		
M Dip Tech	1	Assistant Quantity Surveyor	1		
Matric	3	Owner	1		
National Diploma	2				
National Certificate	1				

6.3.3 Companies' BIM Experience and Expectations

As mentioned in the methodology chapter, this section was different for companies that were making use of BIM from those that did not. 6 questions were formulated for former group and 4 for latter.

The results of the surveys are presented in graphs which contain 3 or 4 different features which need to be considered together. For this reason, a simple scatter plot is selected for presenting distributions of the features which are discussed in each section. For ease of interpretation, related tables of each scatter plot is also provided which are either in the content or in the appendices of the document, as in each case stated.

Companies which were making use of BIM tools

The companies who replied 'yes' to the question on applying BIM in their company were required to respond to six questions which included the duration of BIM implementation in their company, number of BIM specialists either in-house or outsourced, the main functions of BIM from which they are benefitting, their company's main achievement through BIM application, the difficulties they experienced while implementing BIM and the method of training for their employees focusing on BIM.

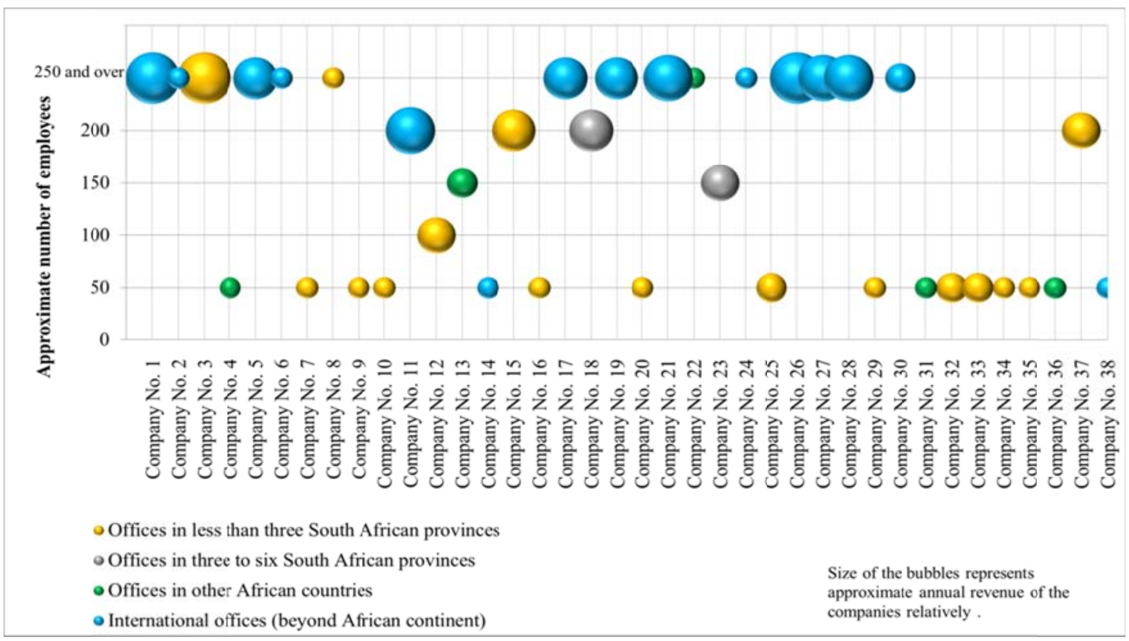

Figure 6.26: Diversity of the companies where BIM is implemented

As shown in figure 6.26, a significant number of companies who have started BIM application are working internationally. They are also defined as large companies with considerable annual revenue, as the bubble size shows (the larger the bubble size, the higher the annual revenue.). There are a considerable number of small firms in this group as well (smaller bubble in the figure 6.26), which are located mostly in only one South African province and with lower annual revenue. For ease of interpretation, this information is also presented in tables 6.4 and 6.5.

Table 6-4: Diversity of the companies where BIM is implemented based on number of employees and geographical spread

Number of employees	Number of companies that have					Total
	Offices in less than three South African provinces	Offices in three to six South African provinces	Offices in six to nine South African provinces	Offices in other African countries	International offices (beyond African continent)	
Less than 50	11	0	0	3	2	**16**
50-100	1	0	0	0	0	**1**
100-150	0	1	0	1	0	**2**
150-200	2	1	0	0	1	**4**
More than 200	2	0	0	1	12	**15**
Total	**16**	**2**	**0**	**5**	**15**	**38**

Table 6-5: Diversity of the companies where BIM is implemented based on number of employees and annual revenue

Number of employees	Number of companies that have approximate annual revenue of						Total
	Less than 10 Million Rand	10 to 50 Million Rand	50 to 100 Million Rand	100 Million to 1 Billion Rand	1 to 10 Billion Rand	More than 10 Billion Rand	
Less than 50	13	3	0	0	0	0	**16**
50-100	0	0	1	0	0	0	**1**
100-150	0	1	1	0	0	0	**2**
150-200	0	0	1	2	1	0	**4**
More than 200	5	1	0	3	3	3	**15**
Total	**18**	**5**	**3**	**5**	**4**	**3**	**38**

Question 1

The first question in this section was about the time the company started using BIM. The responses showed that among 38 companies where BIM tools are applied, close to half (N=16) started making use of BIM technology less than two years ago. As shown in figure 6.27, a considerable proportion of the respondents (N=11) stated that their companies had implemented BIM more than six years ago. It is worth mentioning that 8 of these 11 companies were working internationally, while 3 others have offices only in Gauteng or Western Cape Province.

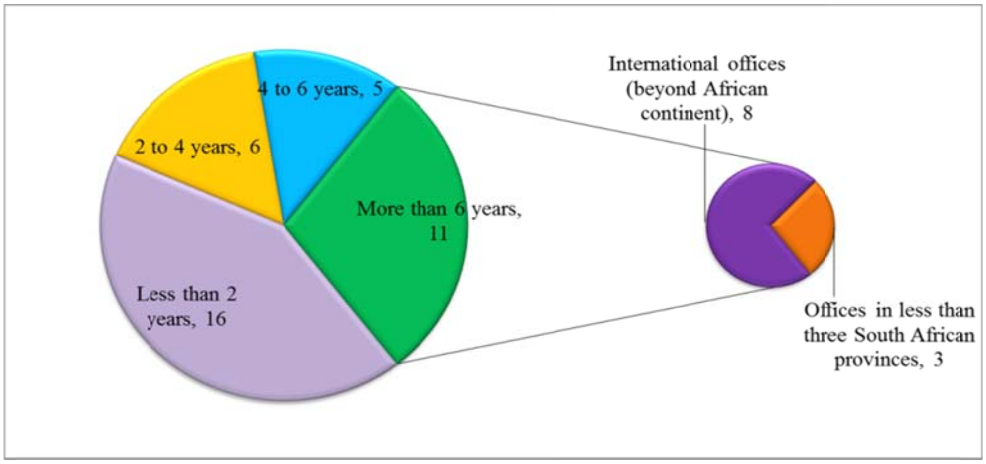

Figure 6.27: Duration of BIM application in the companies

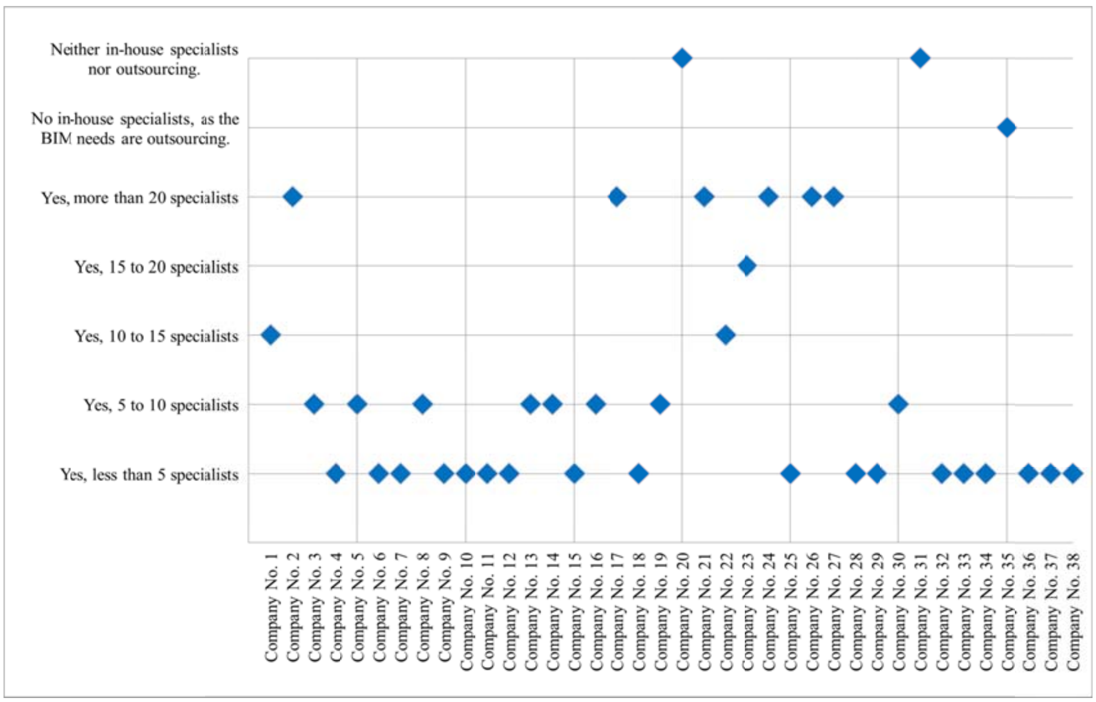

Figure 6.28: Number of BIM specialists in the companies

Question 2

In order to identify how the company was satisfying their BIM needs, the number of BIM specialists employed either in-house or on an outsourced basis needed to be defined. The majority of responses have less than 5 in-house BIM specialists (N=18), and a remarkable number of them (N=8) were benefiting from 5 to 10 specialists in the company. A total of 6 companies had more than 20 in-house BIM professionals employed. There were 2 companies who did not have any special trained employee for their BIM application and 1 of the respondents stated that they were outsourcing their BIM requirements, implying that there was no in-house skilled person in terms of BIM in this company.

The plot in figure 6.28 shows whether the companies had BIM specialists in addition to the approximate number of them.

Question 3

To understand the principle application of BIM in the South African industry, respondents were asked to select the main BIM functions that their company applied. This would also provide information about the academic areas where student knowledge may need to be enhanced. A total of 20 benefits of BIM tools, based on the related literature as discussed in section 2.4.2, were listed to be marked by the respondents.

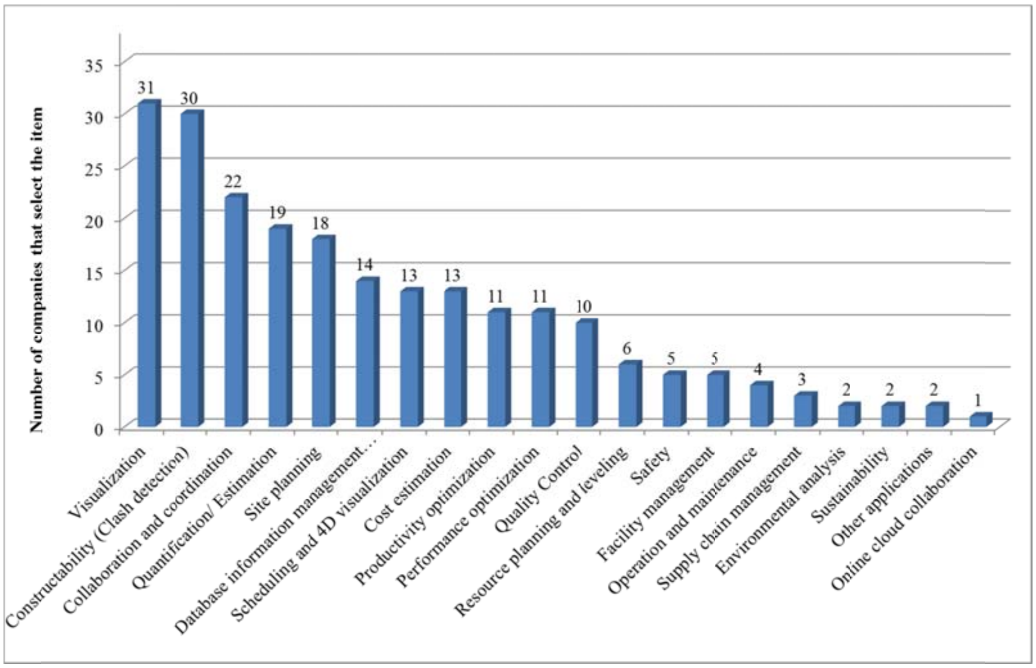

Figure 6.29: Popularity of BIM functions in the companies

The result showed that the visualization and clash detection was the top two ranked features for 31 and 30 companies respectively. The third popular function of BIM was collaboration and coordination which was experienced by 22 companies out of 38. The next four useful features were estimation, site planning, database information management, and structural analysis.

The result is summarized in figure 6.29, which shows that some functions were practiced only in a few companies, such as online cloud collaboration, sustainability and energy analysis. These are the features which may need more technical support and also more demands from clients to be applied in projects, which may explain why few companies apply these features.

Question 4

In order to understand the principle achievements of BIM, company representatives were requested to identify the extent to which BIM has been effective in their company. Six main areas which can be optimized by utilizing BIM (see table 6.6), based on the advantages of BIM discussed in section 2.3, were listed in the survey and the respondents defined the level of effectiveness for each. As shown in table 6.6, amongst the advantages which were strongly effective in the company, creativity was identified as the area that was most influenced by BIM application in 13 companies. This was followed by quality improvement for 11 respondents and shortening of the project time by 8. BIM was also seen to be very effective in cost cutting (for 18 companies), sustainable design (within 13 firms) and construction and quality enhancement (by 12 respondents).

Table 6-6: Number of companies that reported BIM level of effectiveness in each area

Area of influence	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Creativity in the project	1	3	11	10	13
Sustainability in project design	2	3	14	13	6
Quality improvement in project	0	3	12	12	11
Decreasing human resource in project	4	11	8	11	4
Decreasing the cost of project	1	10	5	18	4
Decreasing the time of project	2	8	9	11	8
Average	**2**	**6**	**10**	**13**	**8**

Decreasing human resources was one of the fields which were moderately affected by BIM. The number of the companies for which it has a significant effect and those with little effect were similar. Generally, as the last row in table 6.6 shows, the average influence of improving these items was defined 'effective' and 'very effective'.

The six graphs in figures 6.30 to 6.35 show BIM level of effectiveness on six areas that can be improved by using BIM. These graphs also reflect the company contractual role to give an idea how different parties experienced BIM effectiveness. Looking at the diversity of the company contractual role, shown in figures 6.30 to 6.35, it was obvious that a majority of the consultants and Design-Built firms found BIM to be quite effective in their staff creativity, sustainability and quality improvement. However, only two general contractors were amongst the respondents who experienced BIM effectiveness. The one found quality improvement to be relevant and the other ranked the level of effectiveness as moderate or above in all the areas. Sub-contractors mostly seemed to be satisfied with BIM influence regarding creativity, sustainability and quality improvement. Cost cutting, shortening the project duration, and decreasing the human resource were not influenced highly for sub-contractors.

BIM level of effectiveness on six areas which can be enhanced by using BIM is also shown in tables F.1 to F.6 in appendix F. The tables show the number of companies that experienced different levels of effectiveness through applying BIM based on the contractual role of the company.

Generally, it can be concluded from the results in figures 6.30 to 6.35 that, optimizing human resources, cost and time have yet to be done through application of BIM. Different colours of the bubbles represent the contractual role of the company. The rare use of 4D and 5D models in comparison with 3D models, to link time and cost to the simulated model, can explain the reason for not being mature enough in gaining the advantages of BIM in these areas. The duration of BIM application in the company is another factor which can affect cost effectiveness. This is because in the first year of implementation, the expenses would be high and it takes some years to compensate for it. It also would be the area of requirements to be satisfied through academic programmes; as the more students can practice 4D and 5D models and its related features, the better they can apply it in real-world through their career.

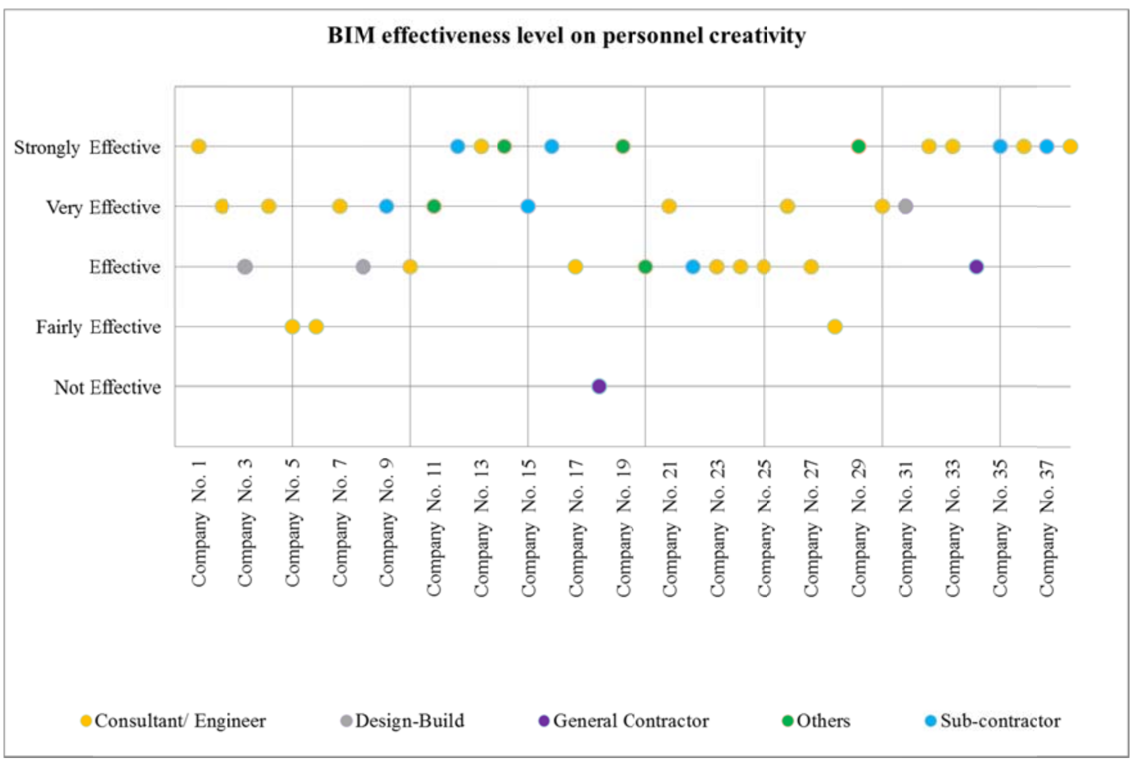

Figure 6.30: BIM effectiveness on personnel creativity based on company contractual role

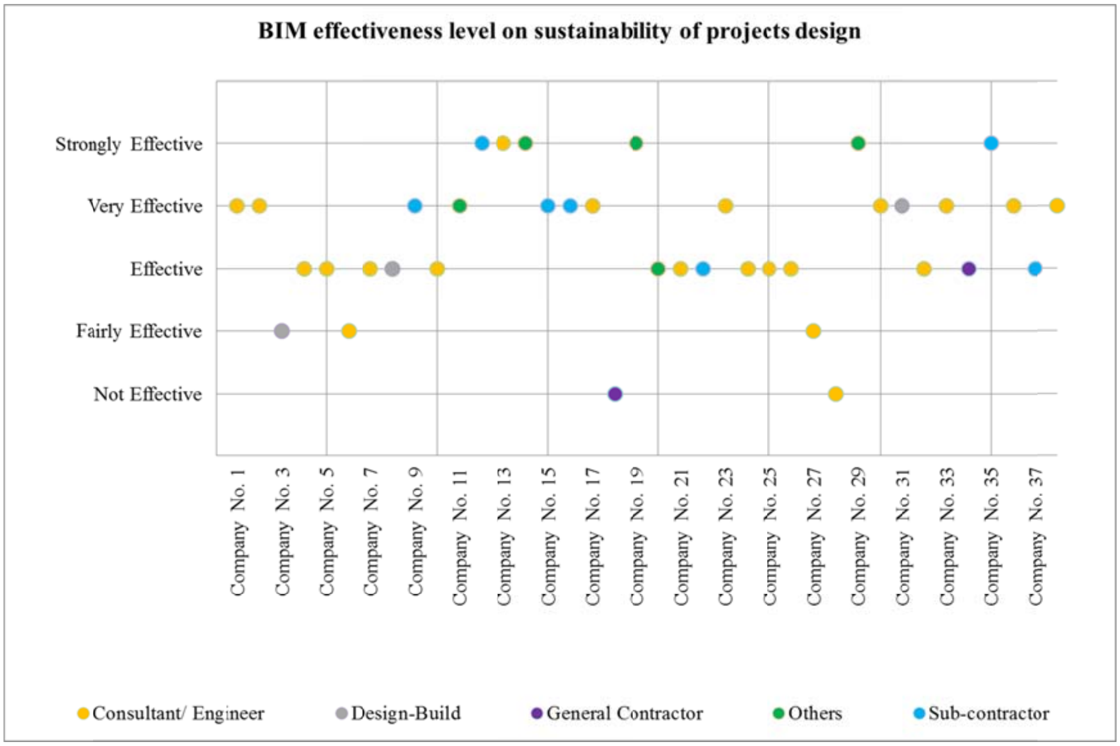

Figure 6.31: BIM effectiveness on sustainability of project design based on company contractual role

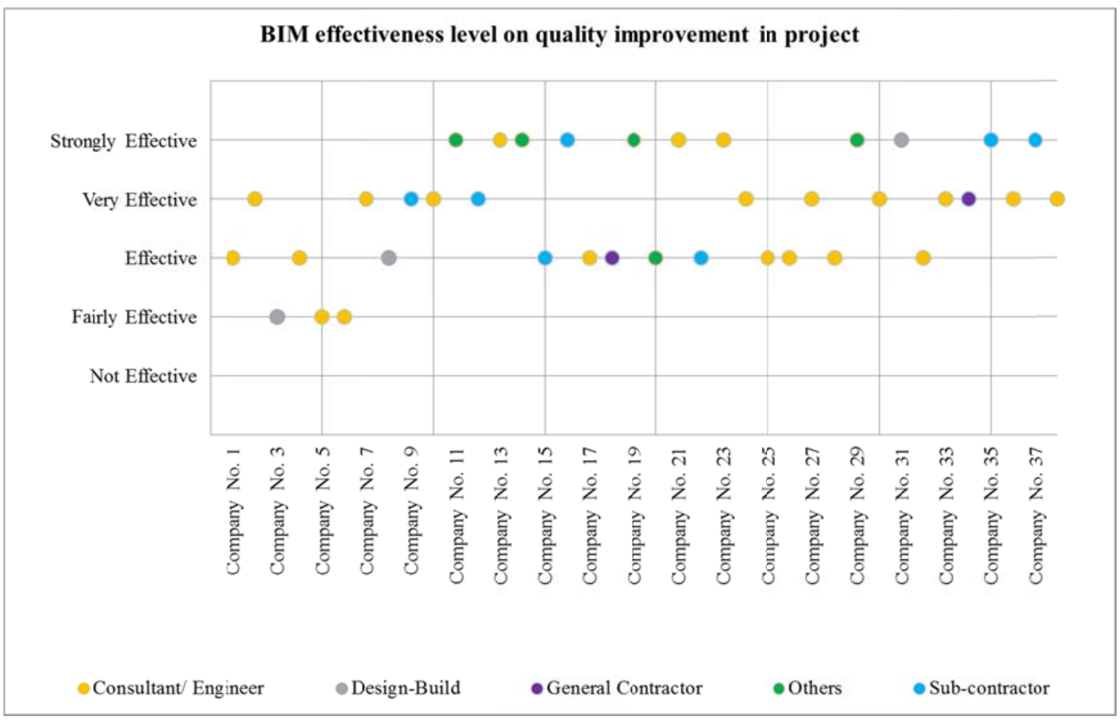

Figure 6.32: BIM effectiveness on quality improvement in project based on company contractual role

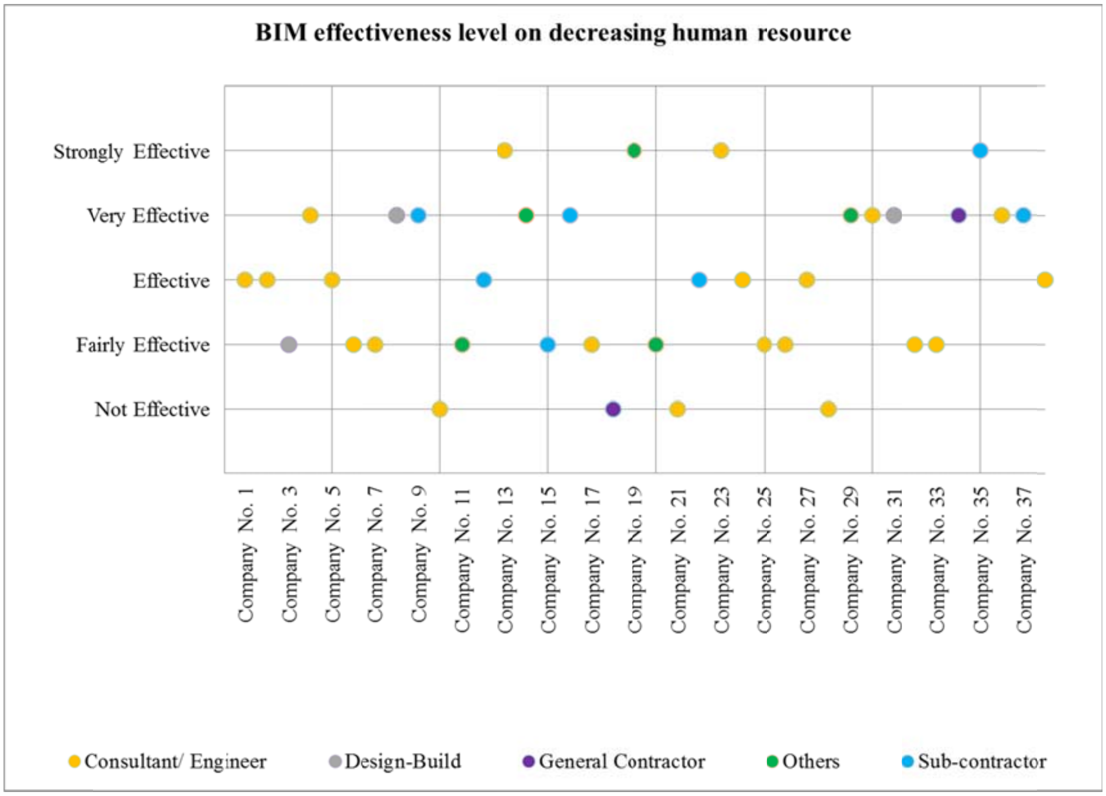

Figure 6.33: BIM effectiveness on decreasing human resources based on company contractual role

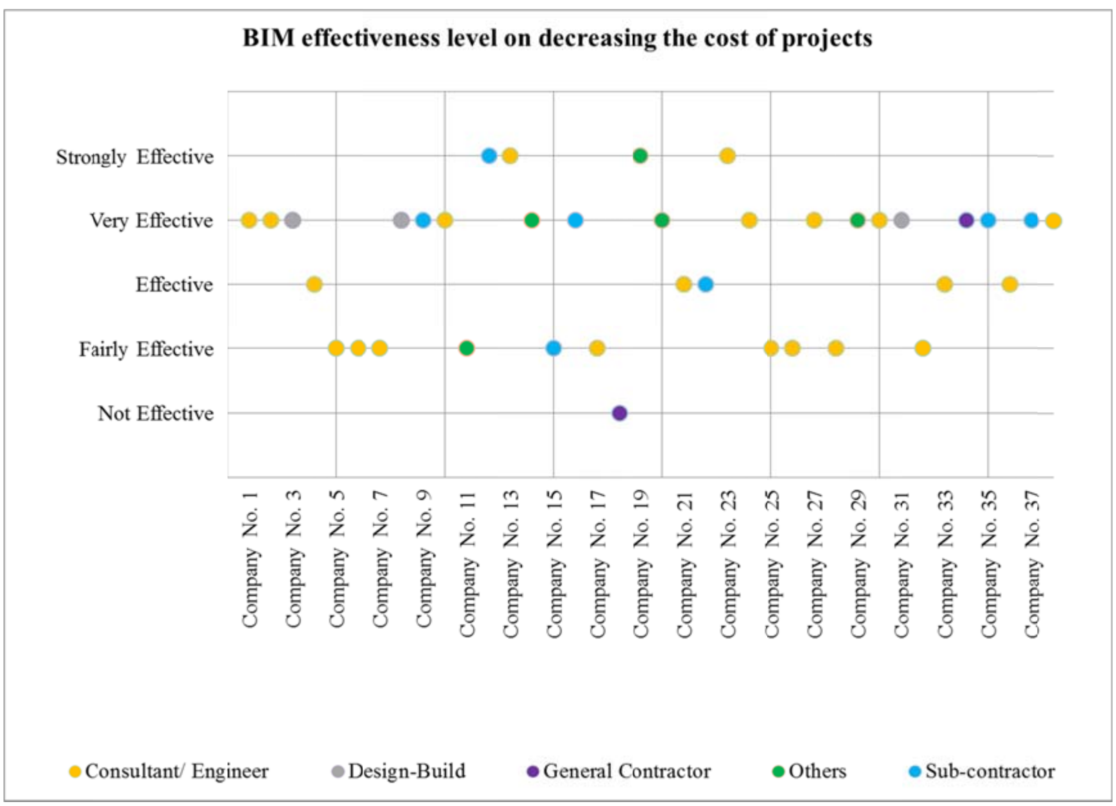

Figure 6.34: BIM effectiveness on decreasing the cost of project based on company contractual role

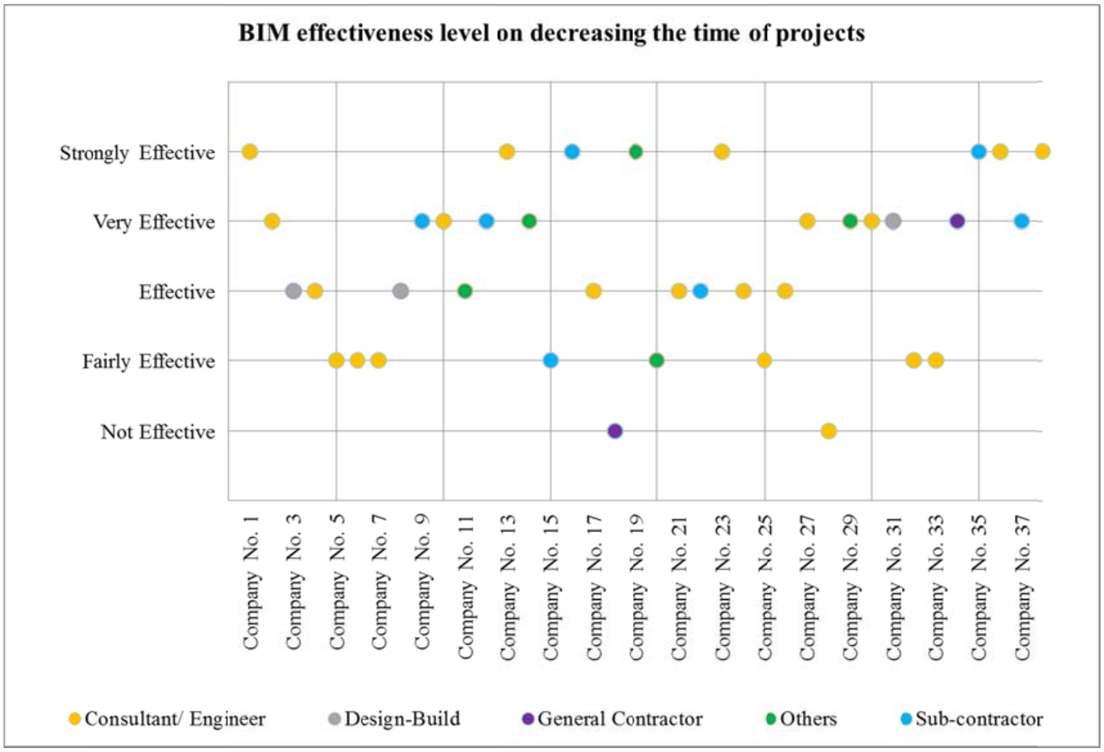

Figure 6.35: BIM effectiveness on decreasing the time of project based on company contractual role

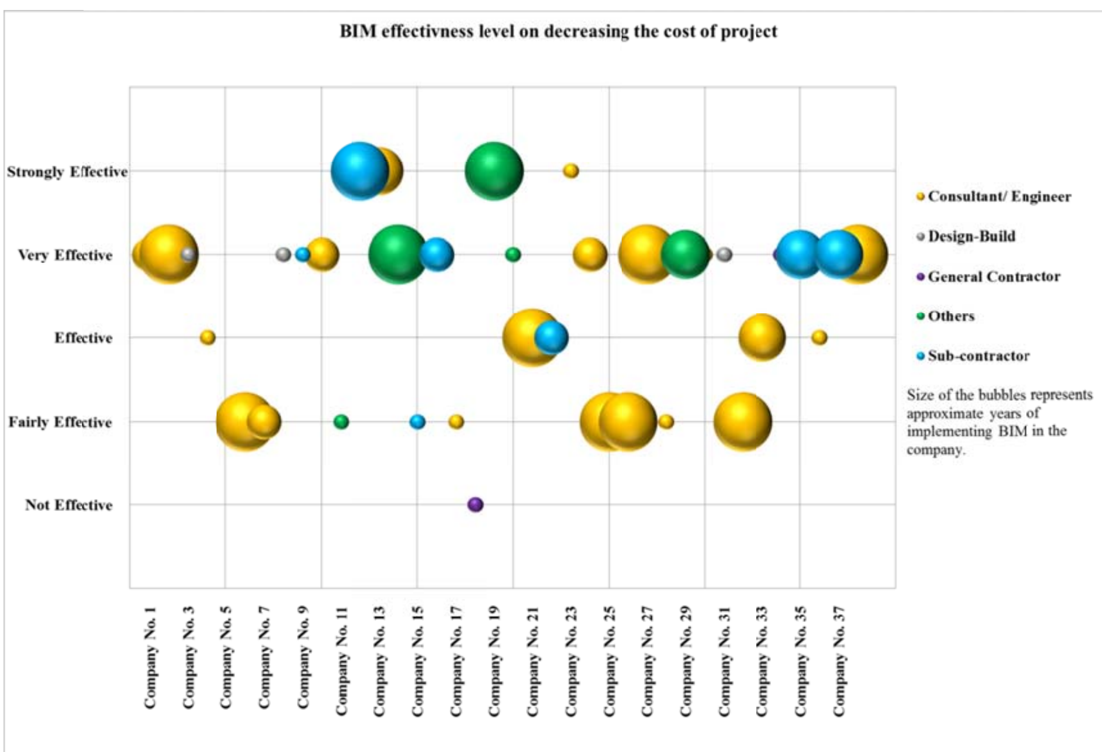

Figure 6.36: BIM effectiveness on cost of project based on company contractual role and years of BIM utilization

In figure 6.36, the size of the bubbles represent the approximate years of implementing BIM in the company. In other words, the longer BIM has been utilized in the company, the larger the bubble. There are more small bubbles in the "not effective" or "fairly effective" categories. In other words, the companies that were implementing BIM for shorter time, experienced less impact on their cost; only 4 companies with longer BIM experience were among them.

BIM effectiveness on decreasing the cost of project, based on contractual role of company and the years of implementing in company, is detailed and shown in table 6.7 and 6.8.

Table 6-7: BIM effectiveness on cost of project based on company contractual role

BIM effectiveness on decreasing the cost of project	Contractual role of company					Total
	General Contractor	Consultant/ Engineer	Sub-contractor	Design-Build	Others	
Not effective	1	0	0	0	0	**1**
Fairly effective	0	8	1	0	1	**10**
Effective	0	4	1	0	0	**5**
Very effective	1	7	4	3	3	**18**
Strongly effective	0	2	1	0	1	**4**
Total	**2**	**21**	**7**	**3**	**5**	**38**

Table 6-8: BIM effectiveness on cost of project based on years of BIM utilization in company

BIM effectiveness on decreasing the cost of project	Number of years that company implemented BIM				Total
	Less than 2 years	2 to 4 years	4 to 6 years	more than 6 years	
Not effective	1	0	0	0	**1**
Fairly effective	5	1	0	4	**10**
Effective	2	1	1	1	**5**
Very effective	7	4	3	4	**18**
Strongly effective	1	0	1	2	**4**
Total	**16**	**6**	**5**	**11**	**38**

The human resources also showed to be less influenced by BIM, which can be due to a lack of skilled and well-trained personnel. If the company is not employing professionals, learning new technology and utilizing it would be time-consuming by employees who are trained for traditional methods. It is therefore not possible to do the work in a shorter time and to release some of the project team members for assigning them to other projects. It would take time for the companies to reach that stage where skilled employees, who spend less hours on the works, will allow the saving of human resources.

Question 5

Getting to know the benefits of BIM application for companies, it is vital to understand the difficulties and barriers they may face during its implementation. Understanding these problems may help to identify the contents that students need to know.

For this reason, the next question comprised a list of likely obstacles, as described in the major risks and barriers of implementing BIM in section 2.4.3. The respondents were asked to rank the level of difficulty in some of the challenges which may occur during BIM implementation. As it has been summarized in table 6.9, the majority of participants agreed that all listed obstacles can be treated (solvable problems). Furthermore, a considerable number of the respondents (12) were of the opinion that a lack of well-trained employees or their resistance and also the cost of software licenses and training are the major problems. Some responses (7) stated that there are difficulties in getting other parties to cooperate and to contribute, lack of collaborative processes and modelling standards as well as compatibility issues between different software systems.

Table 6-9: Number of companies that reported difficulties in each area

No.	Problem	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
1	Lack of skilled personnel/ Employees' reluctance for learning a new technology	4	4	18	12	0
2	Other parties' reluctance (Client, engineer, architects, contractors,...)	4	6	21	7	0
3	Sharing the information/ Model with other parties	6	9	17	6	0
4	Integrating company's system with BIM	7	6	20	4	1
5	Lack of collaborative process and modelling standards	3	6	21	7	1
6	Lack of contractual / legal agreements	2	5	24	5	2
7	Waste of time	12	7	17	1	1
8	Cost of software licence and training	4	1	19	12	2
9	Compatibility issues between different software systems	6	4	20	7	1
Average		**5**	**5**	**20**	**7**	**1**

A remarkable number of participants (12) have the conception that it is not a waste of time to spend time for implementing this new technology before starting to make use of it. While 17 companies considered that sharing the information is a problem that can be addressed easily, for 9 of them it was a problem that can be ignored. There were also some respondents (6) who felt that information sharing can be a real challenge for their companies.

Integrating company systems with BIM was a serious obstacle for only 1 respondent and a concern for 4 others. While lack of standards for collaboration process and compatibility issue was raised by one of the companies, it was experienced with major difficulty in 7 others. Lack of legal and contractual agreement as well as cost of software license and training was the areas of concern for 2 respondents.

In total, the main difficulties during BIM implementation were reported to be the legal and contractual issues, lack of guidelines and standard for collaboration, compatibility and also integrating BIM in current systems of the company.

The scatter of the problems, based on the company contractual role is illustrated in figures 6.37 to 6.45. Different colours of the bubbles represent the contractual role of the company. The four main difficulties for the consultant companies comprised of a lack of professional and employee willingness to learn, lack of procedures and standards, cost of having the software license and also compatibility issues.

The general contractors who participated in the survey were not struggling with any problems apart from the license cost. The main concern of the sub-contractors was with regard to qualified personnel and a few problems with legal and contractual aspects.

The level of difficulty for the problems listed in table 6.9, based on the contractual role of the company is shown in tables G.1 to G.9 in appendix G.

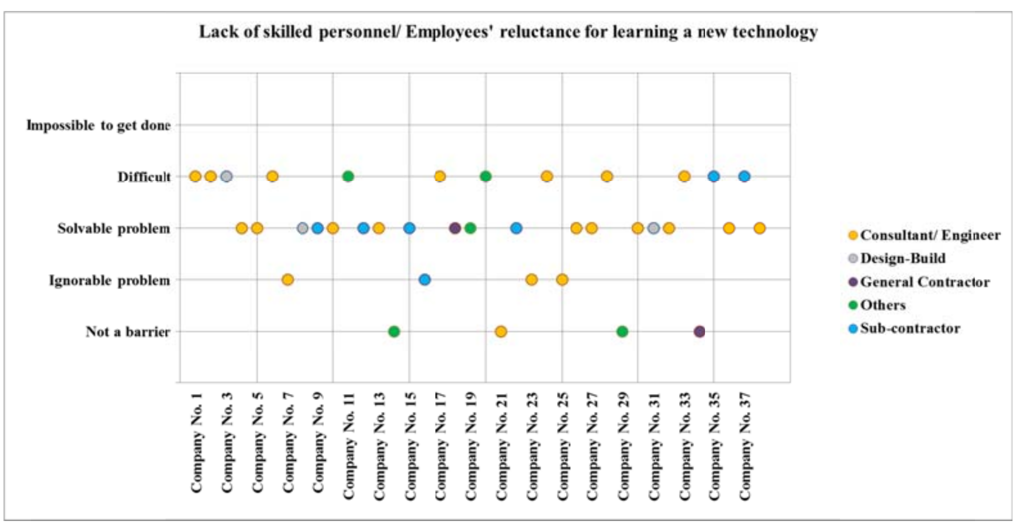

Figure 6.37: BIM implementation problem 1 (lack of skilled personnel/ Employees' reluctance for learning a new technology) based on company contractual role

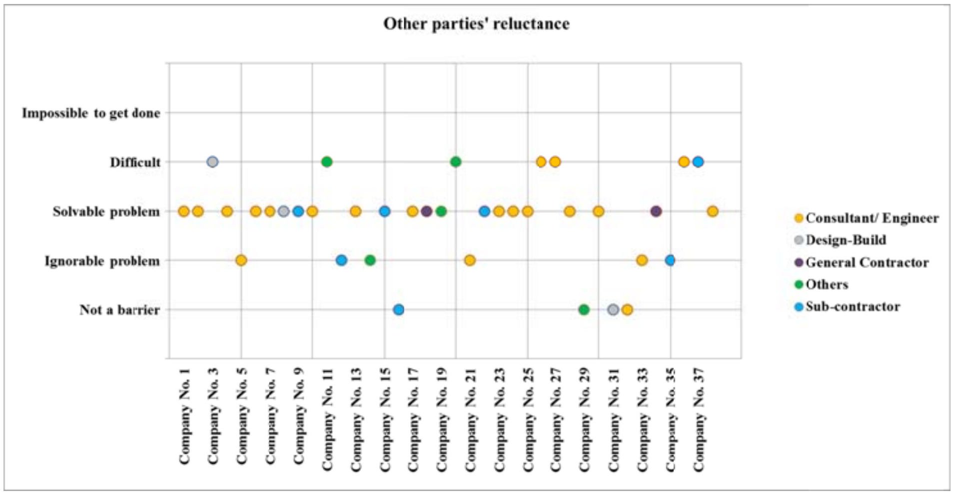

Figure 6.38: BIM implementation problem 2 (other parties' reluctance) based on company contractual role

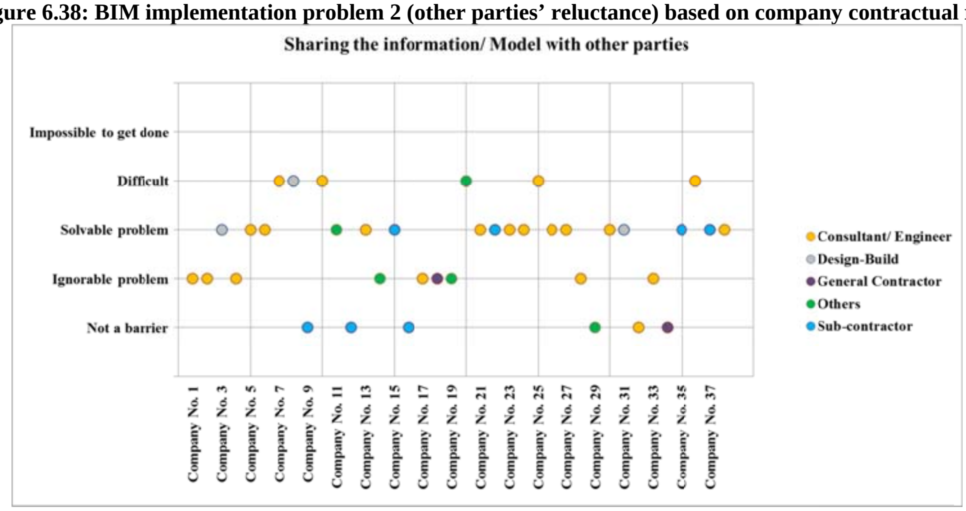

Figure 6.39: BIM implementation problem 3 (sharing the information/ model with other parties) based on company contractual role

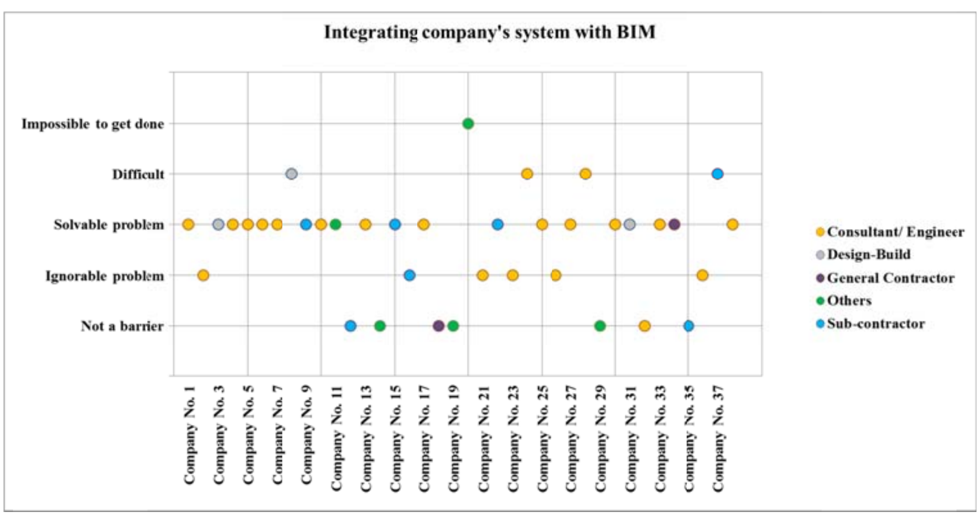

Figure 6.40: BIM implementation problem 4 (integrating the system of the company with BIM) based on company contractual role

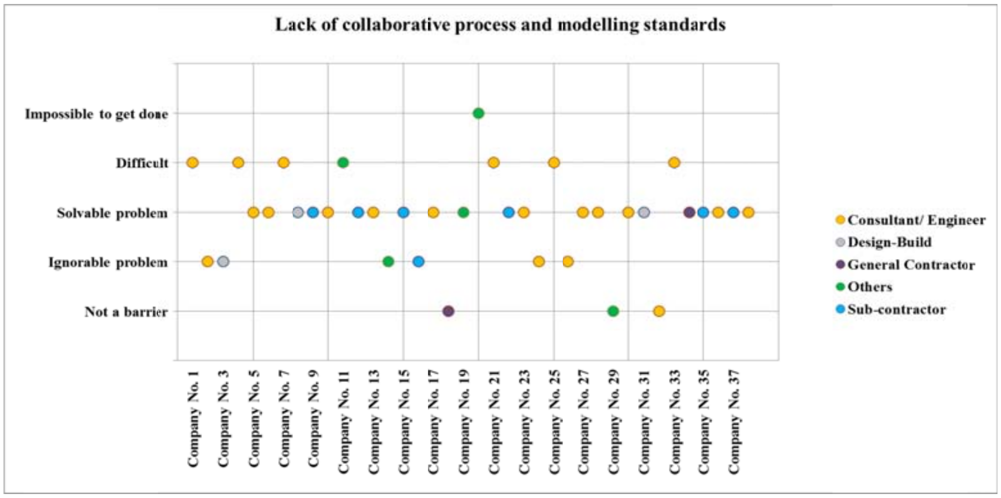

Figure 6.41: BIM implementation problem 5 (lack of collaborative process and modelling standards) based on company contractual role

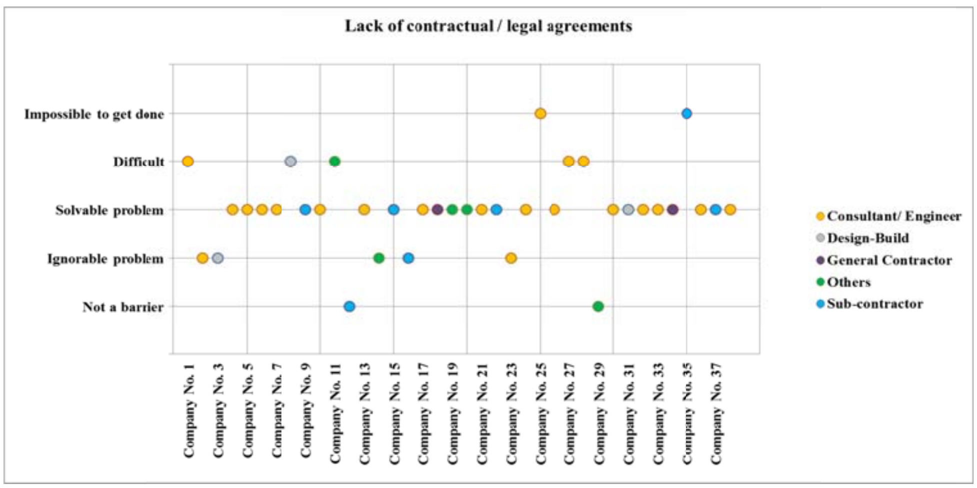

Figure 6.42: BIM implementation problem 6 (lack of contractual agreements) based on company contractual role

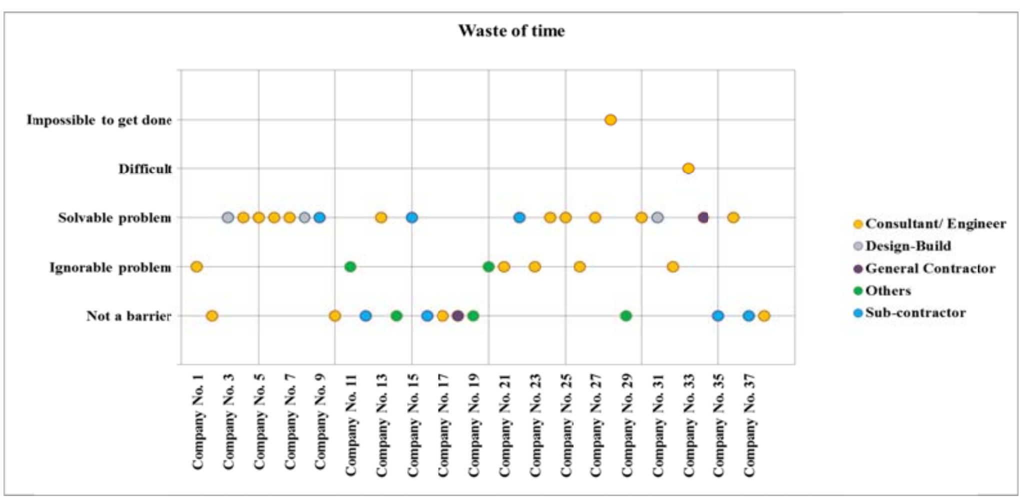

Figure 6.43: BIM implementation problem 7 (waste of time) based on company contractual role

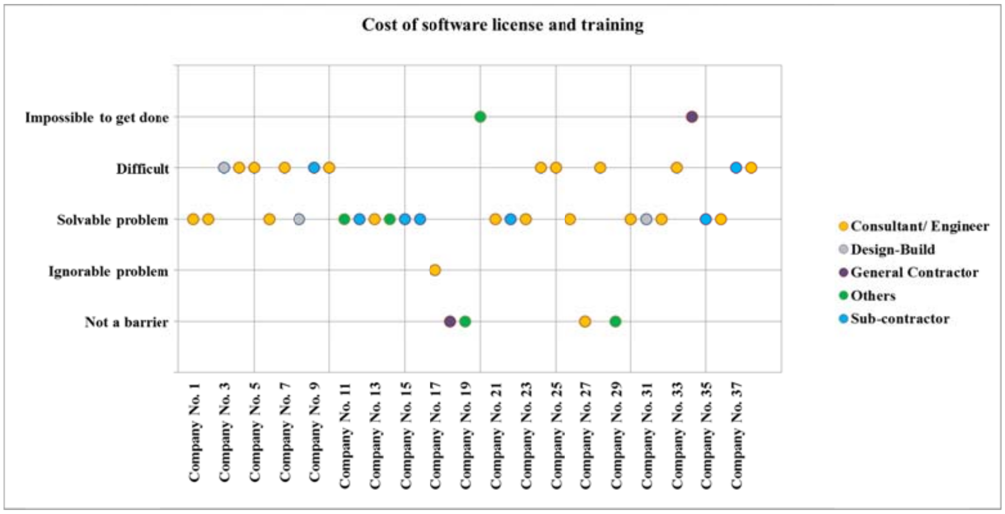

Figure 6.44: BIM implementation problem 8 (cost of software license and training) based on company contractual role

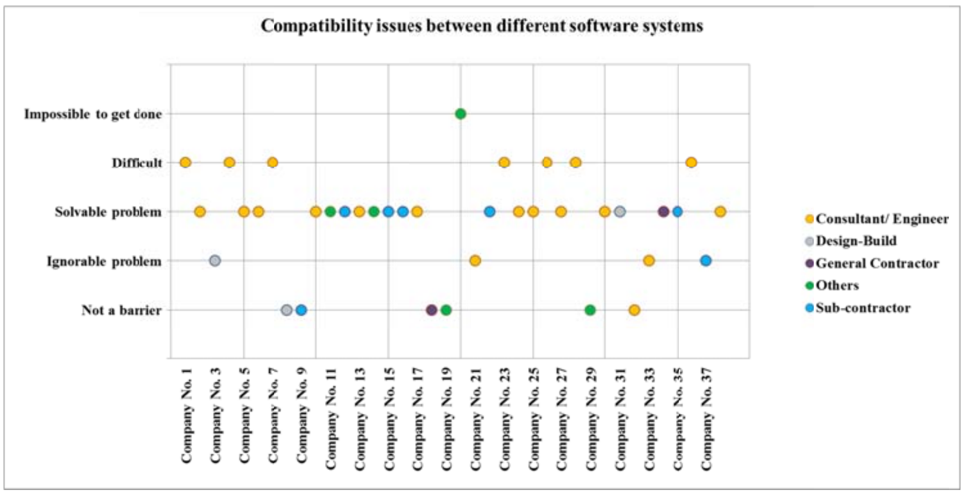

Figure 6.45: BIM implementation problem 9 (compatibility issue between different software systems) based on company contractual role

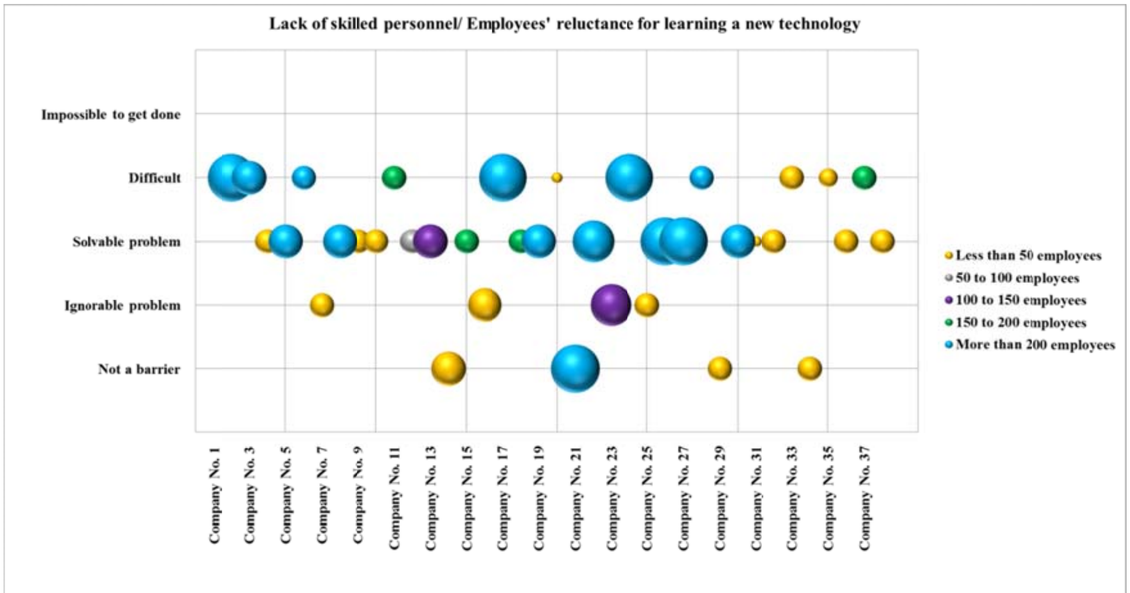

Figure 6.46: Lack of skilled personnel based on company size and number of in-house BIM specialists

Figure 6.46 shows a lack of well-trained employees based on company size and number of BIM specialists which is reflected in the size of bubbles; the more BIM specialist, the bigger the bubble. It seems that larger companies with more BIM professionals are experiencing difficulties in employee knowledge using new technologies. Smaller companies were adopting to new technology with less difficulty.

The level of difficulty reading lack of well-trained employees based on company size and number of BIM specialists is also shown in table 6.10 and 6.11.

Table 6-10: Lack of skilled personnel based on number of employees of company

Number of employees	Level of difficulty due to the lack of skilled personnel/ Employees' reluctance for learning a new technology					Total
	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done	
Less than 50	3	3	7	3	0	**16**
50-100	0	0	1	0	0	**1**
100-150	0	1	1	0	0	**2**
150-200	0	0	2	2	0	**4**
More than 200	1	0	7	7	0	**15**
Total	**4**	**4**	**18**	**12**	**0**	**38**

Table 6-11: Lack of skilled personnel based on number of in-house BIM specialists

Number of employees	Level of difficulty due to the lack of skilled personnel/ Employees' reluctance for learning a new technology					Total
	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done	
Less than 5 specialists	2	2	9	5	0	**18**
5 to 10 specialists	1	1	5	1	0	**8**
10 to 15 specialists	0	0	1	1	0	**2**
15 to 20 specialists	0	1	0	0	0	**1**
More than 20 specialists	1	0	2	3	0	**6**
No in-house specialists, as the BIM needs are outsourcing.	0	0	0	1	0	**1**
Neither in-house specialists nor outsourcing.	0	0	1	1	0	**2**
More than 200	0	0	0	0	0	**0**
Total	**4**	**4**	**18**	**12**	**0**	**38**

Question 6

The last question in this section was about training and the way that works best for each company. Respondents were requested to choose the best method from four options: self-learning, academic learning, Seminar/Workshop or Conferences and in-house training. The participants could choose more than one option in this question. The results, presented in figure 6.47, showed that almost 79% of the respondents agreed that in-house training work best for their requirements. Self-training was ranked second as it was chosen by 28 participants and was very close to in-house training option. Workshops and seminars were almost in the same ranking as academic training; 13 respondents found workshops and conferences to be helpful and 11 participants preferred academic education. This low ratio for appointing skilled staff from academic environments can be due to the gap between the company requirements and the subjects which are taught at the universities. A remarkable number of companies prefer to do it through trial and error by self-training rather than by relying on the academic background of employees.

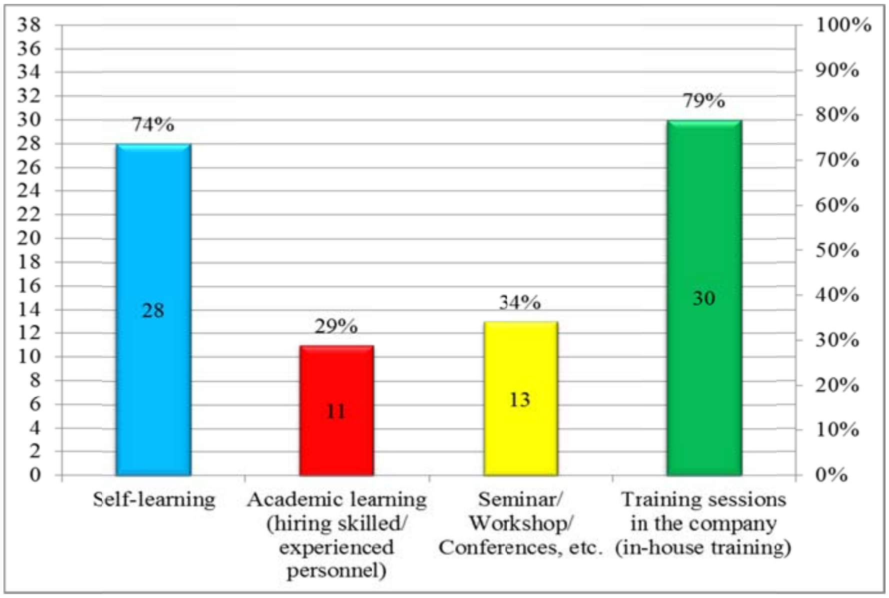

Figure 6.47: BIM learning method preference for the companies

It is worth mentioning that among the 11 participants who chose academic training, there were only 2 that believed this kind of learning is fulfilling their needs on its own and the rest stated that it should be accompanied by other methods.

Companies which were not making use of BIM tools

As mentioned in the last part of 6.2.1, 29 out of 67 companies stated that they were not applying BIM. The questionnaire guided these groups to a set of four questions regarding the main reasons for not applying it, whether their company will approach implementing BIM in the future, the main skills they will consider for employing a fresh graduated engineer and the method they prefer for their employee training.

As shown in figure 6.48 and table 6.12 and 6.13, only a few of companies who were not using BIM were working internationally. Most of them had offices either in less than three provinces in South Africa or working in other African countries, but not beyond the African continent. It is also demonstrated that the majority of companies in this group were small with less than 50 employees and only a few large companies were amongst them.

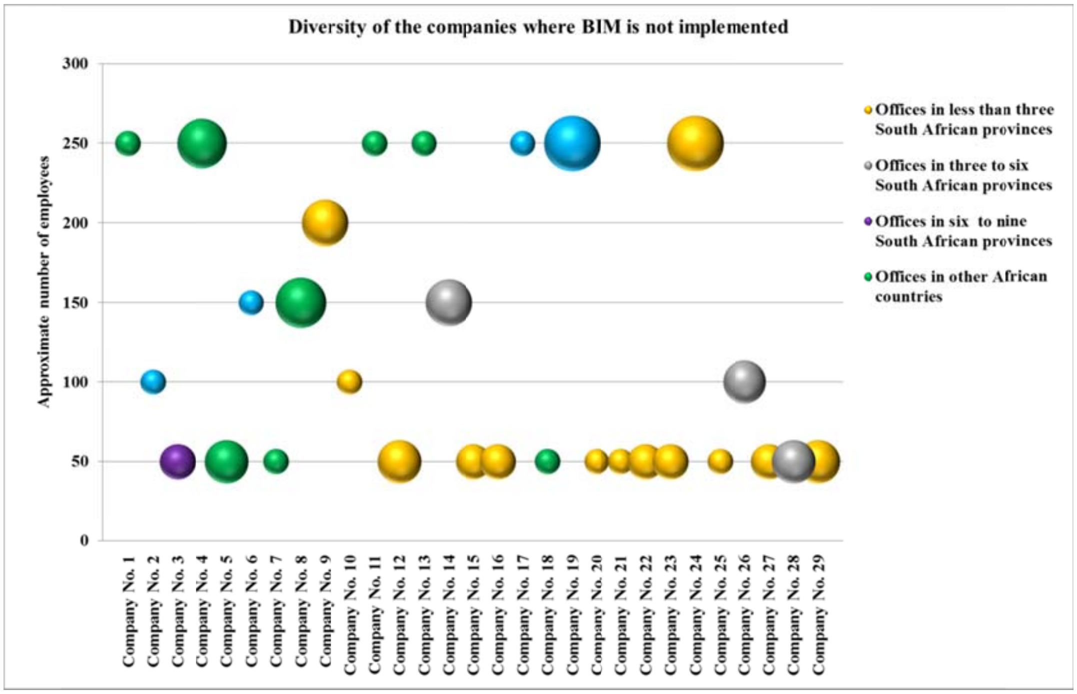

Figure 6.48: Diversity of the companies where BIM is not implemented

Table 6-12: Diversity of the companies where BIM is not implemented based on geographical spread of company

Number of employees	Number of companies that have					Total
	Offices in less than three South African provinces	Offices in three to six South African provinces	Offices in six to nine South African provinces	Offices in other African countries	International offices (beyond African continent)	
Less than 50	10	1	1	3	0	**15**
50-100	1	1	0	0	1	**3**
100-150	0	1	0	1	1	**3**
150-200	1	0	0	0	0	**1**
More than 200	1	0	0	4	2	**7**
Total	**13**	**3**	**1**	**8**	**4**	**29**

Table 6-13: Diversity of the companies where BIM is not implemented based on annual revenue of company

Number of employees	Number of companies that have approximate annual revenue of						Total
	Less than 10 Million Rand	10 to 50 Million Rand	50 to 100 Million Rand	100 Million to 1 Billion Rand	1 to 10 Billion Rand	More than 10 Billion Rand	
Less than 50	5	6	4	0	0	0	**15**
50-100	2	0	1	0	0	0	**3**
100-150	1	0	1	0	1	0	**3**
150-200	0	0	0	1	0	0	**1**
More than 200	4	0	0	0	1	2	**7**
Total	**12**	**6**	**6**	**1**	**2**	**2**	**29**

Question 1

To understand the reason for not applying BIM in the company, a list of possible reasons, based on major risks and barriers as discussed in section 2.4.3, were provided and respondents were asked to prioritize them based on their company situation and experience. The overall conclusion on ranking the obstacles is summarized in table 6.14. Almost half the respondents (13) agreed that implementing BIM would be time consuming and it was ranked as the first reason for not being interested in this new technology.

The second priority was assigned to the lack of contractual agreements and legal issues by 11 respondents. Compatibility was the third concern, as 8 respondents considered it the main barrier for utilizing BIM.

Another highlight of the results was about having enough knowledge regarding BIM and its benefits. 25% of the respondents agreed that this would be the last problem they might deliberate in the process of applying BIM, while for almost the same percentage of respondents it was the first problem that should be addressed. So, there are some companies that are aware of the advantages BIM can bring, but they are avoiding it due to other difficulties. There are also companies that do not have enough knowledge about BIM and its features.

Table 6-14: Reason for not applying BIM

Priority	Reason for not approaching BIM implementation
1	Waste of time
2	Lack of contractual / legal agreements
3	Compatibility issues between different software systems
4	Lack of collaborative process and modelling standards
5	Sharing the information/ Model with other parties
6	Other parties' reluctance (Client, engineer, architects, contractors,...)
7	Lack of skilled personnel/ Employees' reluctance for learning a new technology
8	Cost of software license and training
9	Integrating company's system with BIM
10	Not enough awareness about BIM and its advantages

Question 2

For having a perspective of BIM in future, the participants were asked if they were of the opinion that their company would apply BIM in future. The result showed that about half of these companies were considering approaching BIM technology within less than 5 years, as demonstrated in figure 6.49.

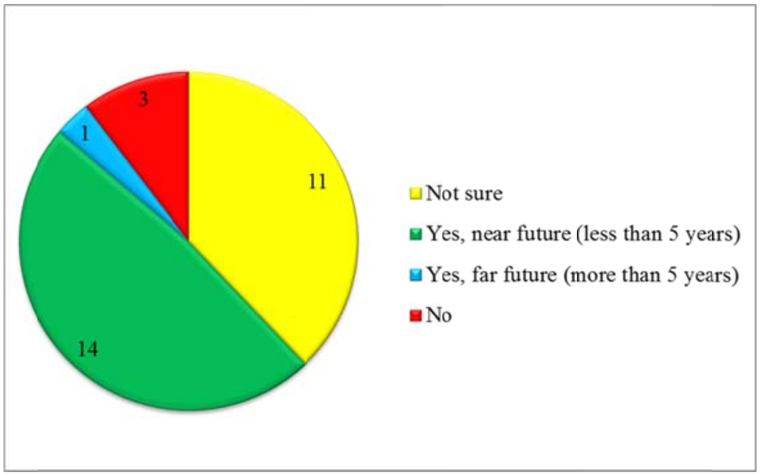

Figure 6.49: Perspective of future BIM usage in companies

While 11 respondents were not sure about implementing BIM, 3 of them were convinced that there would not be any chance of working with BIM technology in their company. Only one of the participants reported that the likelihood of utilizing BIM in his/her company would be increased in future. As shown in figure 6.50 and table 6.15 and 6.16, studying the company responses, in addition to considering their size and geographical spread showed that the three companies which are not willing to apply BIM technology, were small companies and only one of them was working outside South Africa and within African countries.

There was a wide diversity, from small firms with a few local offices to large international companies, among the companies who were of the opinion that they may use BIM in the near future. The number of companies that were doubtful about using BIM in future was very similar to the number of firms who were considering BIM application in the near future.

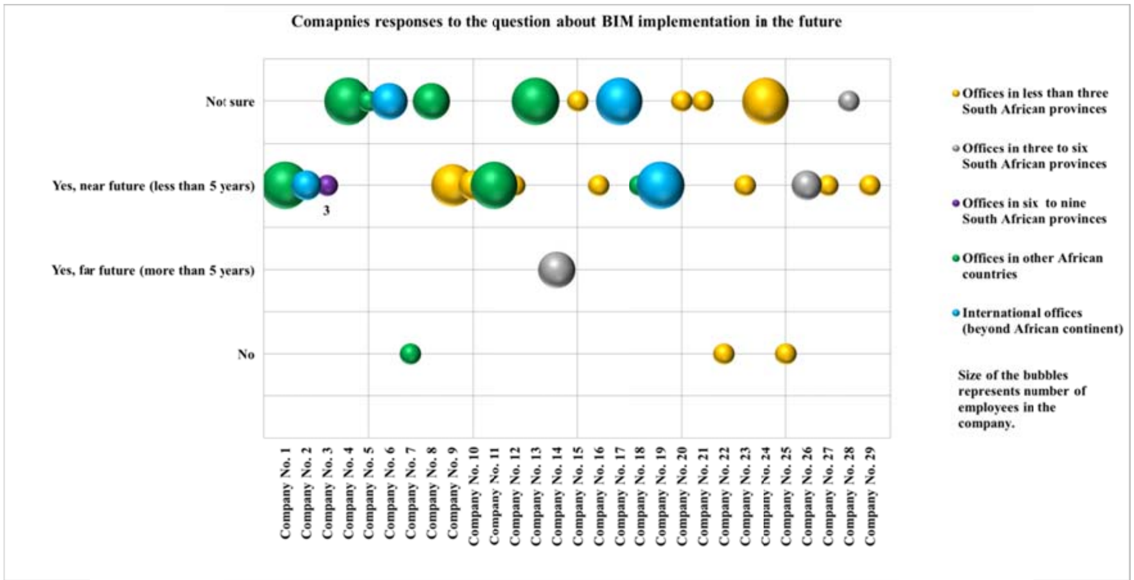

Figure 6.50: BIM future of the companies based on their size and geographical spread

Table 6-15: BIM future of the companies based on their size

Number of employees	If the company considers applying BIM in the future				Total
	Not sure	Yes, near future (less than 5 years)	Yes, far future (more than 5 years)	No	
Less than 50	5	7	0	3	**15**
50-100	0	3	0	0	**3**
100-150	2	0	1	0	**3**
150-200	0	1	0	0	**1**
More than 200	4	3	0	0	**7**
Total	**11**	**14**	**1**	**3**	**29**

Table 6-16: BIM future of the companies based on geographical spread of company

Geographical spread of company	If the company considers applying BIM in the future				Total
	Not sure	Yes, near future (less than 5 years)	Yes, far future (more than 5 years)	No	
Offices in less than three South African provinces	4	7	0	2	**13**
Offices in three to six South African provinces	1	1	1	0	**3**
Offices in six to nine South African provinces	0	1	0	0	**1**
Offices in other African countries	4	3	0	1	**8**
International offices (beyond African continent)	2	2	0	0	**4**
Total	**11**	**14**	**1**	**3**	**29**

Question 3

As one of the main targets of the survey was to understand the gaps between industry needs and educational courses or programmes for BIM, the participants were required to identify the skills they are looking for when hiring a fresh graduate in civil engineering or construction management. The skill list was based on the major capabilities of BIM which can be applied by BIM specialists and they could choose multiple areas of expertise.

The results showed that there are specific fields which are more important for almost half of the companies contributing in the survey, as demonstrated in figure 6.51. ”Quality control” was the first top ranked item among the area of expertise, followed by “performance optimization”, which were chosen by 13 and 12 respondents, respectively. Four skills were ranked equally for the third priority. These are “Quantification/Estimation”, “Cost estimation”, “Collaboration and coordination” and “Productivity optimization”. To improve students’ knowledge in these areas, BIM is a suitable tool as discussed in section 2.4.4. It enables monitoring of the compliance of the work with the contract plans and specifications. This helps for ”Quality control” and may result in “Productivity optimization” as well. Furthermore, providing the foundation for early cost estimating, providing BOQs and enhancing the collaboration process are the other benefits of BIM which have already been discussed in chapter 2. Together, these will improve the performance of work which is another feature that companies require.

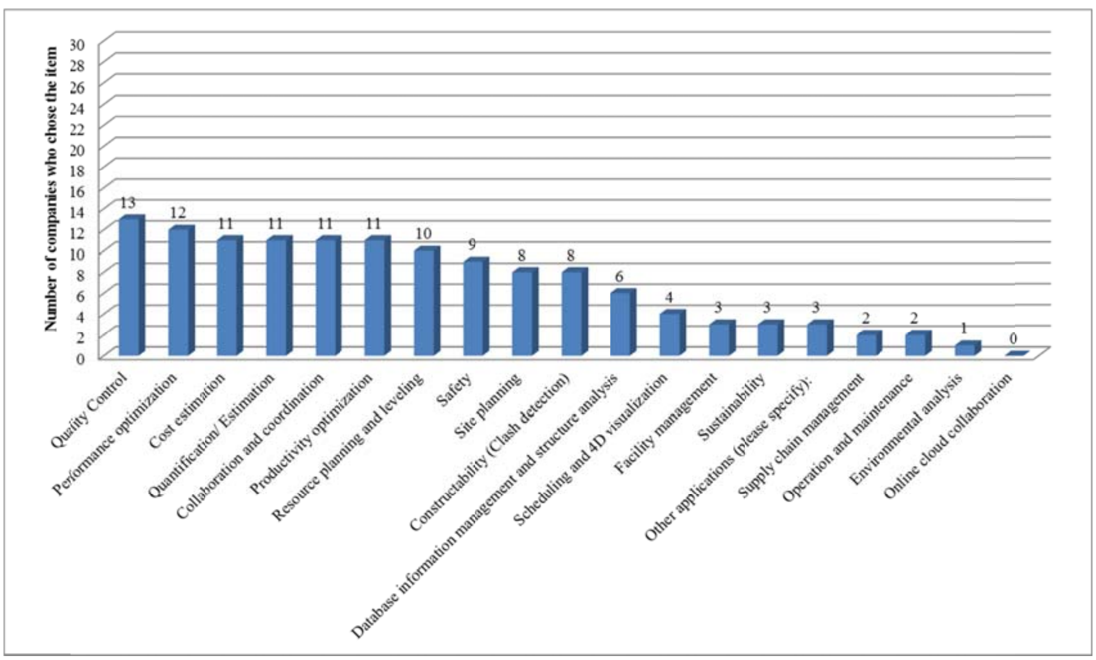

Figure 6.51: Areas of expertise of new graduates from the point of view of the company

Besides, other areas which are on the list but with less demand from the industry, such as resource planning, safety and clash detection and constructability, can be introduced to students while teaching them construction processes using BIM tools.

Question 4

The last question in this section was to identify the companies' preference for training in terms of different skills such as BIM. They could define any combination of four options listed in the questionnaire, including self-learning, academic learning (hiring skilled/experienced personnel), seminar/workshop and conferences, or training sessions in the company (in-house training).

The majority of the respondents (62%) believed in in-house training as the first choice, and self-learning was ranked second with 52% of companies, as shown in figure 6.52. However, the ratio of the companies that were of the opinion that academic training is useful was very close that of those who chose self-learning, 14 and 15 respondents respectively. The least proportion was assigned to learning through workshops/seminars and conferences.

Comparing this result to the same question from BIM user respondents in the previous section of the questionnaire, it seems that for companies that do not know that much about the new technology and who are not exposed to it, employing a skilled graduate engineer would be a good option. However, companies that are already utilizing BIM prefer their in-house and customized training or even trial and error through self-learning more than to hire knowledgeable graduates.

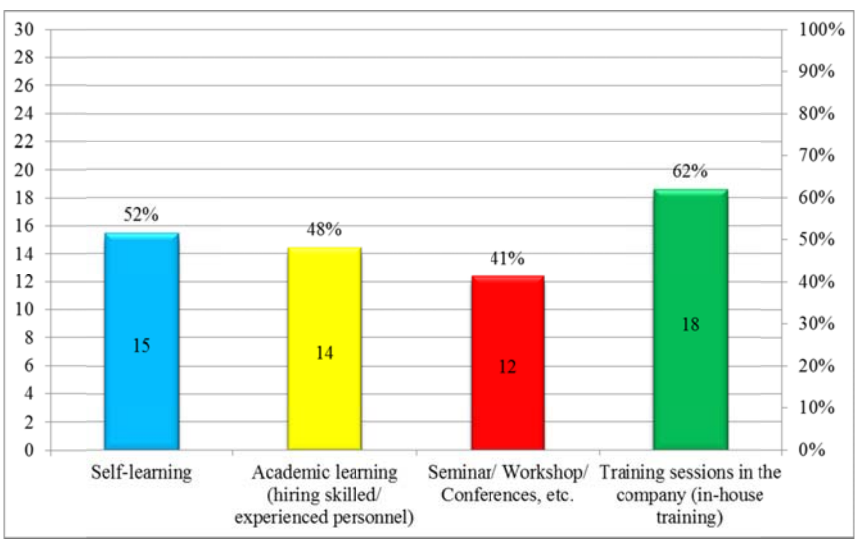

Figure 6.52: BIM learning method preference for the companies where BIM is not implemented

6.3.4 Overall evaluation

A survey was conducted amongst 67 companies that were involved in structural and civil works. The results showed that more than half of these companies (57%) were working with BIM tools. Although many of the companies started using BIM 2 years ago, a considerable proportion had been using BIM for more than 6 years. Large companies that worked internationally were more likely to utilize BIM for both the sub-contractors and consultants. The majority of companies had less than 10 BIM specialists. The main functions of BIM for these companies were visualization, clash detection and collaboration. These might be the areas for which the companies need informed fresh graduate engineers. In a large number of companies where BIM was applied, it was reported that cost cutting, creativity enhancement and quality improvement was highly effected by employing this new technology. The main barriers noticed in this group of companies, included legal and contractual issues, lack of guidelines and standard for collaboration, compatibility and integrating BIM in current systems of the company. In-house training followed by self-learning were the preferred methods for this group to enhance their employees' knowledge. Academic training was the last option for this group of companies.

Almost half of the companies that have not started using BIM stated that they will step towards BIM adoption within 5 years. The main reasons preventing them from implementing BIM included new technology being seen as a waste of time, lack of contractual and legal agreements and compatibility issues between different software systems. The areas which can be enhanced while teaching students about BIM applications consisted of quality control, optimizing productivity and performance, collaboration skill, providing BOQs and cost estimation ability. These are the areas that companies would like newly appointed graduates to help them with. The desired learning method for this group of companies was also in-house training and self-learning, with a low preference for academic learning. In other words, they were also interested in appointing fresh graduate who are well-trained and qualified through studying a university degree.

6.4 Interview with university lecturers

6.4.1 Background

The courses offered for a civil engineering undergraduate degree in five surveyed universities are presented in Appendix D and some of these courses are common amongst these universities. The defined specific outcome of these courses and the topics which are discussed in them, are standardized by the Engineering Council of South Africa (ECSA). This helps to understand whether the course can be considered for including the BIM subject in their curricula. Reviewing the outcomes of the common courses as well as the students' expected capabilities after passing the courses, it was concluded that there are courses with potential of adding BIM contents in their curricula, such as: Structural Steel Design, Reinforced Concrete Design, Advanced Design, Project Management, Engineering Informatics and Engineering Management. The topics, which are likely to be discussed and the aims, which might be achieved through these courses, are presented in table 6.17.

Table 6-17: The main topics of some common civil engineering courses

Course name	Main topics
Engineering Drawing	• Creating freehand and formal pencil drawings. • Create and interpret engineering drawings containing orthogonal projections, dimensions, tolerances and full sections. • Evaluating the correctness and completeness of engineering drawings • Creating and interpreting two dimensional drawings of three dimensional objects • Visualizing three dimensional objects and geometric manipulations • Conceptualizing three dimensional constructions to quantify geometric relationships • Formulating and manipulating geometric models that describe three dimensional physical phenomena • Creating parametric two and three dimensional CAD models of physical objects.
Design (Structural Steel and Reinforced Concrete)	• Physical properties of concrete and steel • Design principles • Structural forces • Bending: fundamentals, analysis and design, redistribution • Design of structural elements for shear forces • Serviceability • Designing columns, slab and flat slab • Detailing rules for structural concrete • Analyse and design elements for effects of pre-stressing forces and bending moments

Course name	Main topics
Advanced Structural Design	• Development of a concept for the structural system for the project defined in the specifications • Preliminary design of a cost effective concept that also takes account of all other functionalities • Preliminary design report and drawings • Final design of selected structural system • Preparation of final documentation for the structure including: • Lay-out drawings for the structure • Detail of structural components • Design of selected connections • Bill of quantities
Engineering Management / Project Management	• The role of the engineer as client, consultant engineer and contractor • Strategic, practice and business development management • Construction Management: Construction equipment, production processes and cycles, Site layout, Project administration • Working with other professions such as town planners, architects, other professional engineers, developers and financers • Tender and contract documentation, Contract administration • Low-cost development projects and Urban Engineering • Asset management, maintenance, rehabilitation and industry • Sustainable management • Project safety and quality control • Construction contract law and risk management • Labour relations
Engineering Informatics	• Object modelling techniques to create object models of simple engineering problems • Theory for a physical problem, namely heat flow • An algorithm for the solution of the equations, namely the finite • element method • Mapping of the algorithm to the computer

Comparing the topics of these current courses (table 6.17) to the topics which are likely to be covered in some BIM courses (table 4.4), it can be seen that some of the topics are already part of current curricula in South Africa. However, there are certain topics which may need to be added to the course content depending on the department strategy for integrating BIM into the programme. This strategy can either focus on introducing BIM as a tool or enhance learning about construction processes through application of BIM. For the purpose of this research BIM application is considered for teaching knowledge of construction processes by using the collaboration and management capabilities.

In order to obtain the views of lecturers on the use of BIM in such courses, interviews were conducted with the lecturers of some of these courses at Stellenbosch University. A detailed schedule and the transcripts of the interviews are presented in Appendix E. The Civil Engineering department was used for the purpose of the investigation. As Engineering Drawing is offered generally for all engineering students and not specifically for civil engineering students, the lecturer of this course was not chosen for an interview.

Table 6-18 Topics which may need to be added to the current curricula based on the result of the surveys

No.	Areas of concern
1	Visualization skill and making use of 3D models
2	Practical working with 3D CAD tools
3	Capturing, storing or analysing geographical information of building components
4	Defining geometry and spatial relationships such as identifying overlaps or whether one component contains or crosses the others
5	Allocating time to the construction components and the project tasks
6	Detecting clashes between the components
7	Providing as-built information for the facility
8	Defining cost for the project elements
9	Integrating the information and models
10	Collaboration and multidisciplinary approach in construction process
11	Quality control knowledge
12	Cost estimation ability
13	Providing a BOQ
14	Optimizing productivity
15	Optimizing performance

Lecturers were first asked about their personal theoretical and practical experience in terms of BIM. Then with the result of the first two surveys as background, being the areas where students' knowledge should be improved and industry expectations from new graduates, a list was compiled as areas of concern (see table 6.18). The lecturers were asked if they are already include or are going to consider the subjects from this list in their courses, and whether they were willing to expose students to these concepts through BIM. After responding to the question about lecturers' willingness for integrating BIM in the courses, their particular comments and ideas were also obtained about integrating BIM into the curricula.

The six lecturers who were interviewed were responsible for five courses including Structural Steel Design, Reinforced Concrete Design, Advanced Structural Design (2 lecturers), Engineering Informatics and Engineering Management. It is worth mentioning that the lecturer of the Structural Steel Design course previously was responsible for the Advanced Structural Design course. Since the courses on Structural Steel Design, Reinforced Concrete Design and Advanced Structural Design mostly focus on design aspects and the Engineering Management course contains management and project issues, all the identified areas from the first two surveys could be discussed in these interviews. In addition, making use of CAD tools and relevant issues, which is the base of Building Information Modelling, is partially discussed in the Engineering Informatics course.

Table 6-19: The information about the courses and lecturers

Identification Code	Course	Offered in	Lecturer's years of experience	
			In practice	At university
Interview 1 & Interview 6	Advanced Structural Design	4th year/ 2nd semester	45	1
			5	3 months
Interview 2	Structural Steel Design	4th year/ 1st semester	3	4
Interview 3	Reinforced Concrete Design	3rd year/ 2nd semester	4	5
Interview 4	Engineering Management	4th year/ 2nd semester	17	15
Interview 5	Engineering Informatics	2nd year/ 2nd semester and 3rd year/ 1st semester	14	22

The list of the courses is presented at table 6.19 in addition to the academic year that students should take them, as well as the years of experience of the responsible lecturer for that course.

6.4.2 The lecturers' knowledge about BIM

The lecturers were first asked to state their personal knowledge about BIM. As presented in the interview transcripts (Appendix E), four of the lecturers were completely aware about the BIM concept, its advantages and drawbacks while two reported to have a basic understanding. Only two lecturers worked with BIM tools in person; however, all of them have seen projects where BIM is applied. One of them had the experience of working on some projects where he/she had used BIM visualization software (BIMSight) to check the models generated by the BIM specialists. In general the lecturers knew what actually can be gained through utilizing BIM.

6.4.3 The extent to which the specific areas are discussed in courses

The relevance of the course contents to identified areas of concern is presented in table 6.20. Table 6.21 shows the topic from typical BIM courses (table 4.4) which is related to each area of concern. The Engineering Informatics course is not mentioned in the table 6.20, as it does not address the engineering or management concepts which are the main focus of this study. It provides the basis to understand the BIM tools and its application. Students are exposed to the definition of the object classes, programing and parametric objects through the Engineering Informatics course, which is the basis of BIM tools.

Table 6-20: Areas of concern which are discussed in each course

No.	Areas of concern	Advanced Structural Design	Structural Steel Design	Reinforced Concrete Design	Engineering Management
1	Visualization skill and making use of 3D models	✓	✓	✓	✓
2	Practical working with 3D CAD tools	✓	✓	✓	×
3	Capturing, storing or analysing geographical information of building components	✓	✓	×	×
4	Defining geometry and spatial relationships	✓	✓	✓	×
5	Allocating time to the construction components and the project tasks	×	×	×	✓
6	Detecting clashes between the components	×	×	×	✓
7	Providing as-built information for the facility	×	×	×	×
8	Defining cost for the project elements, Cost estimation ability, Providing a BOQ	✓	×	×	✓
9	Integrating the information and models	×	×	×	×
10	Collaboration and multidisciplinary approach in construction process	✓	✓	✓	✓
11	Quality control knowledge	×	✓	✓	×
12	Optimizing productivity	×	×	×	×
13	Optimizing performance	×	×	×	×

Table 6-21: Areas of concern and related topics from typical BIM courses

No.	Areas of concern	Engineering graphics and drawings	Basic concepts of BIM	Engineering management	Collaboration
1	Visualization skill and making use of 3D models	✓	✓	✓	✓
2	Practical working with 3D CAD tools	✓	✓	✓	×
3	Capturing, storing or analysing geographical information of building components	✓	✓	×	×
4	Defining geometry and spatial relationships	✓	✓	×	×
5	Allocating time to the construction components and the project tasks	×	×	✓	✓
6	Detecting clashes between the components	×	×	✓	✓
7	Providing as-built information for the facility	×	×	✓	✓
8	Defining cost for the project elements, Cost estimation ability, Providing a BOQ	×	×	✓	✓
9	Integrating the information and models	×	✓	×	×
10	Collaboration and multidisciplinary approach in construction process	×	×	✓	✓
11	Quality control knowledge	×	×	✓	✓
12	Optimizing productivity	×	×	✓	✓
13	Optimizing performance	×	×	✓	✓

Visualization

The potential application of 3D models for enhancing students' visualization ability is different for these five courses. The use of 3D models in the Structural Steel Design is limited and is not used in the Reinforced Concrete Design and Engineering Management courses (interviews 2, 3 and 4). However, the lecturers for the Advanced Structural Design apply 3D models to make videos for explaining the concepts to the students. The student projects in this course must be submitted as a 3D computer model, but they use simple software just for 3D visualization and not as a BIM tool (interview 1). As presented in the interview transcripts (Appendix E), all the lecturers were willing to use 3D models to improve students understanding of the structures and related issues.

Practical working with 3D CAD tools for preparing sectional views

Practical working with tools, for instance for preparing sectional views and cut sheets to present information such as quantity, sizes, lengths, and shapes of the reinforcing bar, is already considered in the Advanced Structural Design course, although students use 2D computer models. It is not likely to use 3D models for preparing such details in the Advanced Structural Design course, as the lecturer is of the opinion that related software is complicated. He stated that it would be possible if students start the course with the ability to use such software or if the software would be simple enough to be used straightaway (interview 1). This topic is not discussed in detail in the Structural Steel Design and Reinforced Concrete Design courses due to the time limitation (interviews 2 and 4). It is also not part of the Engineering Management course content (interview 4).

Capturing, storing or analysing geographical information of building components

The exposure of students to capture, store or analyse geographical information of building components is limited in the Advanced Structural Design course and it is not part of the other mentioned courses. The lecturers of the Advanced Structural Design course were not considering extending the topic. They believed that it is more applicable to a graduate programme and the time of the course is also an issue for adding this topic to the curriculum (interviews 1 and 6).

Defining geometry and spatial relationships

Defining geometry and spatial relationships is discussed in the Advanced Structural Design, Structure Steel Design and Reinforced Concrete courses to a limited extent. This is because of the difficulty of using BIM software which is an obstacle for the lectures (interviews 1, 6, 2 and 4).

Allocating time to the construction components and the project tasks

Allocating time to the construction aspects is not discussed specifically in two of three courses which are more focused on design aspects (interviews 1, 6, 2 and 4). However, in the Engineering Management course, some general concepts of design and constructing time of the elements are discussed and even some company representatives explain the design issues. It is expected of students to consider these aspects while doing their assignments in this course (interview 3).

Detecting clashes and as-built drawings

Only in the Engineering Management course, clash detection is considered as one of the subjects that is taught by showing photographs and through case studies (interview 3). It also is addressed to some extent in the Structural Steel Design course, although it is not specifically stated (interview 2). This also applies to student understanding of as-built drawings; only those with relevant vacation training had some knowledge about it (interview 2).

Cost estimation ability and providing a BOQ

Cost estimation and defining the more economical option are discussed in the Structural Steel Design course (interview 2). The completion of BOQs is part of the Advanced Structural Design and Engineering Management courses, but it is not by using a model or other software. The measurements are done manually from drawings (interviews 1, 6 and 3).

Quality control

Quality control is generally discussed in the Structural Steel Design and Reinforced Concrete Design courses. Students learn about the quality control aspects and the items that should be checked or provided. However, the quality control process would not be taught in these two courses (interviews 2 and 4). The quality control is not actively done in Advanced Structural Design and Engineering Management (interview 1, 6 and 3).

Integrating information into the model

Currently, students are not using any software capable of storing information and properties of elements in any of these courses. Thus, integrating information into the model is not addressed (interviews 1 to 6).

Collaboration and multidisciplinary approach in construction process

Students are learning about collaboration and working with other disciplines through their project in the Advanced Structural Design where they need to consider the requirements of other engineering disciplines including architecture (interview 1). It is also discussed in the Engineering Management course (interview 3). However, students are not formally taught about this in Structural Steel Design and Reinforced Concrete Design and in some cases, they do it without understanding the purpose (interviews 2 and 4).

Optimizing productivity and performance

Optimization of productivity and performance and ways for addressing it, does not form part of these courses (interviews 1 to 6). These are topics which can form part of the Engineering Management curriculum, where the lecturer confirmed that these subjects can be introduced into the course curriculum (interview 3).

6.4.4 Lecturer attitude towards integrating BIM into courses

Generally, lecturers were willing to discuss relevant subjects, from the list in table 6.18, using BIM models and tools. They believed that it is a useful way of teaching students about construction processes. However, the lecturers preferred students coming into their courses with the basic knowledge of using the software. Otherwise, the difficulty of teaching BIM software in the limited available time will cause them to continue with their traditional curriculum (interviews 1 to 6). As a solution, five of the lecturers suggested teaching BIM from the beginning by introducing BIM tools to the students in the drawings subject in the first year (interview 1 to 5). It can be extended to the other courses, by asking students to submit their assignments output through a BIM model. Even if it is not a mature use of BIM tools in each single course, students will gradually learn how to use these tools.

The main obstacle which was pointed out by the lecturers was a software issue, as they need students to have access to the simple licensed software with training (interviews 1, 3 and 4). It can be introduced through a short course on BIM tools and software. For addressing this issue, while understanding the necessity of exposing students to the BIM application, the lectures of the Advanced Structural Design course were planning to use models from the early sessions of the course to help the students to understand these aspects (interviews 1 and 6). The lecturer in Engineering Informatics also was of the opinion that students should apply what they learn through his course and it would result in a better understanding of both the engineering and the informatics concepts (interview 3).

A problem which was mentioned by three of the interviewees was about the capability of the course facilitator (interviews 2, 3 and 5). The lecturers need time to use these tools and to understand their application in their course. It is time consuming for the lecturers to work on these tools and get ready to teach through such tools. They also need to have a unique approach to avoid individual interpretations which might result in students' misunderstanding (interview 5).

It was also pointed out by two of the lecturers that integrating BIM into the curricula needs to be planned thoroughly and correctly and the relevant lecturers should have the enthusiasm to use it (interviews 5 and 6). It is important to define the extent to which BIM will be introduced. As BIM is a wide topic and can cover a variety of aspects, the scope for each particular course needs to be specified (interview 5).

Chapter 7 – Discussion of results

7.1 Chapter introduction

This chapter synthesizes the information from the surveys and interviews presented in chapter 6. A proposal for teaching BIM is also discussed. Also, further studies are suggested for research on this topic. An outline of the topics provided in this chapter is illustrated in figure 7.1.

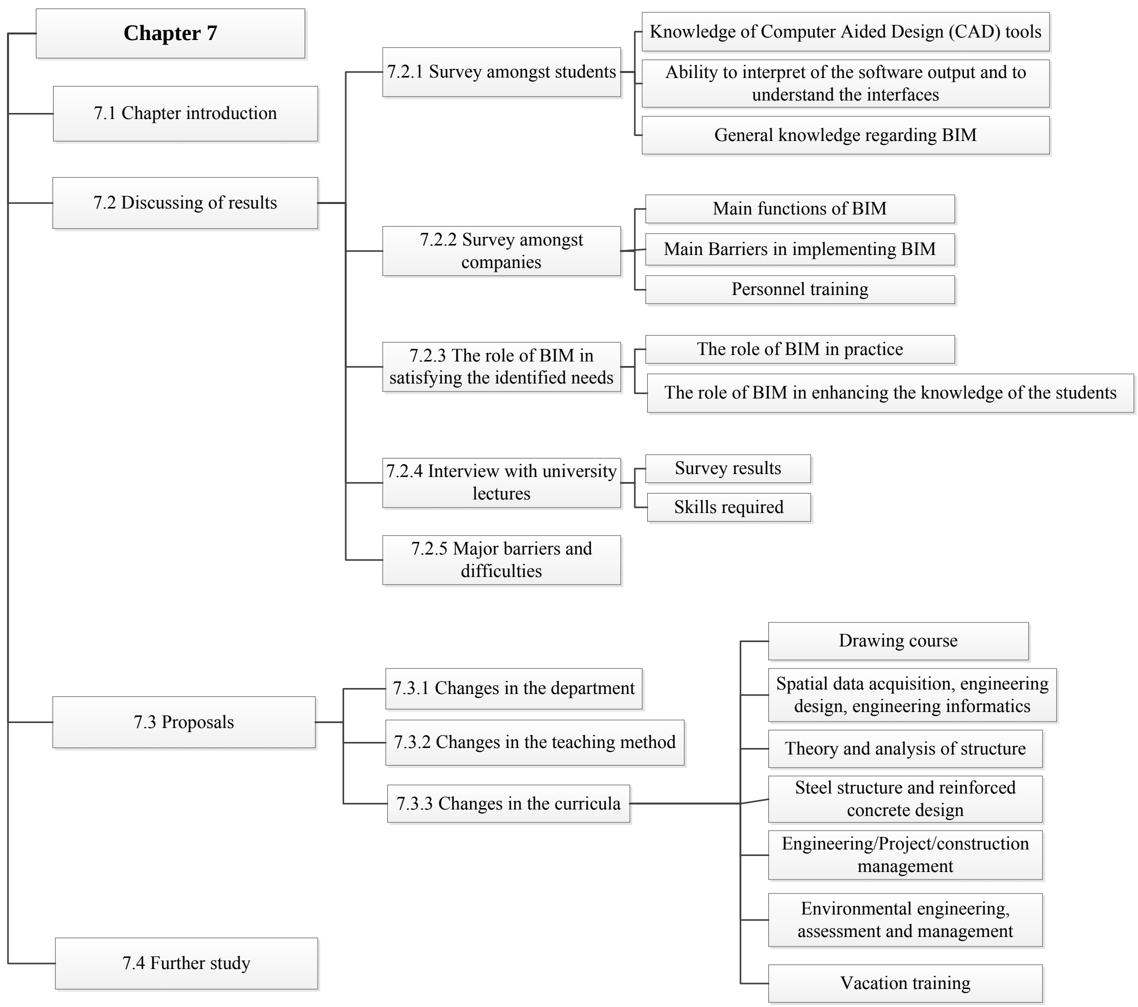

Figure 7.1: Chapter 7 diagram

7.2 Discussion of results

7.2.1 Survey amongst students

As the investigation amongst six South African universities showed, there are some aspects which need more focus when preparing students to make use of BIM tools. The result of the survey showed that civil engineering students have more knowledge of BIM tools compared to the quantity surveying and the construction management students.

There were three main areas which were evaluated to understand the level of awareness and application of BIM amongst students:

- Their knowledge of Computer Aided Design (CAD) tools in general and BIM in particular
- Their ability to interpret the software output and to understand the interfaces
- Their general knowledge regarding BIM

Knowledge of Computer Aided Design (CAD) tools

Survey results

There is a lack of working with 3D CAD tools amongst students. The students' awareness of capturing, storing or analysing geographical information of building components was also at a low level. Understanding the geometry and spatial relationships was another area in which the students had a lack of knowledge.

There was a lack of awareness about defining profiles to create sectional views. Their exposure for integration of information with the model was also limited.

Skills required

The limited experience with 3D CAD tools amongst students needs to be addressed by providing them with the opportunity to work with related tools and software. In other words, students should not be confined to 2D CAD tools for specific outcomes. This may enhance their understanding of geographical information of building components as well as geometry and spatial relationships.

Considering the lack of awareness amongst students regarding integration of information with the model, it is important for them to be introduced to the construction processes while practicing it in a virtual model. It would help them to understand that the properties of the elements are not limited to the size and dimensions, but there are more features and information that might be considered, such as material, time and cost of a building component. They would then realize the necessity of integrating this information.

Ability to interpret the software output and to understand the interfaces

Survey result

The results showed that the students were not completely aware of the need for detecting clashes between building components. Students did not have enough information about as-built drawings and the necessity of providing reliable and updated as-built drawings. There was also a lack of awareness about allocating time to the construction components and defining cost for project elements.

Skills required

Students should learn about actual problems such as clashes and constructability and they need to develop a basic understanding of how to manage these problems. It is also required to expose students to the necessity and the techniques of having reliable as-built drawings.

Since students usually learn about cost estimation and providing simple BOQs, it would be useful if they can integrate this information into a model. This would allow them to have a better sense of cost aspects of the construction processes. Also, understanding the time limitation in the projects and the specific time frame of constructing building components is another skill which can be developed by practicing it in a simulated model.

General knowledge regarding BIM

Survey result

Only a few students were aware of the process of saving, updating and also integrating project information. There was also a limited number of students who knew about tools for managing and integrating the information and models as well as collaboration and a multidisciplinary approach.

Skills required

It is vital to teach students to consider limitations of other disciplines, as they were not familiar with the collaboration issues and multidisciplinary approach in construction processes. Civil engineers should be able to collaborate effectively with other engineering disciplines such as architectural, mechanical, electrical and plumbing and should be able to consider their concerns. This can be facilitated by using tools which can integrate and manage project information.

7.2.2 Survey amongst companies

It emerged from the surveys that companies are looking for people who are knowledgeable enough in some specific aspects. These aspects may vary for the companies where BIM is applied compared to those where it is not.

Main functions of BIM

Companies where BIM was applied

The result showed that visualization and constructability were the most important aspects for the companies that were already applying BIM. The collaborative nature of BIM tools as well as cost estimation and site planning were the other areas where BIM application was useful. They would therefore consider appointing engineers who are able to make use of BIM tools in these aspects.

Companies where BIM was not applied

In the companies where BIM was not applied, the most demanding skills for a graduate engineer which can also be applied through BIM tools, included quality control and performance optimization. It was also shown in the results of the survey that having knowledge about productivity optimization, collaboration skills and cost estimation are very important. Constructability, site planning and database management were also categorized as high priority skills when the company was considering appointing a new employee.

Main Barriers in implementing BIM

Companies where BIM was applied

Integrating BIM in to the current project execution system of a company is difficult. Companies, that were applying BIM, were struggling with the lack of legal agreements and collaboration standards. The compatibility issues and cost of licensed software as well as the lack of well-trained employees or their resistance to learning BIM skills were the other barriers.

Companies where BIM was not applied

For companies that were not using BIM tools, training their staff was a major and time consuming issue. It was followed by their concern about availability of the collaboration standards. Legal concerns and software compatibility issues were also considered as main problems

Personnel training

According to the survey as well as the worldwide trade, which is pointed out in the literature review, there are companies that are utilizing BIM technology and also companies that are likely to consider implementing BIM in the near future. The number of current specialists and skilled engineers in terms of BIM is limited. Therefore, the demand for engineers with BIM knowledge is growing.

The industry is trying to satisfy this need mostly by in-house training and allowing their employees to practice it through trial and error, and through self-learning.

7.2.3 The role of BIM in industry and academia

The role of BIM in industry

According to the literature, as stated in section 2.3.1, the visualization feature of BIM tools for understanding the project situation from the conceptual phase of a project through the design, construction and commissioning phases has proved to be helpful. BIM also helps with identifying the constructability issues and clash detection in the design phase. Because of the centralized information feature of BIM, it can improve collaboration amongst the project team members. This feature also enhances the accuracy of cost estimation while shortening the time of providing BOQs. As such, managing a unique database, which is updated regularly, is straightforward through applying BIM tools.

Having a simulated and integrated model, provides the opportunity for checking the quality of the work to be at an accepted level, and improves the quality control process, as discussed in section 2.2.4.

As it is stated in section 2.3.2, BIM helps to improve the quality of work by enhancing the communication and interoperability. It is also beneficial for saving time and cost during the project life cycle which would optimize the productivity and performance. As a result, utilizing BIM can satisfy the requirements which were identified through the industry survey.

Applying this knowledge through BIM tools would help engineers as well as companies to optimize their performance and productivity which is a major need of the industry.

The role of BIM in enhancing the knowledge of the students

As described in section 5.3, the questions in the survey amongst students were formulated based on the output of BIM courses and defined goals of BIM software program as showed in tables 4.1 and 4.2, in addition to the course descriptions. In other words, the areas which were defined to be enhanced in section 6.2.5 are also part of BIM features. Therefore, industry needs can be satisfied through engineers who are able to work effectively with BIM tools and who can interpret the outcomes. Thus, civil engineers should be capable of preventing clashes and of recognizing them before construction starts. They also should be aware of quality control of construction processes, and should understand the time and cost of constructing the building components. As such, they need to be able to work with relevant software, interpret the outcomes and use the visualized model as a media.

7.2.4 Interview with university lectures

Survey results

As the result of the survey amongst companies showed, the need of the industry is mostly satisfied through in-house training. However, if South African universities start addressing these identified issues in their curricula, companies can appoint fresh graduates who are fairly knowledgeable about BIM as well as about construction processes. Thus, there can be an academic solution for addressing these issues.

Considering the background knowledge of the students as well as the requirements from industry, it was identified that certain topics would need to be part of the curricula for an academic degree. Generally, students' awareness in certain defined areas should be improved and a suitable way of teaching them about these aspects is by making use of BIM tools. There are also some topics which are common in some BIM courses which can be used as guidelines for integrating BIM into the curricula.

From an academic point of view, however, there are other concerns that should be solved for targeting such a goal. The extent to which BIM will affect the curricula should be defined based on the needs of the industry and the flexibility of the curricula. It also should be defined whether BIM tools and techniques should be taught as a specific subject or offered as an integrated subject to current courses. It is also important to have lecturers with enough knowledge for these concepts who are willing to facilitate this course. If the preference is to add a BIM application to the current curriculum, then an evaluation would be required to gauge the lecturers' limitation as well as their enthusiasm. The other aspects that a university should consider, is about providing access to the appropriate licensed software to allow students an opportunity to apply these tools. The cost and market related issues then should be considered as well, which are excluded from the scope of this study.

Skills required

Some of the identified areas of concern, that are considered curricula addition, are already taught in civil engineering courses. The problem is that the students are not learning to make use of related tools. Considering the worldwide rapid growth of BIM, students need to be taught about BIM and its applications in construction processes. Practicing the concepts through a proper tool, would lead to a better understanding of the real design and construction facts and students can learn to work with related tools and software which is essential for their future careers.

7.2.5 Major barriers to adopting BIM in academia curricula

The discussion in sections 7.2.1 to 7.2.4 shows the benefits of using BIM and adding its concepts into the curricula. However, the negative aspect should also be considered which include the barriers and disadvantages.

Adding a new subject to the current fully intensive curricula is also difficult, as discussed in section 4.3. It is even more complicated for BIM in particular, as it is a wide topic. There are also some obstacles in making use of software, as learning BIM tools can be time consuming and students need to make considerable efforts to master the tools. Another issue is related to the lectures, as offering such a course needs qualified facilitators that can link BIM content to the traditional style. The problem of individual interpretations of BIM concept amongst the lecturers should also be considered and addressed properly.

7.3 Proposals

As shown in the preceding discussion, the rapid growth of BIM application in industry has led to the introduction of BIM concepts through degree programmes in pioneering countries. As the two surveys amongst the students and the companies showed, teaching BIM tools can enhance the students' awareness and also satisfy the industry needs. University lecturers are also enthusiastic about inclusion of BIM in the curricula, although there are some predecessor requirements to make it practical.

Referring to section 4.2.4, there are several methods for introducing BIM to students. These methods can vary based on the department which offers the course or programme, educational level of the course or programme, whether it would be a stand-alone course or BIM integrated into other course, whether it would be a compulsory or an elective course, the collaboration type for the offered course as well as its content. The main aspects that should be defined for such an aim is presented in table 7.1 in addition to the proposed strategy.

Table 7-1: General training strategy options and proposed strategy

Aspects of BIM training strategies	Proposed strategy
Department which offers the course module	Civil engineering
Educational Level	Undergraduate
Stand-alone BIM course versus BIM integrated into other courses	Partial BIM Course, integrated into some relevant courses
Course content and teaching methodology	Adding some BIM content to the current curriculum
Compulsory or elective course	Based on the main course within which BIM is integrated
Collaboration type	Single discipline course

In this study, teaching BIM to enhance learning about construction processes for undergraduate civil engineering is investigated. Such a programme should aim to fulfil the students' lack of knowledge and meet the need of industry. The scope of the BIM module can be wide due to the diversity of the identified area of concern, as revealed in this study. In other words, it needs to cover practical working with 3D CAD tools including understanding of geographical information of building components, geometry and spatial relationships. However, it is also required to include some technical issues such as time and cost allocation, clash detection, as-built producing. Moreover it should contain the knowledge about integrating the information and models and collaboration and multidisciplinary approach in construction process. Comparing the typical topics in some BIM courses (table 4.4) to the current topics in relevant modules in civil engineering curricula (table 6.17), it can be seen that several topics can be covered in different current modules (see table 7.2). This implies that a stand-alone BIM module can hardly satisfy these subjects together. It is therefore recommended that BIM and components thereof be introduced into other suitable course modules.

Table 7-2: Courses in current curricula which are relevant to some topics of BIM courses

Category	Main Topic	Relevant course in current curricula
Engineering graphics and drawings	• Visualization skill • Practical working with 3D CAD tools • Providing isometric and sectional views • Understanding the background of physical component of the model • Understanding geometry and spatial relationships	Engineering Drawing Engineering Informatics Design (Structural Steel and Reinforced Concrete)
Basic concepts of BIM	• Understanding parametric model and object modelling • Understanding graphical user interface technology • Understanding relational database technology and database processing techniques • Understanding the analytical mode • Basic building and structural objects and quantity take-off	Engineering Drawing Engineering Informatics
Engineering management	• Understanding the properties linked to the building components and information management • Coordinating design and construction • Quality control of the model and updating it throughout project life cycle	Design (Structural Steel and Reinforced Concrete) Advanced Structural Design Engineering Management / Project Management
Collaboration	• Understanding other disciplines requirements while Mechanical, Electrical and plumbing information are added to the model • Managing to avoid the clashes and overlaps • Understanding project delivery system and techniques for integrated practice	Advanced Structural Design Engineering Management / Project Management

The BIM topic should be made compulsory or elective, based on the main courses within which BIM is integrated. Adding the BIM introduction via a course will affect the course content and curriculum which in turn, influences the departmental educational culture and condition. Teaching BIM, even if it is limited to the civil engineering department, and not the whole engineering faculty, needs some fundamental change to be applied in the department, contents of the courses and the lecturers' teaching methods. It is therefore recommended to pilot BIM introduction through a single department before it is extended to a multidisciplinary course afterwards.

7.3.1 Changes in the department

For the purpose of adding BIM concept to the courses, students need to have the basic information and skill for making use of the related tools and software. This is not possible unless there are relevant facilities available for students to use during their degree programme. The departmental computer laboratory should be equipped with the appropriate licensed software to enable students to apply BIM tools. Software simplicity is important due to the lack of time for learning how to make use of it. Besides, it is not possible to cover software teaching in the technical courses. Therefore, it is important to choose software which is simple to use. As it is mentioned in the scope of the study, evaluating the availability of software and the suppliers' options for universities are not discussed in this study.

7.3.2 Changes in teaching methods

Qualified course facilitators in the department are needed for successfully integrating BIM into the degree programme. The lecturers should be notified about this new technology and tools and be informed of the way of using it. This will prepare them to integrate BIM through their courses and in turn require students to submit assignments and projects using BIM tools. There is the need to organize specific seminars or presentations to raise lecturers' awareness and skills on the application of BIM tools during their courses. Although they may already have some knowledge about BIM through different sources and experiences, their understanding of BIM may vary in some aspects due to the individual's interpretations. To add BIM into the curricula, it is needed to provide them with an integrated approach to carry a single message through courses. This can mitigate the risk of conflicts and misunderstanding for the students.

7.3.3 Changes in the Curricula

Different aspects of BIM can be introduced through different courses, based on the extent to which it is applicable in each course. As explained in section 6.4.1, looking at the current civil engineering curricula in the universities that are discussed in this study (as per Appendix D), there are some similar courses among these universities in civil engineering students. A list of these courses, which are more likely to be included in the civil engineering curricula, is mentioned below in detail and the specific concept of BIM which may be included in each course is recommended.

Drawing course

The current compressed and full curriculum does not allow lecturers to teach to work with the software. There are particular subjects in each course that should be discussed by the lecturer which already takes the full time assigned to that course. Considering that the third and fourth year courses are more specialized in different aspects of civil engineering, students should come into those courses with basic knowledge regarding the software that they may use. Usually, there is a drawing course in the first year of the engineering degree in South African universities in which students learn to draw and work with simple 2D software. It is suggested that the target of the drawing course be changed from 2D to making use of 3D drawings tools, where students can do some projects to understand basic use of software. Even if it is limited to the simple drawings, it would lead them to a better understanding of the software features. By applying 3D tools in the early stage, students will start making use of it in different assignments and projects of other courses in the following years. They can learn to draw using 3D software and add some properties to the drawing components. This would be the foundation of their basic knowledge on BIM. It is also important to make sure that students are able to store the information and models as it can be beneficial for reusing information in other courses.

In order to meet this need, it is suggested that qualified instructors be coordinated to teach the fundamental BIM software application to the students. This can be done through the software distributers and resellers, if they offer training to be included in their licensed software packages that university obtains. Given the restricted time of learning, it is very important to provide software training with professional facilitators.

Spatial data acquisition, engineering design, engineering informatics

Some universities offer courses on spatial data acquisition, engineering design or engineering informatics in the second year, which also can be availed to the students through applying BIM tools. This can help them to understand geometry and spatial relationship deeply and recognize the overlaps of the components. In turn, this can create a link for discussing clash detection when students learn about construction aspects in later courses. Also, the tools for modelling different structural elements and how they are employed should be defined to the students. This will give students a basic understanding of 3D modelling, spatial relationships and user interfaces technology while at the same time enhancing their visualization ability in preparing them to apply these skills in other courses.

Theory and analysis of structures

In the course where structure theory and analysis is discussed, BIM tools can be used for modelling the beams, columns, slabs and other elements. Students will also learn how to use or convert the model for structural analysis, and to explain load cases and combinations. They will notice the parametric model and how defining one element can affect the other. In this way, students can experience how the structure would be influenced by material changes. The lecturer might briefly explain the integrated database and how it controls the elements of the model. Also, students should learn how to analyse and interpret the analysis using the tools.

Structural steel and reinforced concrete design

As a design course is offered as a successor to theory of structure, students are already exposed to the basic structural knowledge. It is also worth mentioning that because of the ability to re-use information of an existing model, students can speed up their design process step by step through different courses. Practicing design in a 3D model format would help them to identify structural elements and realize the space allocation and the limitations due to the requirements of other disciplines as the interfaces are more tangible. Furthermore, students can apply quality control checks on the model to understand the concept of the quality control while making use of the software. Students should also learn how to provide Non-Conformance Reports (NCR) by using the tools and should be able to interpret it. These NCRs document the detail of non-conformances identified in a quality audit, and help optimizing the performance and productivity.

In terms of reinforcement in design, students can learn working with BIM tools for preparing sectional views and cut sheets to provide information such as quantity, sizes, lengths, and shapes of the reinforcing bar. It is also useful, in concrete design, to show students the differences between the cast-in-situ and precast concrete construction elements as they can examine different options on the software and recognize the preferences. Through these steps, students will improve their performance as future engineers and would learn about productivity and the method of enhancing it by utilizing BIM tools.

Cost estimation and calculating cost for the elements and providing BOQs can be discussed in the Design course. However, some universities offer an extra advanced design course to teach this subject to the students, due to the limited time of the design course. If students come into the course with basic knowledge regarding making use of BIM, it is useful to practice doing quantity calculation on a model. Then, students can also experience the effect of changes and modifications on the cost of the elements.

Engineering/Project/construction management

There are several courses in different universities that are targeting teaching management to the civil engineering students mostly offered to the final year students. In other words, by that time students are almost ready to start their professional career while taking these courses and it would be a suitable time to learn about managerial aspects of the project.

It is recommended that students be introduced to the collaboration and multidisciplinary nature of the construction projects through these courses. As implementing BIM in South African engineering faculty is its infancy, it is not likely to have the opportunity to offer a multidisciplinary project amongst students from different engineering disciplines. Therefore, students might be asked to do a group project in these courses where each of them is acting as one of the party involved in the project, such as the client, consultant and contractor to learn about collaboration. They should understand defining work flow and responsibilities which becomes more practical when done using BIM tools. Students experience individually how changes should apply to the model and how the outputs may be interpreted. For this reason, even a particular change, such as material replacement or different concrete casting methods would be defined to be considered in some stage of the project. The importance of reliable as-built drawings can also be pointed out while applying changes into the model. Students can also detect clashes through the model they generate and may be requested to consider safety issue in their model and control its quality. It is also suggested that students provide a time schedule for the project and reschedule it based on the changes.

Environmental engineering, assessment and management

BIM can be used to expose students to construct green buildings and applying SANS 204 standard while designing. This can be included in any environmental related course which may be offered in civil engineering curricula. They will learn about sustainable designing and the consideration of energy consumption of the buildings, while applying a reliable tool for developing it.

Vacation training

The majority of the universities consider some vacation trainings during a civil engineering degree. Looking at the result of the survey amongst companies, it is apparent that a number of companies have already implemented BIM. It would be useful if universities can arrange an agreement with these types of companies to accommodate their students for some vacation trainings. It would be a valuable opportunity for the students to practice BIM on a real world project and in a company where BIM is applied.

The proposed changes and how they can satisfy the areas of concern (mentioned in table 6.18) are presented in tables 7.3 and 7.4.

Table 7-3: The areas of concern which can be addressed by changing the course contents

Courses / **Areas of concern**	Drawing course	Spatial data acquisition/ Engineering Design/ Engineering Informatics	Theory and analysis of structure	Structural steel design/ Reinforced concrete design	Engineering/ project/ construction management	Environmental engineering	Vacation training
Visualization skill and making use of 3D models	✓	✓	✓	✓	✓	✓	✓
Practical working with 3D CAD tools	×	✓	✓	✓	✓	✓	✓
Capturing, storing or analysing geographical information of building components	✓	✓	✓	✓	✓	✓	✓
Defining geometry and spatial relationships	✓	✓	✓	✓	×	×	✓
Allocating time to construction components and the project tasks	×	×	×	×	✓	×	✓
Detecting clashes between components	×	✓	×	×	✓	×	✓
Providing as-built information for the facility	×	×	×	×	✓	×	✓
Defining cost for project elements, Cost estimation ability, Providing a BOQ	×	×	×	✓	✓	×	✓
Integrating information and models	×	×	✓	✓	✓	✓	✓
Collaboration and multidisciplinary approach in construction process	×	×	×	✓	✓	×	✓
Quality control knowledge	×	×	×	✓	✓	×	✓
Optimizing productivity	×	×	×	×	✓	✓	✓
Optimizing performance	×	×	×	✓	✓	×	✓

Table 7-4: Summary of the proposed addition to the course content

No.	Courses	Course Content
1	Drawing course	making use of 3D drawings
2	Spatial data acquisition/Engineering Design/Engineering Informatics	Applying BIM tools to understand geometry and spatial relationship/ Modelling different structural elements
3	Theory and analysis of structure	Using the model for calculating structural forces and explaining load cases and combinations, Explaining the integrated database and how it controls the elements of the model
4	Structural steel design/Reinforced concrete design	Practicing design in a 3D model format to realize the space allocation and the limitations due to the requirements of other disciplines, Practicing quality control process, Identification of structural elements
5	Engineering/ project/ construction management	Introducing collaboration and multidisciplinary nature of the construction projects, group project where each student acts as one of the party involved in the project, applying a particular change to the model to understand its effects, Providing time schedule for the project and rescheduling it based on the changes
6	Environmental engineering	Learning about green buildings and SANS 204 standard
7	Vacation training	Arranging an agreement with the companies that are applying BIM to accommodate some of the students for vacation training

7.4 Proposal for further research

Further research should be performed related to the gap between the expectation of industry and offered BIM courses which are already taught worldwide. Also, course content needs to be offered for a specific university due to its condition. Even piloting a BIM introduction course for the students should be done and the students' feedback needs to be analysed to evaluate whether it affects their understanding of subsequent courses.

Furthermore, investigating the infrastructure requirements for implementing BIM in industry, including the benchmarking for different software licenses needs to be studied.

A study on available standards and guideline for BIM and collaboration in needed to provide a customized collaboration standard for South African industry.

Besides, value management through application of BIM tools needs be explored and the method of using it for optimizing construction management should be studied.

Further investigation is needed to define the appropriate course contents if the department strategy is to teach students about the graphical user interface or working with open source BIM in particular.

Chapter 8 – Conclusions

8.1.1 BIM and its role in construction projects worldwide

The specific nature of construction projects requires a considerable amount of resources including material, machinery and man-hours which are controlled through project management tools. Also, due to the involvement of different parties, there are usually communication and collaboration issues as well as claims that should be addressed by the project management team. Moreover, safety and environmental concerns should be considered while executing a project. The innovative approach in construction process is affecting the industry through applying different methods and tools to do their projects in a shorter time while decreasing the expenses of the resources. Building Information Modelling (BIM) became one of the most desired tools for responding to this requirement by having the advantages of multidisciplinary collaborative approach added to a 3D model. Besides, BIM is enabling safety management and sustainable design, which is essential for an efficient project management. Generally, applying BIM technology has facilitated the construction processes from feasibility study and early design steps to the project delivery and facility management.

The adoption of BIM is growing fast amongst AEC industry and its effect on improving ROI and decreasing time and cost of projects is reported by several firms around the world. However, there are also problems in applying BIM due to the employees' resistant to change as well as compatibility issues, legal concerns and cost of the suitable software.

8.1.2 BIM in academia worldwide

Making use of BIM tools requires special skills from employees of the AEC industry. The demands from industry forced academic institutions to integrate BIM into their degree programmes. For this purpose, a considerable number of universities worldwide started including BIM concepts into their curricula to increase the possibility of having engineers who are educated in terms of BIM. There are a variety of methods and tools for introducing BIM to enhance learning about construction processes and universities have tried different strategies for teaching it.

8.1.3 BIM application and education in South Africa

The South African AEC industry has stepped towards implementing BIM tools. Some companies working as part of construction projects have started utilizing BIM to execute their projects, while others plan to implement BIM in the near future. Considering the industry movement in terms of BIM and the undeniable link between industry and academia, South African universities should start preparing students by extending BIM into their degree programmes. To understand how academia can help for improving BIM knowledge amongst the students, three different sources need to be studied:

the current level of awareness amongst local students, the extent to which BIM is applied in South African industries and the condition of universities for adding new subjects to their curricula.

8.1.4 Results of the surveys

To define the level of awareness in terms of BIM amongst local students and the main concepts which are needed to be introduced in the courses or programmes, an investigation was done through six local universities.

To identify the current situation of the industry as well as its expectations from graduated students, some companies were studied and surveyed.

The condition of the academia, regarding the possibility of adding a BIM subject to the programme, was evaluated through interviews with lecturers.

The combination of the results, gained via these studies, makes it apparent that there are skills for utilizing BIM that should be developed and improved amongst students to satisfy the need of the industry. For this reason, there is a need to integrate BIM concepts into the curricula. (See table 8.1)

Table 8-1: Identified areas of concern that should be enhanced amongst the students (based on two surveys)

No.	Areas of concern
1	Visualization skill and making use of 3D models
2	Practical working with 3D CAD tools
3	Capturing, storing or analysing geographical information of building components
4	Defining geometry and spatial relationships
5	Allocating time to the construction components and the project tasks
6	Detecting clashes between components
7	Providing as-built information for a facility
8	Defining cost for project elements, Cost estimation ability, Providing a BOQ
9	Integrating information and models
10	Collaboration and multidisciplinary approach in construction process
11	Quality control knowledge
12	Optimizing productivity
13	Optimizing performance

However, there are some difficulties in adding such a subject to the curricula, as the current curricula are already full and compressed and time is limited for adding new topics. As such, students should learn to work with new tools which also need time. There are also barriers in combining BIM with the traditional style of teaching due to its collaborated and integrated nature. Furthermore, lecturers should be prepared for such a change and be provided by a unique approach for introducing BIM to the students.

8.1.5 Proposal

An analysis of the results suggests that the current curricula introduce BIM aspects through several courses rather than providing a stand-alone BIM course in civil engineering undergraduate programme. It is therefore, proposed to start with a partial BIM course integrated into some relevant courses in the civil engineering department which can be extended to a multidisciplinary course afterwards. Recommendations for the subjects that can be discussed through BIM application are provided; the general topics taught in some courses can be made available to the students via a Building Information Modelling approach (See table 8.2). Subsequent changes in the department and course facilitators' methods should also be planned and addressed.

Table 8-2: Summary of the proposed addition to the course content

No.	Courses	Proposed addition to the course content
1	Drawing course	making use of 3D drawings
2	Spatial data acquisition/Engineering Design/Engineering Informatics	Applying BIM tools to understand geometry and spatial relationship/ Modelling different structural elements
3	Theory and analysis of structure	Using the model for calculating structural forces and explaining load cases and combinations, Explaining the integrated database and how it controls the elements of the model
4	Structural steel design/Reinforced concrete design	Practicing design in a 3D model format to realize the space allocation and the limitations due to the requirements of other disciplines, Practicing quality control process, Providing BOQs, Identifying
5	Engineering/ project/ construction management	Introducing collaboration and multidisciplinary nature of the construction projects, group project where each student acts as one of the parties involved in the project, applying a particular change to the model such as material replacement or different concrete casting methods, Introducing as-built drawings, Providing time schedule for the project and rescheduling it based on the changes
6	Environmental engineering	Learning about green building and SANS 204 standard
7	Vacation training	Arranging an agreement with the companies that are applying BIM to accommodate students for vacation training

Implementing BIM based courses for civil engineering students would prepare them for starting their careers in industry with a holistic approach of construction processes. Such students would be able to use BIM tools to represent their engineering knowledge via an electronic communication media. This can increase their performance in the innovative approach of construction projects, which is highly influenced by information technology development.

References

Abbasnejad, B. & Moud, H.I. 2013. BIM and Basic Challenges Associated with its Definitions, Interpretations and Expectations. *International Journal of Engineering Research and Applications,* 3

AEC3. *The right BIM solution-BIM guide for Germany.*

AIA. *American institute of architects contract documents, integrated project delivery (IPD) family.* [Online]. Available: http://www.aia.org/contractdocs/AIAS076706 [23/8/2010]

AIA. 2014. *BIM awards 2008 TAP BIM: Exploring the paradigm shift in architectural engineering education.* [Online]. Available: http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiap074026.pdf

AIA/AGC. Aug. 22,2013. Level of Development Specification for Building Information Models. Paper presented at BIMForum.

Akinci, B., Fischer, M., Kunz, J. & Levitt, R. 2002. Representing Work Spaces Generically in Construction Method Models. *Journal of Construction Engineering and Management,* 128(4).

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. & O'Reilly, K. 2011. BIM Adoption and Implementation for Architectural Practices. *Structural Survey,* 29(1).

Arayici, Y., Egbu, C. & Coates, P. 2012. Building Information Modelling (BIM) Implementation and Remote Construction Projects: Issues, Challenges, and Critiques. *Journal of Information Technology in Construction,* 17

Australian Institute of Architects & Consult Australia. 2014. *BIM education*. [Online]. Available: https://revitall.files.wordpress.com/2014/06/e-bim-education-working-group-aia-ca.pdf

Autodesk, Inc. *Improving building industry results through integrated project delivery and building information modeling.* [Online]. Available: http://images.autodesk.com/adsk/files/bim_and_ipd_whitepaper.pdf

Autodesk, Inc. *University of Minnesota, education success story.* [Online]. Available: http://images.autodesk.com/adsk/files/univ_minn_final.pdf

Azhar, S. 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering,* 11(3).

Azhar, S. & Brown, J. 2009. BIM for Sustainability Analyses. *International Journal of Construction Education and Research,* 5(4).

Azhar, S., Carlton, W.A., Olsen, D. & Ahmad, I. 2011. Building Information Modeling for Sustainable Design and LEED® Rating Analysis. *Automation in Construction,* 20(2).

Azhar, S., Khalfan, M. & Maqsood, T. 2012. Building Information Modeling (BIM): Now and Beyond. *Australasian Journal of Construction Economics and Building, The,* 12(4).

Babič, N.Č., Podbreznik, P. & Rebolj, D. 2010. Integrating Resource Production and Construction using BIM. *Automation in Construction,* 19(5).

Baldwin, A., Thorpe, A. & Carter, C. 1999. The use of Electronic Information Exchange on Construction Alliance Projects. *Automation in Construction,* 8(6).

Barison, M.B. and Santos, E.T. 2010b. Review and Analysis of Current Strategies for Planning a BIM Curriculum. Paper presented at Proc., CIB W78 2010 27th International Conference.

Barison, M.B. and Santos, E.T. 2010a. BIM Teaching Strategies: An Overview of the Current Approaches. Paper presented at Proc., ICCCBE 2010 International Conference on Computing in Civil and Building Engineering.

Barlish, K. & Sullivan, K. 2012. How to Measure the Benefits of BIM—A Case Study Approach. *Automation in Construction,* 24

Baxter, P. 2013. BIM Adoption and Developments. Paper presented at One team conference 2013.

Bazjanac, V. 2004. Virtual Building Environments (VBE)-Applying Information Modeling to Buildings. Paper presented at eWork and eBusiness in Architecture, Engineering and Construction: Proceedings of the 5th European Conference on Product and Process Modelling in the Building and Construction Industry-ECPPM 2004, 8-10 September 2004, Istanbul, Turkey.

Becerik-Gerber, B. 2014. *Ce 499: Building information management.* [Online]. Available: http://cee.usc.edu/assets/013/60319.pdf

Becerik-Gerber, B., Gerber, D.J. & Ku, K. 2011. The Pace of Technological Innovation in Architecture, Engineering, and Construction Education: Integrating Recent Trends into the Curricula. *Journal of Information Technology in Construction,* 16

Becerik-Gerber, B. & Rice, S. 2010. The Perceived Value of Building Information Modeling in the US Building Industry. *Journal of information technology in Construction,* 15(2).

Bedrick, J. 2008. Organizing the Development of a Building Information Model. *The American Institute of Architects,* 9

Berwald, S. 2008. From CAD to BIM: The Experience of Architectural Education with Building Information Modeling. Paper presented at AEI 2008@ Building Integration Solutions.

BIM Journal. 2011. Public Sector Demand for BIM. 3(25). http://www.bimjournal.com/wp-content/uploads/2011/05/BIM-JOURNAL-VOL.3-FINAL-Low-Res-2.pdf

Birkeland, J. 2009. Eco-Retrofitting with Building Integrated Living Systems. Paper presented at Proceedings of: the 3rd CIB International Conference on Smart and Sustainable Built Environment: SASBE09:

Booyens, D., Bouwman, H. & Burger, M. 2013. The Status of Building Image Modelling in the South African Construction Industry.

Brewer, G. and Gajendran, T. 2010. A Case Study of the Effects of Attitude, Behaviour, and Project Team Culture on Building Information Model use in a Temporary Project Organisation| NOVA. the University of Newcastle's Digital Repository.

Briggs, I. & Brumpton, S. 2001. Embrace e-Construction with Care! *Australian Construction Law Bulletin,* 13(4).

Bronet, F. 2007. Draft "the Future of Architectural Education AIA TAP".

Broquetas, M. 2013. BIM Standards and Guidelines. Paper presented at CAD Addict.

BSI. 2013. New Standard for BIM to Help Meet 2016 Government Savings Target. http://www.bsigroup.com/en-GB/about-bsi/media-centre/press-releases/2013/3/new-standard-for-bim-to-help-meet-2016-government-savings-target/#.VBaja_mSxggMarch 2013

Building Research Establishment. 2005. *Putting a price on sustainability.* Building Research Establishment

CADEX. 2004. *BSMbaker- achimota shopping mall.* [Online]. Available: http://www.cadexsa.com/2014/BSMBaker_ACHIMOTA%20SHOPPING%20MALL.html

Cesaretti, G., Dini, E., De Kestelier, X., Colla, V. & Pambaguian, L. 2014. Building Components for an Outpost on the Lunar Soil by Means of a Novel 3D Printing Technology. *Acta Astronautica,* 93

Charlton, S. 2014. Royal HaskoningDHV Article. *Weekly,* (February 7-13).

Cheung, F.K., Rihan, J., Tah, J., Duce, D. & Kurul, E. 2012. Early Stage Multi-Level Cost Estimation for Schematic BIM Models. *Automation in Construction,* 27

Christensen, S., McNamara, J. & O'Shea, K. 2007. Legal and Contracting Issues in Electronic Project Administration in the Construction Industry. *Structural Survey,* 25(3/4).

Chuang, T., Lee, B. and Wu, I. 2011. Applying Cloud Computing Technology to BIM Visualization and Manipulation. Paper presented at 28th International Symposium on Automation and Robotics in Construction.

CIFE - Center for Integrated Facility Engineering. 2014. *Stanford university.* [Online]. Available: http://cife.stanford.edu/mission

Constructech. 2010. BIM Helps Find Feasibility of Construction. 13:

CRCC Innovation. 2007. Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House. *Cooperative Research Center for Construction Innovation, Brisbane, Australia,*

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

Dawood, N. & Iqbal, N. 2010. Building Information Modelling (BIM): A Visual & Whole Life Cycle Approach.

Dawood, N., Scott, D., Sriprasert, E. & Mallasi, Z. 2005. The Virtual Construction Site (VIRCON) Tools: An Industrial Evaluation.

Dean, R. 2007. Building Information Modeling (BIM): Should Auburn University Teach BIM to Building Science Students. *Graduate Capstone, Department of Building Science, Auburn University,* Deborah, O. & Ryan, S. 2008. *Proceedings of the 2006 building technology educators' symposium : August 3-5, 2006, university of Maryland, school of architecture planning and preservation.* Idaho: The Building Technology Educator's Society

Denzer, A. & Hedges, K. 2008. From CAD to BIM: Educational Strategies for the Coming Paradigm Shift. *AEI,*

Department of Minerals and Energy. 2014. *Energy efficiency strategy of the republic of South Africa.* [Online]. Available: http://www.energy.gov.za/files/esources/electricity/ee_strategy_05.pdf

Dilg, B. C. 2014. *The migration from AutoCAD to BIM using REVIT at Ferris state university.* [Online]. Available: http://www.ferris.edu/energy/presentations/2010/Building-Information-Modeling-Bruce-Dilg.pdf

Dong, K. 2009. Ac 2009-1724: Collaborative Teaching to Create Integrated Building Envelopes.

Dong, K., Doerfler, J. and Montoya, M. 2009. Collaborative Teaching to Create Integrated Building Envelopes. Paper presented at Frontiers in Education Conference, 2009. FIE'09. 39th IEEE.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C. & McNiff, S. 2013. BIM Implementation Throughout the UK Construction Project Lifecycle: An Analysis. *Automation in Construction,* 36

Eastman, C., Teicholz, P., Sacks, R. & Liston, K. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.* Wiley

Feng, C., Chen, Y. & Huang, J. 2010. Using the MD CAD Model to Develop the time–cost Integrated Schedule for Construction Projects. *Automation in Construction,* 19(3).

Fox, S. & Hietanen, J. 2007. Interorganizational use of Building Information Models: Potential for Automational, Informational and Transformational Effects. *Construction Management and Economics,* 25(3).

Gao, J. & Fischer, M. 2008. Framework and Case Studies Comparing Implementations and Impacts of 3D/4D Modeling Across Projects.

GCR, N. 2004. Cost Analysis of Inadequate Interoperability in the US Capital Facilities Industry.

George Mason University. 2014. *Civil and infrastructure engineering courses.* [Online]. Available: http://catalog.gmu.edu/preview_course_nopop.php?catoid=19&coid=203712

Georgia Tech. 2014. *Architecture courses.* [Online]. Available: http://www.arch.gatech.edu/content/coa-8901-building-information-modeling-case-studies

Goedert, J.D. & Meadati, P. 2008. Integrating Construction Process Documentation into Building Information Modeling. *Journal of Construction Engineering and Management,* 134(7).

Gu, N. & London, K. 2010. Understanding and Facilitating BIM Adoption in the AEC Industry. *Automation in Construction,* 19(8).

Guidera, S. 2007. Ac 2007-1775: Digital Design, BIM, and Digital Fabrication: Utilization and Integration in Architectural Engineering Curriculums.

Ham, N., Min, K., Kim, J., Lee, Y. and Kim, J. 2008. A Study on Application of BIM(Building Information Modeling) to Pre-Design in Construction Project. Paper presented at Convergence and Hybrid Information Technology, 2008. ICCIT'08. Third International Conference on.

Hardin, B. 2009. BIM and Construction Management: Proven Tools. *Methods, and Workflows,*

Hartmann, T. & Fischer, M. 2008. Applications of BIM and Hurdles for Widespread Adoption of BIM. *2007 AISC-ACCL eConstruction Roundtable Event Rep,*

Hartmann, T., Gao, J. & Fischer, M. 2008. Areas of Application for 3D and 4D Models on Construction Projects. *Journal of Construction Engineering and Management,* 134(10).

Hedges, K. 2008. Real-Time Simultaneous Collaboration in the BIM Repository. Paper presented at The Oxford Conference: A Re-evaluation of Education in Architecture.

Hedges, K.E., Denzer, A.S., Livingston, C. & Hoistad, M. 2008. Socially Responsible Collaborative Models for Green Building Design. *Proc., AIA Research for Practice Program Grant,*

Hergunsel, M.F. 2011. *Benefits of building information modeling for construction managers and BIM based scheduling. Unpublished thesis.* Worcester Polytechnic Institute.

Hermund, A. 2009. Building Information Modeling in the Architectural Design Phases: And Why Compulsory BIM can Provoke Distress among Architects. *eCAADe 2009,*

Hietanen, J. and Drogemuller, R. 2008. Approaches to University Level BIM Education. Paper presented at IABSE Symposium Report.

Hooper, M. and Ekholm, A. 2010. A Pilot Study: Towards BIM Integration-an Analysis of Design Information Exchange & Coordination. Paper presented at CIB W78 2010.

Hu, W. 2007. Implementing a Simultaneous Construction Model to Educate Undergraduates in Collaboration. Paper presented at Proc., Annual Conference of the ASEE.

Hu, Z., Zhang, J. & Deng, Z. 2008. Construction Process Simulation and Safety Analysis Based on Building Information Model and 4D Technology. *Tsinghua Science & Technology,* 13

ICE-SA. 2014. *Past, present and future directions in BIM by prof. Chimay J. anumba.* [Online]. Available: http://www.ice-sa.org.za/physical-event/past-present-and-future-directions-building-information-modelling-bim-stellenbosch

Indiana University. 2009. *IU BIM guideline and standards for architects, engineers and contractors.* [Online]. Available: http://www.indiana.edu/~uao/docs/standards/IU%20BIM%20Guidelines%20and%20Standards.pdf [5/7/2012]

International Organization for Standardization (ISO). 2014. *ISO 16739:2013 - industry foundation classes (IFC) for data sharing in the construction and facility management industries* [Online]. Available: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=51622 [2/23/2014]

J.C. Cannistraro. 2009. Shop Talk-how much does BIM Save? *Quaterly,* (9). http://www.cannistraro.com/Newsletter%20Q3%2009(final).pdf

Johnson, B.T. and Gunderson, D.E. 2010. Educating Students Concerning Recent Trends in AEC: A Survey of ASC Member Programs. Paper presented at Associated Schools of Construction Annual International Conference, and CIB Workgroup 89. Wentworth institute of Technology. April 07-10, 2010.

Juhola, V. 2011. Finland, Norway, Singapore, USA Lead Progress in Construction. Paper presented at BIMsight.

Jung, Y. & Joo, M. 2011. Building Information Modelling (BIM) Framework for Practical Implementation. *Automation in Construction,* 20(2).

Jung, Y. & Gibson, G. 1999. Planning for Computer Integrated Construction. *Journal of Computing in Civil Engineering,* 13(4).

Kaner, I., Sacks, R., Kassian, W. & Quitt, T. 2008. Case Studies of BIM Adoption for Precast Concrete Design by Mid-Sized Structural Engineering Firms.

Kashiwagi, D., Kashiwagi, J., Kashiwagi, A. & Sullivan, K. 2012. Best Value Solution Designed in a Developing Country. *Journal for the Advancement of Performance Information & Value,* 4(2).

Khemlani, L. 2005. CORENET e-PlanCheck: Singapore's Automated Code Checking System. *AECbytes,*

Kim, K.P. & Park, K.S. 2013. BIM Feasibility Study for Housing Refurbishment Projects in the UK. *Organization, Technology & Management in Construction: An International Journal,* 5(Special).

Kiviniemi, A. 2008. *Review of the development and implementation of IFC compatible BIM.* Erabuild

Koo, B. & Fischer, M. 2000. Feasibility Study of 4D CAD in Commercial Construction. *Journal of Construction Engineering and Management,* 126(4).

Koppinen, T. and HENTTINEN, T. 2012. BuildingSMART Nordic Ja Eesti Avatud BIM Ümarlaud.

Kotze, C. Jun. 14, 2013. Engineering News- BIM Technology Uptake Increasing in SA. http://www.engineeringnews.co.za/article/bim-technology-uptake-increasing-in-sa-2013-06-14

Ku, K. & Taiebat, M. 2011. BIM Experiences and Expectations: The Constructors' Perspective. *International Journal of Construction Education and Research,* 7(3).

Kymmell, W. 2008. *Building information modeling: Planning and managing construction projects with 4D CAD and simulations (McGraw-hill construction series) (set 2).* McGraw-Hill Professional

Laiserin, J. 2002. Comparing Pommes and Naranjas.

Lang, J.D., Cruse, S., McVey, F.D. & McMasters, J. 1999. Industry Expectations of New Engineers: A Survey to Assist Curriculum Designers. *Journal of Engineering Education,* 88(1).

Lê, M., Mohus, F., Kvarsvik, O. and Lie, M. 2006. The HITOS Project-A Full Scale IFC Test. Paper presented at Proceedings of the 2006 ECPPM Conference.

Lew, J. and Lentz, T. 2010. Designing for safety–applications for the Construction Industry. Paper presented at W099-Special Track 18th CIB World Building Congress May 2010 Salford, United Kingdom.

Liu, Z. 2010. Feasibility Analysis of BIM Based Information System for Facility Management at WPI.

Luleå University of Technology. 2014. *Civil and environmental engineering courses.* [Online]. Available: http://www.ltu.se/edu/course/P70/P7006B/P7006B-Datorstodd-byggproduktion-1.69034?kursView=kursplan&ugglanCat=student&l=en

Luth, G.P., Schorer, A. & Turkan, Y. 2013. Lessons from using BIM to Increase Design-Construction Integration. *Practice Periodical on Structural Design and Construction,* 19(1).

Mahalingam, A., Kashyap, R. & Mahajan, C. 2010. An Evaluation of the Applicability of 4D CAD on Construction Projects. *Automation in Construction,* 19(2).

Mayo, G., Giel, B. &Issa, R. 2012. BIM use and requirements among building owners, *Computing in civil engineering (2012).* ASCE Publications.Pages 349-356 in

McGraw-Hill Construction. 2014b. Smart Market Report: The Business Value of BIM in Australia and New Zealand.

McGraw-Hill Construction. 2014a. Smart Market Report: The Business Value of BIM for Construction in Major Global Markets.

McGraw-Hill Construction. 2012. Smart Market Report: The Business Value of BIM in North America.

McGraw-Hill Construction. 2010. Smart Market Report: The Business Value of BIM in Europe.

McGraw-Hill Construction. 2009. Smart Market Report: The Business Value of BIM- Getting Building Information Modeling to the Bottom Line.

Milwaukee School of Engineering. 2014. *Courses.* [Online]. Available: http://catalog.msoe.edu/preview_program.php?catoid=8&poid=401

Milwaukee School of Engineering. 2014. *Courses syllabus.* [Online]. Available: http://catalog.msoe.edu/preview_program.php?catoid=6&poid=223

MIT. 2014. *Architecture courses.* [Online]. Available: http://ocw.mit.edu/courses/architecture/4-501-architectural-construction-and-computation-fall-2005/

Montana State University. 2014. *Civil engineering course.* [Online]. Available: http://www.montana.edu/catalog/courses/ddsn.html

Moon, H.S., Kim, H.S., Kang, L.S. & Kim, C.H. 2012. BIM Functions for Optimized Construction Management in Civil Engineering. *Gerontechnology,* 11(2).

Mutai, A. and Guidera, S. 2010. Building Information Modeling in Construction: Current Practices and their Implications for Construction Engineering Education. Paper presented at American Society for Engineering Education.

NATSPEC, (Rooney , K.) 2014. BIM Education - Global - Summary Report. (1).

Navon, R. & Berkovich, O. 2005. Development and on-Site Evaluation of an Automated Materials Management and Control Model. *Journal of Construction Engineering and Management,* 131(12).

NBS (UK National Building Specification). 2014. NBS National BIM Report 2014.

Nejat, A., Darwish, M.M. & Ghebrab, T. 2012. AC 2012-5582: BIM Teaching Strategy for Construction Engineering Students.

NIBS (National Institute of Building Sciences). 2008c. Journal of Building Information Modeling. 2014http://www.wbdg.org/pdfs/jbim_spring08.pdf

NIBS (National Institute of Building Sciences). 2008cb.2014. *NBIMS-US™ V3 ballot submission period now open.* [Online]. Available: http://www.nibs.org/news/127862/NBIMS-US-V3-Ballot-Submission-Period-Now-Open.htm [Jun. 5, 2013]

NIBS (National Institute of Building Sciences). 2008a.2014. *United states national building information modeling standard, Version 1- Part1: Overview, principles, and methodologies.* [Online]. Available: http://nbimsdoc.opengeospatial.org [Oct. 30, 2009]

NIBS (National Institute of Building Sciences).2007. *BuildingSMART alliance, national building information modeling standard version 1 - part 1: Overview, principles, and methodologies .* [Online]. Available: http://www.wbdg.org/pdfs/NBIMSv1_p1.pdf

Nielsen, D., Fleming, M. & Kumarasuriyar, A.C. 2009. An Innovative Learning Model for Teaching Architectural Technology using Building Information Modelling: A Queensland University of Technology Perspective.

Niemandt, M. KRU detailing company. Appendix E of this thesis

NYC Polytechnic School of Engineering. 2014. *Civil engineering courses.* [Online]. Available: http://bulletin.engineering.nyu.edu/preview_course_nopop.php?catoid=5&coid=14073

NYC Polytechnic School of Engineering. 2014. *Civil engineering courses.* [Online]. Available: http://bulletin.engineering.nyu.edu/preview_course_nopop.php?catoid=5&coid=14081

Oluwole Alfred, O. 2011. A Preliminary Review on the Legal Implications of BIM and Model Ownership.

Önür, S. 2009. IDS for Ideas in Higher Education Reform. Paper presented at CIB IDS, First International Conference on Improving Construction and use Through Integrated Design Solution.

Penn State University. 2014. *Architectural engineering courses syllabus.* [Online]. Available: http://www.engr.psu.edu/ae/courses/course_syllabi/2010_FA_597G.pdf

Penn State University. 2014. *Architectural engineering courses.* [Online]. Available: http://www.engr.psu.edu/ae/courses/course_descriptions/ae597g.asp;

Permala, A., Kiviniemi, A., Sirkiä, A., Hiljanen, H., Granqvist, J. & Lehtinen, H. 2008. Integrated Supply Chain Information Systems. *Scientific Activities in Building and Construction 2008,* Peterson, F., Hartmann, T., Fruchter, R. & Fischer, M. 2011. Teaching Construction Project Management with BIM Support: Experience and Lessons Learned. *Automation in Construction,* 20(2).

Plume, J. & Mitchell, J. 2007. Collaborative Design using a Shared IFC Building model—Learning from Experience. *Automation in Construction,* 16(1).

Poerschke, U., Holland, R.J., Messner, J.I. and Pihlak, M. 2010. BIM Collaboration Across Six Disciplines. Paper presented at Proc., Int. Conf. on Computing in Civil and Building Engineering.

Popov, V., Juocevicius, V., Migilinskas, D., Ustinovichius, L. & Mikalauskas, S. 2010. The use of a Virtual Building Design and Construction Model for Developing an Effective Project Concept in 5D Environment. *Automation in Construction,* 19(3).

Project Management Institute, . 2008. *Construction extension to the PMBOK guide, third edition.* Newtown Square, Pa: Project Management Institute

Project Management Institute., . 2013. *A guide to the project management body of knowledge : (PMBOK® guide).* Newtown Square, Pa.: Project management institute

Purdue University. 2014. *Computer graphics technology.* [Online]. Available: https://tech.purdue.edu/courses/cgt-46000

Rex, B., Park, K. & Kox, M. 2014. *Digital modeling 2: Building modelling syllabus.* [Online]. Available: http://www.arch.ttu.edu/courses/2008/fall/3341/090/3341_090%20Syllabus.pdf

Reynolds, L. 2007. South African Energy Efficiency Standards for Buildings.

Rundell, Rick. *Building information modeling rolls out in South Africa.* [Online]. Available: http://www.cadalyst.com/cad/building-design/building-information-modeling-rolls-out-south-africa-2800

Russell, A.D., Chiu, C. & Korde, T. 2009. Visual Representation of Construction Management Data. *Automation in Construction,* 18(8).

Russell, J.S. & Stouffer, W. 2005. Survey of the National Civil Engineering Curriculum. *Journal of Professional Issues in Engineering Education and Practice,* 131(2).

Sacks, R. & Barak, R. 2009. Teaching Building Information Modeling as an Integral Part of Freshman Year Civil Engineering Education. *Journal of Professional Issues in Engineering Education and Practice,* 136(1).

Sacks, R. & Pikas, E. 2013. Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis. *Journal of Construction Engineering and Management,* 139(11).

Sacks, R. 2004. Evaluation of the Economic Impact of Computer-Integration in Precast Concrete Construction. *Journal of Computing in Civil Engineering,* 18(4).

Sacks, R. & Barak, R. 2008. Impact of Three-Dimensional Parametric Modeling of Buildings on Productivity in Structural Engineering Practice. *Automation in Construction,* 17(4).

Salazar, G., Mokbel, H. and Aboulezz, M. 2006. The Building Information Model in the Civil and Environmental Engineering Education at WPI. Paper presented at ANNUAL CONFERENCE OF THE AMERICAN SOCIETY FOR ENGINEERING EDUCATION, New England.

Scheer, D. 2006. From an Educational Perspective: BIM in the Architectural Curriculum. Paper presented at Government/Industry Forum, October.

Schlueter, A. & Thesseling, F. 2009. Building Information Model Based energy/energy Performance Assessment in Early Design Stages. *Automation in Construction,* 18(2).

Sebastian, R. 2010. Breaking through Business and Legal Barriers of Open Collaborative Processes Based on Building Information Modelling (BIM). Paper presented at W113-Special Track 18th CIB World Building Congress May 2010 Salford, United Kingdom.

Shen, Z. & Issa, R.R. 2010. Quantitative Evaluation of the BIM-Assisted Construction Detailed Cost Estimates.

Shiokawa, T. 2013. Building Construction and BIM in Japan.

Smit, D., Wall, J. and Betts, M. 2005. ICT & Curriculum Design to Bridge the Gap between Industry and Academia–A Discussion Paper. Paper presented at Proceedings of the Queensland University of Technology Research Week International Conference, Queensland University of Technology.

South African National Department of Transport. 2005. National Freight Logistic Strategies.

Staub-French, S. & Khanzode, A. 2007. 3D and 4D Modeling for Design and Construction Coordination: Issues and Lessons Learned. *ITcon,* 12

Stauffer, G.K. 2006. Design-Build Vs Design-Bid-Build: A Procurement Method Selection Framework.

Strauss, Andre. 2014. *Life, BIM and nuclear science in southern Africa- discussion on BIM applications and implementation in southern Africa.* [Online]. Available: http://bimblogsa.wordpress.com/2012/08/30/bim-a-discussion-about-oranges/

Sulankivi, K., Kähkönen, K., Mäkelä, T. and Kiviniemi, M. 2010. 4D-BIM for Construction Safety Planning. Paper presented at Proceedings of W099-Special Track 18th CIB World Building Congress.

Taiebat, M. and Ku, K. 2010. Discussion of the Construction industry's Evaluation Survey. Paper presented at Proceedings of the 46th ASC Annual Conference. Boston, MA.

Tatum, C. 2010. Core Elements of Construction Engineering Knowledge for Project and Career Success. *Journal of Construction Engineering and Management,* 137(10).

Tatum, C. 2010. Core Elements of Construction Engineering Knowledge for Project and Career Success. *Journal of Construction Engineering and Management,* 137(10).

Taylor, J., Liu, J. and Hein, M. 2008. Integration of Building Information Modeling (BIM) into an ACCE Accredited Construction Management Curriculum. Paper presented at Proceedings of the 44th ASC National Conference.

Techel, F. and Nassar, K. 2007. Teaching Building Information Modeling (BIM) from a Sustainability Design Perspective. Paper presented at 3rd International ASCAAD Conference on Embodying Virtual Architecture ASCAAD.

Technion. 2014. *Civil and environmental engineering courses syllabus.* [Online]. Available: http://int.technion.ac.il/014008-graphical-engineering-information/

Technion. 2014. *Civil and environmental engineering courses syllabus.* [Online]. Available: http://architecture.technion.ac.il/files/syllabus/019627%20BIM%20Graduate%20Course%20-%202014.pdf

Technion. 2014. *Civil and environmental engineering courses.* [Online]. Available: http://www.graduate.technion.ac.il/eng/Subjects/?SUB=014008

Technion. 2014. *Civil and environmental engineering courses.* [Online]. Available: http://www.graduate.technion.ac.il/eng/Subjects/?SUB=19627

Teicholz, P. 2004. Labor Productivity Declines in the Construction Industry: Causes and Remedies. *AECbytes Viewpoint,* 4(14).

Thompson, D. & Miner, R.G. 2006. Building Information Modeling-BIM: Contractual Risks are Changing with Technology. *WWW document] URL http://www.aepronet.org/ge/no35.html*,

UK cabinet Office. *Government construction strategy*. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61152/Government-Construction-Strategy_0.pdf

Underwood, J., Isikdag, U. & Global, I. 2010. *Handbook of research on building information modeling and construction informatics: Concepts and technologies.* Information Science Reference Hershey, NY

University of New South Wales. 2014. *Built environment (architecture program) courses.* [Online]. Available: http://www.handbook.unsw.edu.au/postgraduate/courses/2013/BENV7151.html

University of Pretoria. 2014. *OKU 313 REVIT for 2014.* [Online]. Available: web.up.ac.za/pdfs/8231_OKU%20313%20REVIT%20for%202014.pdf

University of Southern California. 2014. *Civil engineering course syllabus.* [Online]. Available: http://cee.usc.edu/assets/015/69368.pdf

University of Southern California. 2014. *Civil engineering course syllabus.* [Online]. Available: http://web-app.usc.edu/soc/syllabus/20141/29680.pdf

University of Southern California. 2014. *Civil engineering course.* [Online]. Available: http://classes.usc.edu/term-20133/classes/ce/

University of Southern California. 2014. *Civil engineering course.* [Online]. Available: http://classes.usc.edu/term-20133/course/ce-570/

University of Stanford. 2014. *Civil & environmental engineering.* [Online]. Available: https://explorecourses.stanford.edu/search?view=catalog&filter-coursestatus-Active=on&page=0&catalog=&academicYear=&q=CEE+110%3A+Building+Information+Modeling&collapse=

University of Stanford. 2014. *Civil & environmental engineering.* [Online]. Available: https://explorecourses.stanford.edu/search?view=catalog&filter-coursestatus-Active=on&page=0&catalog=&q=CEE+210%3A+Building+Information+Modeling&collapse=

University of the Witwatersrand. 2014. *BSc construction studies brochure.* [Online]. Available: http://www.wits.ac.za/files/u5uq6_207826001353571119.pdf

University of Washington. 2014. *Built environments Construction management.* [Online]. Available: http://www.washington.edu/students/crscat/constmgmt.html

University of Wyoming. 2014. *Architectural engineering course.* [Online]. Available: http://www.uwyo.edu/registrar/university_catalog/are_.html

Walls, R. 2014. BSM Baker Company.

Wang, E., Shen, Z. & Barryman, C. 2011. A Building LCA Case Study using Autodesk Ecotect and BIM Model.

Wang, Y., Wang, X., Wang, J., Yung, P. & Jun, G. 2013. Engagement of Facilities Management in Design Stage through BIM: Framework and a Case Study. *Advances in Civil Engineering,* 2013

Watermeyer, D.R. 2014. Leadership Towards Implementing the Natiional Development Plan. Unpublished thesis. Stellenboach University: CMP Course.

Wisconsin Department of Administration. *BIM implementation announcement.* [Online]. Available: ftp://doaftp1380.wi.gov/master_spec/BIM%20Guidelines%20&%20Standards/BIM%20Implementation%20Announcement.pdf [2009]

Wix, J. 1997. Information Models and Modelling: Standards, Needs, Problems and Solutions. *International Journal of Construction Information Technology,* 5

Wong, A., Wong, F.K. and Nadeem, A. 2009. Comparative Roles of Major Stakeholders for the Implementation of BIM in various Countries. Paper presented at Proceedings of the International Conference on Changing Roles: New Roles, New Challenges, Noordwijk Aan Zee, The Netherlands, 5-9 October.

Woo, J., Wilsmann, J. and Kang, D. 2010. Use of as-Built Building Information Modeling. Paper presented at Construction Research Congress.

Woo, J.H. 2006. BIM (Building Information Modeling) and Pedagogical Challenges. Paper presented at Proceedings of the 43rd ASC National Annual Conference.

WSP Group. 2014. *BIM around the world / Sweden.* [Online]. Available: http://www.wspgroup.com/en/wsp-group-bim/BIM-around-the-world/Sweden/

WSP Group. *Case studies about BIM.* [Online]. Available: http://www.wspgroup.com/en/BIM/Case-studies/Case-Studies/National-Route-N3--New-Van-Reenens-Pass/

Yalcinkaya, M. & Arditi, D. 2013. Building information modeling (BIM) and the construction management body of knowledge, *Product lifecycle management for society.* Springer.Pages 619-629 in

Yan, H. and Damian, P. 2008. Benefits and Barriers of Building Information Modelling. Paper presented at 12th International Conference on Computing in Civil and Building Engineering 2008.

Young, N.W., Jones, S.A. & Bernstein, H.M. 2008. SmartMarket Report on Building Information Modeling (BIM): Transforming Design and Construction to Achieve Greater Industry Productivity.

Zarzycki, A. 2009. BIM as Design Exploration Tool in Architecture. Paper presented at Proceedings of the ASEE Northeast Section Conference.

Zhang, J., Anson, M. and Wang, Q. 2000. A New 4D Management Approach to Construction Planning and Site Space Utilization. Paper presented at Proceedings of the 8th International Conference on Computing in Civil and Building Engineering.

Zhang, X. 2009. Automating Progress Measurement of Construction Projects. *Automation in Construction,* 18(3).

Zuppa, D., Issa, R.R. & Suermann, P.C. 2009. BIM's Impact on the Success Measures of Construction Projects. *Computing in Civil Engineering,*

Appendix A- Questionnaire of the survey amongst students

Study Topic: Students' knowledge about Building Information Modelling

Dear Student

I am performing research for a Master of Engineering in the division for Construction Engineering and Management of the Department of Civil Engineering at Stellenbosch University. The topic of my research is "Teaching construction process improvement using Building Information Modelling (BIM)".

For the purpose of this topic, I need to investigate:

- The extent to which BIM can improve construction processes;
- The awareness level of under graduate students about BIM and its applications;
- The extent to which BIM is applied in the South African construction industry.

Finally the research aims to address a way to enhance the knowledge of students on project processes using BIM tools.

I would like to invite you to participate in this study and would appreciate your feedback on a questionnaire. It shouldn't take more than 10 minutes of your time to complete as it is mainly based on making appropriate choices from potential answers.

Participation in the study is voluntary and you are free to withdraw at any time. All the information would be treated in strict confident and data will be used for academic purposes only. Individuals and, or companies will not be identified in the research results.

Your participation will help to understand current knowledge amongst students regarding BIM as well as to identify the requirements for course content to enhance students' ability for applying BIM. The result of the research would be available to share with the participants upon request.

The research is led by Prof. Jan Wium who can be reached for further information at: janw@sun.ac.za or +27 21 808 4348.

I sincerely thank you for your cooperation.

Faithfully yours,

MahsaTabesh

Tel: +27 21 8839850

Cellphone:+27 83 546 5667

Email: 17640962@sun.ac.za

Stellenbosch University

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UNIVERSITY

* **Your university:**

- Nelson Mandela Metropolitan University
- Stellenbosch University
- University of Cape Town
- University of Pretoria
- University of the Witwatersrand
- University of Johannesburg

* **Your field of study:**

- Civil engineering
- Architecture
- Urban and regional planning
- Construction Management
- Quantity Surveying

Please Note:

The survey consists of 3 pages, with a total of 26 questions.
In order to submit the form successfully, **ALL** questions need to be answered.
Thank you for your cooperation!

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Using Tools

* **1- To what extent do you know setting up a 2D or 3D computer-aided design model?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **2- To what extent have you tried working with a 2D computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **3- To what extent have you tried working with a 3D computer-aided design tool?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **4- To what extent do you know about applying <u>geometry and spatial relationships</u> of building components within computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **5- To what extent do you know about applying <u>geographic information</u> of building components within computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **6- To what extent do you know about applying quantities and properties of building components within computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.

- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 7- To what extent do you know about generating detailed design plans using computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 8- To what extent do you know about providing cut sheets for steel fabrication using computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 9- To what extent do you know about generating cross sections on drawings using computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 10- To what extent do you know about defining profiles to create a section view within computer-aided design tools?**

(Profile definition is mainly based on topological references to already existing structural elements, as well as to auxiliary concepts used in the early stage of the design.)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 11- To what extent do you know about exporting data to other similar tools using computer-aided design tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

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Building Information Modelling: Tools Interpretations

*** 12- To what extent do you know about reading three orthogonal views?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 13- To what extent do you know about preparing an isometric view?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 14- To what extent do you know about developing design documents using 2D or 3D models?**
(Design documents such as: design criteria, manufacturer's product data, cost estimating, etc.)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 15- To what extent do you know about the possibility of considering design cost in a 2D or 3D model?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 16- To what extent do you know about the possibility of applying project time in a 3D model?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 17- To what extent do you know about the possibility of developing as-built information using 2D or 3D modelling tools?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.

- I have not heard about it.

*** 18- To what extent do you know about the possibility of detecting clashes between components from different disciplines by using any tool?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 19- To what extent do you know about reading the symbols of different engineering disciplines?**
(such as: levels, detail views and cross sections; for mechanical, electrical, and plumbing fixtures and lines; for welding and joining structural steel; for reinforcing bars and meshes; for stairs and ramps; and for marking openings in concrete slabs and walls.)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

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Building Information Modelling: Fundamental knowledge

* **20- To what extent do you know about the process of saving and updating the information provided through the design process?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **21- To what extent do you know about the process of integration between disciplines regarding the information provided through the design process?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **22- To what extent do you know about the process of collaboration between different parties in the project?**
(Different project parties such as Client, Engineering Consultant, Contractor, Sub-contractors, ...)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **23- To what extent do you know about any tools for managing Information provided through the design process?**
(such as: levels, detail views and cross sections; for mechanical, electrical, and plumbing fixtures and lines; for welding and joining structural steel; for reinforcing bars and meshes; for stairs and ramps; and for marking openings in concrete slabs and walls.)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

* **24- To what extent do you know about any tools for integrating Information provided through the design process?**
(such as: levels, detail views and cross sections; for mechanical, electrical, and plumbing fixtures and lines; for welding and joining structural steel; for reinforcing bars and meshes; for stairs and ramps; and for marking openings in concrete slabs and walls.)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 25- To what extent do you know about any tools for managing the communication/ collaboration between different parties?**
(Different project parties such as Client, Engineering Consultant, Contractor, Sub-contractors, ...)

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

*** 26- To what extent do you know about BIM (Building Information Modelling)?**

- I am fully aware of it.
- I am familiar with the concept.
- I have heard about it; but have not personally experienced it.
- I have not heard about it.

Thank you for taking the survey!

Appendix B- Questionnaire of the survey amongst companies

Study Topic: Application of Building Information Modelling within South African Industries

Dear Sir/ Madam,

I am performing research for a Master of Engineering in the division for Construction Engineering and Management of the Department of Civil Engineering at Stellenbosch University. The topic of my research is "Teaching construction process improvement using Building Information Modelling (BIM)".

For the purpose of this topic, I need to investigate:

- The extent to which BIM can improve construction processes;
- The extent to which BIM is applied in the South African construction industry;
- The awareness level of under graduate students about BIM and its applications.

Finally the research aims to address a way to enhance the knowledge of students on project processes using BIM tools, considering South African construction industries' requirements.

I would like to invite you to participate in this study and would appreciate your feedback on a questionnaire. It shouldn't take more than 10 minutes of your time to complete as it is mainly based on making appropriate choices from potential answers.

Participation in the study is voluntary and you are free to withdraw at any time. All the information would be treated in strict confidence and data will be used for academic purposes only. Individuals and, or companies will not be identified in the research results.

Your participation will help to understand current usage of BIM amongst South African industries as well as to identify the barriers for applying BIM in the industries.The result of the research would be available to share with the participants upon request.

The research is led by Prof. Jan Wium who can be reached for further information at: janw@sun.ac.za or +27 21 808 4348.

I sincerely thank you for your cooperation.

Faithfully yours,

MahsaTabesh

Tel: +27 21 8839850

Cellphone:+27 83 546 5667

Email: 17640962@sun.ac.za

Stellenbosch University

Company Background

Your Company's name:
(Optional)

* **Your company's primary contractual role:**
- General Contractor
- Sub-contractor
- Construction manager
- Consultant/ Engineer
- Design-Build
- Client/ Owner
- Others:

* **Your company's specializations:**
You may define more than one option.
- Building Services
- Civil
- Development
- Environmental
- Geotechnical
- Industrial
- Structural
- Transportation
- Architecture
- Rural Development
- Project Management
- Quantity Surveying
- Town Planning
- Multidisciplinary
- Information Systems
- Facilities Management
- GIS

* **Approximate annual revenue of your company:** R

* **Number of employees at your company:**
- Less than 50
- 50-100
- 100-150
- 150-200
- More than 200

* **Geographical spread of your Company:**
- The Eastern Cape
- The Free State
- Gauteng
- The Northern Cape
- North West
- The Western Cape

You may define more than one option.

- [ ] KwaZulu-Natal
- [ ] Limpopo
- [ ] Mpumalanga
- [ ] Other African Countries
- [ ] International (Beyond Africa)

* **Is your company applying Building Information Modeling (BIM) technology?**

- ( ) Yes
- ( ) No

Interviewee Background

* **Your highest academic degree:**

* **Your position in the company:**

* **How do you evaluate your personal involvement with Building Information Modeling (BIM)?**

- No or limited exposure
- Basic understanding of BIM
- Advanced knowledge about BIM
- Supervise/ lead/ manage BIM implementation

Company's BIM Experience and Expectations

*** For how many years has your company implemented BIM?**

- Less than 2 years
- 2 to 4 years
- 4 to 6 years
- more than 6 years

*** Do you have BIM specialists in your organization?**
(using software such as: Revit, Tekla, Graphisoft, Bently,etc.)

- Yes, less than 5 specialists
- Yes, 5 to 10 specialists
- Yes, 10 to 15 specialists
- Yes, 15 to 20 specialists
- Yes, more than 20 specialists
- No in-house specialists, as the BIM needs are outsourcing.
- Neither in-house specialists nor outsourcing.

*** What are the main functions of BIM that your company is applying?**
You may choose more than one option.

- Visualization
- Site planning
- Quantification/ Estimation
- Scheduling and 4D visualization
- Cost estimation
- Constructability (Clash detection)
- Collaboration and coordination
- Quality Control
- Productivity optimization
- Performance optimization
- Resource planning and leveling
- Operation and maintenance
- Facility management
- Database information management and structure analysis
- Online cloud collaboration
- Supply chain management
- Environmental analysis
- Sustainability
- Safety
- Other applications (please specify):

*** How would you evaluate BIM's advantage for your company?**

*

	Not effective 1	2	Effective 3	4	Strongly effective 5
Creativity in the project/ company's activity	○	○	○	○	○

Sustainability in the project/ company's activity	○	○	○	○	○
Quality improvement in the project/ company's activity	○	○	○	○	○
Decreasing human resource in the project/ company's activity	○	○	○	○	○
Decreasing the cost in the project/ company's activity	○	○	○	○	○
Decreasing the time in the project/ company's activity	○	○	○	○	○

* **How would you evaluate the difficulties in applying BIM technology in your company?**

*

	Not a barrier 1	2	Solvable 3	4	Impossible to get done 5
Lack of skilled personnel/ Employees' reluctance for learning a new technology	○	○	○	○	○
Other parties' reluctance (Client, engineer, architects, contractors,...)	○	○	○	○	○
Sharing the information/ Model with other parties	○	○	○	○	○
Integrating company's system with BIM	○	○	○	○	○
Lack of collaborative process and modelling standards	○	○	○	○	○
Lack of contractual / legal agreements	○	○	○	○	○
Waste of time	○	○	○	○	○
Cost of software licence and training	○	○	○	○	○
Compatibility issues between different software systems	○	○	○	○	○

* **Which of the following can be the best way for employees to learn to apply BIM?**
You may choose more than one option.

- ☐ Self-learning
- ☐ Academic learning (hiring skilled/ experienced personnel)
- ☐ Seminar/ Workshop/ Conferences, etc.
- ☐ Training sessions in the company (in-house training)

Company's Experience and Expectations

* **How would you rank the main reasons of not applying BIM technology in your company?**
(Please choose each number just once and do not categorized two options at the same priority.)

	*Priorities									
	1	2	3	4	5	6	7	8	9	10
Not enough awareness about BIM and its advantages	○	○	○	○	○	○	○	○	○	○
Lack of skilled personnel/ Employees' reluctance for learning a new technology	○	○	○	○	○	○	○	○	○	○
Other parties' reluctance (Client, engineer, architects, contractors,...)	○	○	○	○	○	○	○	○	○	○
Sharing the information/ Model with other parties	○	○	○	○	○	○	○	○	○	○
Integrating company's system with BIM	○	○	○	○	○	○	○	○	○	○
Lack of collaborative process and modelling standards	○	○	○	○	○	○	○	○	○	○
Lack of contractual / legal agreements	○	○	○	○	○	○	○	○	○	○
Waste of time	○	○	○	○	○	○	○	○	○	○
Cost of software licence and training	○	○	○	○	○	○	○	○	○	○
Compatibility issues between different software systems	○	○	○	○	○	○	○	○	○	○

* **Do you think that your company will consider applying BIM in the future?**

- ○ Not sure
- ○ Yes, near future (less than 5 years)
- ○ Yes, far future (more than 5 years)
- ○ No

* **When you are hiring a freshly graduated student in civil engineering or construction management, which of the following skills are you looking for ?**
You may choose more than one option.

- ☐ Site planning
- ☐ Quantification/ Estimation
- ☐ Scheduling and 4D visualization
- ☐ Cost estimation
- ☐ Constructability (Clash detection)
- ☐ Collaboration and coordination
- ☐ Quality Control
- ☐ Productivity optimization
- ☐ Performance optimization
- ☐ Operation and maintenance
- ☐ Facility management
- ☐ Database information management and structure analysis
- ☐ Online cloud collaboration
- ☐ Supply chain management
- ☐ Environmental analysis
- ☐ Sustainability
- ☐ Safety
- ☐ Other applications (please specify): ________

- [ ] Resource planning and leveling

* **Which of the following ways can be the best for employees to be skillful in a specific field?**
You may choose more than one option.

- [ ] Self-learning
- [ ] Academic learning (hiring skilled/ experienced personnel)
- [ ] Seminar/ Workshop/ Conferences, etc.
- [ ] Training sessions in the company (in-house training)

Thank you for your time and taking this survey.

Appendix C- Questionnaire of the interview with lecturers

Interview Topic: Integrating BIM into the civil engineering undergraduate curricula

Interviewer: Mahsa Tabesh

All the information will be treated in strict confidence and data will be used for academic purposes only. Individuals and, or companies will not be identified in the research results. The interviewee can withdraw from the process at any time and has the right to be anonymous.

Date and time:

Lecturing Subject:

1. Your personal theoretical knowledge about BIM:
   - No or limited exposure
   - Basic understanding of BIM
   - Advanced knowledge about BIM

2. Your personal practical experience with BIM:
   - No or limited exposure
   - Basic understanding of BIM
   - Advanced knowledge about BIM
   - Supervise/ lead/ manage BIM implementation

3. Does your course allow you to consider any of the following concepts in your course?
If yes, are you willing to expose students to these concepts through BIM tools?

Areas of concern for the students [1]

- Visualization skill and making use of 3D models
- Practical working with 3D CAD tools preparing sectional views and cut sheets for providing information such as quantity, sizes, lengths, and shapes of the reinforcing bar
- Capturing, storing or analysing geographical information of building components
- Defining geometry and spatial relationships such as identifying overlaps or whether one component contains or crosses the others
- Allocating time to the construction components and the project tasks
- Detecting clashes between the components
- Providing as-built information for the facility
- Defining cost for the project element s
- Integrating the information and models
- Collaboration and multidisciplinary approach in construction process
- Quality control knowledge
- Cost estimation ability
- Providing a BOQ
- Optimizing productivity
- Optimizing performance

4. Are you willing to include BIM concepts in your course? Please motivate your response.

5. Do you have any particular comment or idea about integrating BIM in the curricula?

---

* These areas are defined based on two surveys:
A survey amongst students to identify the scopes where their knowledge need to be improved and a survey through industries to evaluate their requirements and needs while hiring a freshly graduated students

Appendix D- Civil Engineering courses in five South African universities

Year of study	University of Johannesburg	University of Pretoria	Stellenbosch University
First year	Applied Mathematics Introduction to Engineering Design Mathematics Physics Chemistry Applied Mathematics Draughting Mathematics Physics Electrotechnics Concrete Technology	Graphical Communication Calculus General Chemistry Materials Science Humanities and Social Sciences 1 Linear Algebra Physics Mechanics Electricity and Electronics Humanities and Social Sciences 2 Workshop Practice	Engineering Mathematics Applied Mathematics Engineering Chemistry Engineering Drawings Professional Communication Computer Programming Electro-Techniques Strength of Materials
Second year	Mathematics Geology Fluid Mechanics Modelling Applied Mathematics Strength of Materials for Civil Engineering Heritage Assessment Environmental Management for Engineers Communications	Calculus Differential Equations Strength of Materials Professional and Technical Communication Geomaterials and Processes Statics Community-based Project Mathematics Numerical Methods Structural Analysis Pavement Materials and Design Engineering Statistics Civil Engineering Measurement Techniques	Applied Mathematics Engineering Geology Engineering Mathematics Strength of Materials Land Surveying Applied Mathematics Building Materials Engineering Informatics Strength of Materials Vacation Training
Third year	Geotechnical Engineering Structural Engineering Hydraulic Engineering Statistics for Engineering Complementary Studies Transportation Engineering Project Management Surveying	Hydraulics Structural Analysis Civil Engineering Economics Programming and Information Technology Soil Mechanics Timber Design Hydraulics Geotechnical Engineering Civil Building Materials Steel Design Reinforced Concrete Design Transportation Engineering	Engineering Informatics Engineering Statistics Hydraulics Geotechnique Theory of Structures Structural Design Transport Science Vacation Training
Fourth year	Geotechnical Engineering Project Management Structural Engineering Urban Hydraulics Urban Development Studies Civil Design Civil Project Investigation Civil Professional Practice Legal Applications in Engineering Practice	Hydraulics Research Project Steel Design Reinforced Concrete Design Infrastructure Planning Engineering Professionalism Practical Training Environmental Geotechnology Civil Engineering Construction Management Computer Applications in Civil Engineering Detailed Design	Philosophy and Ethics Hydrology Engineering Project Management Structural Design Transport Science Advanced Design Engineering Management Environmental Engineering Project (Civil Engineering)

The information is gathered from the university websites.

Year of study	University of the Witwatersrand	University of Cape Town
First year	Chemistry I Engineering Computing Engineering Skills Mathematics l Critical Thinking and Philosophical Reasoning Physics I Mechanics	Chemistry for Engineers Introduction to Engineering Mathematics 1A for Engineers Mathematics 1B for Engineers Engineering Statics Engineering Drawing Physics A for Engineers Physics B for Engineers
Second year	Earth Materials and Processes Engineering Planning and Design Introduction to Environmental Engineering Economics and Management Materials and Structures I Materials and Structures II Numerical Methods Probability theory and Mathematical Statistics for Engineers Mathematics II Surveying for Engineers Practical Training Vacation Work I	Mechanics of Materials Structural Engineering I Spatial Data Acquisition & Management Civil Engineering Camp Experimental Methods & Statistics Geotechnical Engineering I Fluid Mechanics Geology for Engineers Vector Calculus for Engineers A Linear Algebra and DEs for Engineers Materials Science in Engineering Practical Experience
Third year	Construction materials I Geotechnical Engineering I Structural Steel Design Reinforced Concrete Design Hydrology Basic Hydraulics Structural Engineering IA Structural Engineering IB Infrastructure Planning and Management System Analysis and Optimization Vacation Work II	Structural Engineering II Structural Engineering III Geotechnical Engineering II Hydraulic Engineering Engineering Hydrology Transportation Planning Water Treatment Urban Water Services Economics for Engineers
Fourth year	Construction Materials II Structural Engineering II Civil Engineering Design Geotechnical Engineering II Investigational Project Integrated Resource Management Hydraulic Engineering II	Structural Engineering IV Design Project Professional Practice Waste Water Treatment Urban Design & Management Research Project Introduction to Environmental Assessment & Management

The information is gathered from the university websites.

Appendix E- Transcripts of the interview with the lecturers

Interview no. 1 (Date and time: 14/10/2014, 9:00)

What is the subject you are lecturing? Is it Advanced Design?

Interviewee: *Yes it is GO466, we are doing the structure part of that, Dr. C and myself and then there is also the transportation section and then the hydraulic section. So we are six lecturers for the whole course. So two-two-two for the different sections*

So you are busy with structure section?

Interviewee: *Yes, Mr. R the transportation and Ms. B and prof. B do Hydraulic.*

Your personal theoretical knowledge about BIM, is it limited, basic or advanced?

Interviewee: *I work with BIM a lot. I don't know how to use the software, but I've worked with BIM models a lot. I don't know whether I class as advanced but I know how the systems work.*

I have another question about your practical experience with BIM.

Interviewee: *Practically, I've used BIMSight a lot. Within 3D models, integrating, I'll get my draftsman to send models to mechanical engineering…so there is a lot of interface, but I don't use Tekla, I don't use Revit.*

So you just use the output?

Interviewee: *Yes, use the output and I tell them what to change in the model but I don't know how to use the software myself. And I know what to request.*

After having two surveys, one amongst students of six South African universities to identify the scopes where their knowledge need to be improved and a survey through industries to evaluate their requirements and needs while hiring a freshly graduated students, I've defined some areas which should be emphasized in our courses for exposing students to BIM. I would like to know if any of these areas of applicable in your course. Are you going to consider these areas in your course? And if yes, or maybe you are already having them in your subject, are you willing to expose students to these concepts through BIM tools?

One of them is visualization skill and making use of 3D models

Interviewee: *That we did quite a bit in class through lectures. I put 3D models on the screen show them around. I am not sure if you have seen the videos I created for the students. I put them together* *and use 3D models to explain concepts, how to details during reinforcing, how to analyse design strength… all of these videos have BIMSight models in them to explain different concepts. This one (showing a model on the computer) is how to use the normal AutoCAD but this is a 3D model and this is how you draw that 3D model.*

So you are already applying it.

Interviewee: *Yes, we are using it in the course. But you could debate with it proper BIM or not, because it's a 3D model and some people say is it BIM or isn't it BIM*

And what about practical working with 3D CAD tools for preparing cut sheets for providing information such as quantity, sizes, lengths, and shapes of the reinforcing bar

Interviewee: *That we do it in AutoCAD, but not in 3D.They have to produce and hand in drawings. I can show you their projects, they actually use 3D models. There are some of them with Sketchup, some of them got rendering, 3D analysis, That's visualization (showing some of the students' projects). They have to hand in a 3D model. It's different from group to group.*

But they are not using these models for calculation for reinforcement.

Interviewee: *No, they do hand calculations. They use the software for drawings, but then it is Procon for 3D design.*

Do you think there would be a chance to add this feature to their project in the course?

Interviewee: *Probably not, simply because of complexity of using BIM. AutoCAD takes long enough to learn, never mind BIM. I'm actually maybe gonna put less emphasis on CAD next year. Simply because their design struggle so much just to get the understanding of structure there. I've rather get them the design rather than the software first. To teach them BIM, if it is something straightforward, if it is Sketchup or something… maybe that's a good way to do it. As long as it is something they can learn fairly quickly. Simple software yes, for all we'll most willing to work, to introduce it. If it's Tekla or Revit, I think it gonna take them a long time.*

And what about capturing, storing or analysing geographical information of building components?

Interviewee: *In their project they'll given a drawing with Google Earth information imported into it. So they actually did get a sort of whether you call it is a GIS, I don't know. They do the Google* *overlay to get the idea but it is not advanced. It's just basic stuffs. So they have got basic exposure to those .And then also they've got some levels which are taken from Google Earth, but it is not really…*

So, you actually prefer to work with simple stuff…

Interviewee: *Yes, we are just struggling to get their basic understanding. And it is just the time thing; we are running out of time to fit in. I mean, we are getting the stuff back and they can have this beautiful 3Dm model' but their design is bad, so it's gonna miss the point. If there is simple software, definitely like to include it. That would be great. It's useful for visualization.*

But are you pointing out to the ability of BIM while you are lecturing this course to the students?

Interviewee: *I have, when I did the lecture on BOQ, I'm fairly sure I said to them during the lecture. I know I've pointed it to the postgraduate students, but I'm not sure about undergraduates. But I'm sure I've mentioned them in the past…Also I've did a lecture for Chris Jurgens the other day on BIM.it was an hour lecture or something. I did present these things to the fourth year students on quantities and various things.*

Was it in Engineering Management?

Interviewee: *Yes. What I did in that lecture, I emphasized the good and bad. I show them how wonderful things you can do and I said listen, be careful of the following…*

About defining geometry and spatial relationships such as identifying overlaps or whether one component contains or crosses the others?

Interviewee: *That was useful for the lectures when we pulled up the model…for explaining to the class*

Students are not able to do these by themselves?

Interviewee: *Maybe they can. The software is normally a problem, using it…They did it with Sketchup I mean, you can see they actually got 3D models they've produced. The problem was producing a 3D model in Sketchup and then redoing the whole thing in AutoCAD. So you can see it is not really a BIM model because of the interface problem between the AutoCAD and Sketchup. If I have the full version of Sketchup, I think then you can export it to AutoCAD. Then that might be otherwise if we can have the full version of Sketchup here. Then we could actually look at integrating it into the curriculum, maybe that's an easy way. I don't know.*

Is allocating time to the component something that you discuss about during your course?

Interviewee: *No, you mean 4D modelling kind of thing?*

Not actually 4D modelling, just to make a sense for the students who long it would take to make a component

Interviewee: *That we did in these lectures. It's literally explaining this is how you analysing, this is how you design it, and this is how you build it, this how these fit together…So that was done but sort of in the video.*

So they don't experience it by themselves to evaluate it.

Interviewee: *Not really, I was actually thinking if we should do is for issue the model. Because one thing I found it they are not understanding it is how buildings fit together… it would be nice if we can get BIM models and you actually give them BIM models at the beginning of the project, and ask them go and look at this, go and understand them, go and look at the member sizes, go look at the different components. Getting them understanding the structure, then design it. They design it, and then they design it wrong but they don't know what actually they do. So maybe that's the way we could in cooperate that…I'm thinking about including that for next year for the course. But I might need to get hold of more models or something, because sometimes people are not willing to share their model.*

And about detecting clashes between the components

Interviewee: *We didn't specifically discuss it in relation to them.*

And what about providing as-built information for the facility?

Interviewee: *It wasn't discussed. It was in the presentation I did, but I didn't do much in terms of that.*

Is defining cost for the project elements a part of your course? And are students doing cost estimation and providing a BOQ?

Interviewee: *We did budgeting but we didn't link budgeting to BIM. They have to provide a cost for the structure but they don't know yet how to get the tonnages from a Tekla file or something like that.*

They have to do a BOQ for their project. They have to give us budget. But they haven't done the BIM model to get the budget from. So they will design a project and they will work out and measure it to know in AutoCAD or whatever software is. That measuring gives us the quantity.

Are you informing them about integrating the information and models, for instance material of a component?

Interviewee: *As it is not just a line, it's a line with properties…We didn't specifically address that. I mean, if they can look at the model, they can see it's a beam, it's a column, but it hasn't the information how stored. Maybe they understand it, maybe they don't. It's not a topic we address.*

What about collaboration and multidisciplinary approach in construction process?

Interviewee: *We gave them a multidisciplinary project, so they had to consider mechanical works, electrical works, and they did. But it wasn't a topic to say how to do coordination. They kind of had to do it. They had to it but they didn't consider doing it to learn. They just know about it as here is your machine; fit it into your building. That's about it.*

And quality control?

Interviewee: *They had to do quality control on their project, but it depends whether their project was in 3D or not. So…maybe not… There wasn't a topic they had to look at. Hopefully the people of the project did check the model or their drawings or whatever. But it isn't something that we actively are trying to do it.*

Are you discussing about optimizing productivity or performance?

Interviewee: *We never discussed that.*

Generally, are you willing to include BIM concept in your course?

Interviewee: *We really are. I think it's a question of how we do it. I think I would like to give them models in the future, so they actually can look at it, can understand it. But I don't know if we use BIM software for them to generate the drawings. If the software is simple enough and we get licenses and training, then maybe. Then we could introduce it. But then we need to know it's not gonna be too time consuming…I mean they struggle drawing lines and getting line types right. I know the draftsman in my office took him long time to get used to Revit, and the Tekla guy as well…Maybe it's personal…*

Maybe it should be started sooner, as this lecture is for forth year students.

Interviewee: *It's too late. If they come into the course knowing how to do it, I have no problem then doing the models in whatever software like that…but they generally don't. And we don't have time to teach them to work with these tools, so that's the challenge.*

Do you have any particular comment or idea about integrating BIM in the curricula?

Interviewee: *It's the time thing and the software thing. And also what is BIM, is this using Sketchup BIM, is it BIM if it's a pretty model, is it BIM because of it's got intelligence, none of those Sketcup model have got intelligence, they are just sheet and stuff. People debate what BIM is…*

Interview no. 2 (Date and time: 15/10/2014, 10:00)

May I ask about your personal theoretical knowledge about BIM?

Interviewee: *I would say… I don't know if I have that much theoretical knowledge. I think I have a general understanding of what is implied by BIM. You know the fact that it is more than just a 3D drawing type scenario that you actually capturing the total building information structure analysis, volumes, quantities, all those type of things. I think, I have a general knowledge of what BIM implies, I have not studied or really any more…*

Ok, may I categorize it as Basic understanding of BIM?

Interviewee: *Yes, I think so.*

And what about your practical experience with BIM models?

Interviewee: *Do you refer to as a lecturer or general?*

I mean in general.

Interviewee: *When I was still in practice, we worked on one or two projects where the project team was encouraged to use, again they called it BIM but I don't know if it was generally using that as a Building Information Model. So, I think it was more in terms of 3D modelling of structures to avoid clashes, that type of things. So, and I have worked with things like Revit and not necessary that time Revit ones I've worked with, but there is the stuff like StruCad, I've used it to check, what you call it fabrication drawings for structure steel work.*

After having two surveys, one amongst students of six South African universities to identify the scopes where their knowledge need to be improved and a survey through industries to evaluate their requirements and needs while hiring a freshly graduated students, I've defined some areas which should be emphasized in our courses for exposing students to BIM. I would like to know if any of these areas of applicable in your course. Are you going to consider these areas in your course? And if yes, or maybe you are already having them in your subject, are you willing to expose students to these concepts through BIM tools? One of them is visualization skill and making use of 3D models.

Interviewee: *I have used it; limited used it, maybe important to say that. But and I will be more than willing to use it more actually.*

And what about practical working with 3D CAD tools for preparing cut sheets for providing information such as quantity, sizes, lengths, and shapes of the reinforcing bar

Interviewee: *I don't…in my course currently for design of steel structures, I can say before it was basically visualization, we have had used it in a CAD environment. But maybe I should mention that now, if I think back in the past when I taught Advanced Design, for the final years, they were actually encouraged to produce 3D concepts using something like Revit. It's not a direct answer, but yes I would consider using it more.*

About defining geometry and spatial relationships?

Interviewee: *Yes, I couldn't say that we've specifically used it. But again once more I think it starts again with the previous question. It's especially in steel design, it is important that they sort of grasp the spatial relation between things. It's often something that it's not so easily grasped. So, again I think I would definitely be interested in using it more. At the moment we don't use it all that much.*

And what about capturing, storing or analysing geographical information of building components?

Interviewee: *I haven't used that now.*

May you consider that in the future?

Interviewee: *Yes, It's interesting again for specially project conception or the detail design. … I think it's important.*

While students are learning about structure design, are they also exposed to allocating time and considering time for construction process?

Interviewee: *Yes, they are, especially in the course Advanced Design. In the course for design of structure steel work, I would not say that is necessarily an issue, definitely not in a BIM framework. We have not used it like that. I have a bit of reservation whether that's possible to work it into a course that deals with design of structures. Just because there is then this overlap of project management almost wanna say actual design issues. Although, obviously it's very important that they consider the design issues, when doing the project schedule. You know, how complicated the structure becomes when executing it. So, that's a difficult one to answer with a tick box. I would say, I'm not likely to consider that aspect in my courses.*

And about clash detection, are they exposing to it?

Interviewee: *I don't think they are experienced in that. I think we try to lead them in that way that obviously they are, especially in steel structure that you have elements that are generally of smaller dimension, for example than concrete structures. But you know, they still can occupy the same space. So, it's something that is not, I mean we're not using BIM in that aspect. But it's something that would be very useful for it.*

Not only through BIM, but have they already learn about the happening of such clashes?

Interviewee: *I don't think they realize at this point and the opportunity that is…*

What about as-built drawings?

Interviewee: *I don't think… no, that's it's something that I think this is a bit lacking. I think our students have a general…I mean those that did for example vacation training will have a better understanding of the fact that you have to develop an as-built after the design changes have been incorporated. But it's not something we deal with it during my courses.*

What about the cost for different elements?

Interviewee: *Yes, I would say we deal with that, specifically for the steel structures, there is a general discussion of what options are more economical, standardization, that type of thing, repetition of elements, even to level of discussing which section is easier to manufacture and fabricate than others. So, yes, I think they have a bit of understanding.*

Maybe from that point I can ask about BOQ, are they learning about providing a BOQ?

Interviewee: *In the past, when I taught them Advanced Design, we did ask them to do a preliminary or condensed BOQs, considering only main material quantities, you know, structural concrete, formwork, mass of steel work, mass of reinforcing. I wouldn't say any more detail than that, but they do have a bit of understanding I think about it.*

But not in your current course?

Interviewee: *In the course we do for design steel structures, it's not on the menu. No…*

What about integrating the information? Do they have any knowledge to have the information for a component centralized?

Interviewee: *I don't think so, no… I think as an example, I have tried in the past to, you know, probably not formally examined but, when you for example do BOQ of painting to steel structure, you* *know that all corrosion protection in general, that the surface area of the element is linked back to the element you actually use and that is linked to the, what do you call it, corrosion protection…which is then linked to the mass of structure. So, I wouldn't go so fast to say we formally deal with that, but in the course I teach at the moment it is a sort of subject of a concern.*

I**t guided me to ask you about quality control, are they exposed to quality control through your course?**

Interviewee: *They are exposed to that again in a very general fashion when we, in the past, a couple of years ago, for example I taught a course on design of concrete structures and also the one in design steel structures. There is a large component of codified design. So, for the concrete design course for example, they exposed to the South African code for quality management or materials in concrete structures for example…*

So it is for specific aspect...

Interviewee: *Yes, it's not general; I would say it is not general consideration. But I mean there are things like tolerances and lack of fit and that type of thing, we do discuss.*

What about collaboration, or working with other disciplines?

Interviewee: *They don't have any major exposure to that. I don't think so. I try to teach them, especially from structure view point about collaboration with architects. But again I think it would be very valuable to work from a model for example where you can show them the requirement that another designer might have. For example the window has to be this big, so you consider columns in there. But we don't actually… I don't have the opportunity to formally teach them that now.*

But Are you willing to do it then?

Interviewee: *Yes, I am… definitely.*

Are there any specific topics in your course covering productivity or performance optimization?

Interviewee: *Optimizing…I wouldn't say so…no. I think in my course it's more about fundamental design. So it almost touches on a different aspect.*

It is not applicable then in your course.

Interviewee: *It is not really applicable. It's more in advanced things really, in terms of management. In Advanced Design which I taught last year, it's discussed again in general terms. So in that course,* *because of the nature of the course there is more opportunity to discuss these general interlinking of these topics. But in the basic design course, it's not so much applicable.*

So, in general as far as I've understood you are willing to include some of these topics with even using BIM tools.

Interviewee: *Definitely, I think, I mean I have considered it in the past; it's probably a matter of time as well, when you have to teach yourself how to do this things. But I think it's a good tool because students…it's sort of motivate that sort of top-down approach. You know, instead of the bottom-up approach. Where you've started a structure that visually is accessible and you can walk around insight of it and see how it fits together and then discuss the issues involved. I just note, I haven't got that far yet. I haven't got to that point but I think it's definitely something to consider.*

And do you have any specific idea or comment regarding having BIM integrated into curriculum?

Interviewee: *Yes, I think BIM is a very general term and as civil engineers we have road guys, guys doing GIS stuff and everything. So it would be difficult to put something together that satisfy all the disciplines. But I think it would be worth a lot when maybe considering the CAD in practice of teaching students drawings in the first year and the drawings have nothing to do with civil engineering or structure engineering for that matter. So the BIM course like this would be valuable to expose them both to modelling and then software capabilities of modern software, have the capabilities of them producing 3D layout. So you sort of combine modelling in a 3D sense with the production of structure drawings for example, or layout drawings for roads, or whatever the case may be. So I really think a course like should… I mean you have to structure it so that it is a component of drawings and annotating drawings. But it is also a component of all these other things that you can also possibly get out of it. I think that's the general comment I can make.*

Interview no. 3 (Date and time: 16/10/2014, 11:00)

May I ask about your personal theoretical knowledge about BIM? How you can rank it?

Interviewee: *I know about it, I never physically used it. So, I never pressed buttons. I know what it can do, I know what the advantages are, disadvantages…I think so…and I know what the purpose is. And I've seen some models and I've heard how people use it, but I haven't done that physical work with it. I have not work on a project with it.*

It was my second question, if you had any practical knowledge regarding BIM.

Interviewee: *Yes…I've seen some projects where they have given views, but it was more just a visualization general thing. I haven't used it or seen how they use it to clash detection or programming or any similar thing.*

After having two surveys, one amongst students of six South African universities to identify the scopes where their knowledge need to be improved and a survey through industries to evaluate their requirements and needs while hiring a freshly graduated students, I've defined some areas which should be emphasized in our courses for exposing students to BIM. I would like to know if any of these areas of applicable in your course. Are you going to consider these areas in your course? And if yes, or maybe you are already having them in your subject, are you willing to expose students to these concepts through BIM tools?

Interviewee: *So, I'm responsible for the course in engineering management, there are things there that we do about collaboration and design management and contracts, safety, constructability…so definitely see that we can use it there.*

So may I ask specifically if for example you use any visualization while teaching them in engineering management course?

Interviewee: *Well, at the moment I show them photographs and examples I think. So, what we can do with this, is to be more specific for them to understand what we talk when we say about design management, clash detection, or…you know…constructability and things…it would be useful to show that. Specifically at the moment we show photographs and they don't understand, not necessarily.*

As far as I've understood, through your course it is not really applicable to have something like providing cut sheets or detailing on design part.

Interviewee: *No, it depends on what they do on other courses. You know, so if they do that on other courses, that's fine; if they don't do it there, then we can just show an example of how it works and so on.*

I think they are exposed to it in design of structure or later in Advanced Design.

Interviewee: *ok.*

What about capturing and storing geographical information? I assume that it is not also applicable for the course you are lecturing as it is more related to the design aspect while engineering management is more into the management aspects.

Interviewee: *No, it's not that much related.*

Do students expose to allocating time to the construction components?

Interviewee: *Yes, we expose them to construction companies where people from industry come and talk to them about the company and… for example they talk about site safety and they talk about site layout and that type of things. So, there are couple of lectures that address this and we give them some assignments on that type of things.*

So they would experience it in practice.

Interviewee: *Yes, they could do that.*

As you mentioned, you are already considering defining clash detection…

Interviewee: *Yes*

What about cost estimation, providing a BOQ,…?

Interviewee: *yes, we do a section where they need to do BOQs for a little example project that BIM can ideally be used for that.*

What about integration of information to a model? I mean, do they understand that this is not an object with size and it has got some properties?

Interviewee: *Well, at the moment they don't. But that (BIM) would probably expose them to that.*

And do you generally talk about optimization of productivity and performance in your course?

Interviewee: *Do we have optimization? Not really. But we can probably include something in there. But by using BIM, we will obviously speed up the design and coordination process which will end up with a better optimized project. But we don't specifically address that, not for now.*

So, in general, you are willing to include BIM in your course?

Interviewee: *Yes…Yes, but I don't want to teach them to press the buttons. Nobody else does that. There maybe are the short sections that we can include teach them the basics for stuff to learn with us. But I think that can be one lecture where you get the software, use it and then tell them press this button and that button and…to draw something and how to put that information…maybe two classes. Bu…t I see that one can use it.*

So you prefer students come into your course when they know how to use the related software.

Interviewee: *Ideally they should have some knowledge of using it.*

Do you have any particular comment or idea about integrating BIM into the curricula?

Interviewee: *I think, it must become something which they use throughout, you know…They've got their design subjects, they should be using it in the engineering management, and…so, from the early year, first year already, maybe they should do some basic…get some basic exposure of how the thing works. As they go along they should be given assignments, use of this throughout the university carrier. So, becomes a part of that.*

So, you believe that students' knowledge about BIM should be developed during these four years and not in a specific course.

Interviewee: *Yes, I don't think that there should be one course where we say now we do BIM. Maybe at the drafting class, right in the beginning couple of lectures to help them draw some … you know…instead of doing AutoCAD drawings, they can use this to draw these things. From then onwards, as students go along, they should be given assignments where they use that.*

Interview no. 4 (Date and time: 22/10/2014, 10:00)

May I ask which course are you lecturing at the moment?

Interviewee: *I'm lecturing the third years, the reinforced concrete design.*

May I ask about your personal knowledge about BIM?

Interviewee: *I know about it conceptually, and when I was in practice, we just started using Revit, which is maybe a soft BIM tool. You know it's not a hard core BIM, but there is a bit of BIM concept built into that. Right? So, I've got a little bit of exposure, and then I know, you know obviously, what BIM is from attending some lectures and tutorial and things around…*

So, you also have worked with Revit in person.

Interviewee: *Yes…but just a little bit, not much. Because Revit just started to come into our office like a month before I left. So, I have very limited exposure, you know, to Revit. But, at least I know of it. I know more or less what it can do, but I won't be very fast in modelling with it, myself.*

These are the areas that I identified through these two surveys that I described and I want to know if any of them is applicable to your course, and if yes, is there any chance to introduce it to the students through BIM?

Interviewee: *Well, let me first say, that I think in the course currently there is very little BIM content. We are working at the moment just with drawings, either it's a plan view or section or an elevation but in 2 dimensions only, and they are required themselves to, you know, in their mind get the picture of what the building looks like in order to design different elements. So, the course is more focused on element design, beam, column, slabs, and so on. And yes, the course is very very full. I told you before. I'm already struggling badly to squeeze everything in there, as it is at the moment. So, if we want to build BIM in there, it will require a quite creative way of thinking, in order to work less rather than more, in spite of adding something in. But let me just go through these items.*

As far as I've understood, visualization is not something that you are dealing with in your current course.

Interviewee: *Not really, they need to have the ability to visualize from a plan drawing and a section, what the thing looks like in 3D, but we are not using 3 dimensional tools, like AutoCAD or Revit or anything else…*

But it should be beneficial if students can use such a tool while they are attending your course.

Interviewee: *Yes, sure. That would be nice. I mean, if you can set them up beforehand and just give it to them as a tool for them to help them visualize what the structure looks like.*

What about preparing cut sheets for providing information such as quantity, sizes, lengths, and shapes of the reinforcing bar

Interviewee: *They need to also consider in design, you know, where and how the rebar must be placed. It's not a priority in our course, you know, for them to do bending schedule, things like that. So, I just want them at least to know that the steel (rebar) come in top of the beam if it's a bending moment over a support, you know. That kind of stuff… So, we are not really focusing on it in a lot of detail on rebar…*

Are there such discussions in Advanced design?

Interviewee: *Yes, for Advanced Design, they have to hand in project with all the drawings, including reinforcement details and bending schedules and everything. So, there they do it, are required to do it.*

So it's because of the time limit in your course that it is not discussed there.

Interviewee: *Absolutely.*

What about geographical information of the building components?

Interviewee: *No, it's not included in the course at all.*

What about geometry and spatial relationship, such as identifying overlaps or if any component is included in the others?

Interviewee: *Yes, well, to a limited extent. I mean, if you have column, you know, that's passing through a slab, it's usually tied into the slab. But when they do the weight calculations, they need to know that if they already added the weight of the slab, they don't need to count that little bit of concrete of the column, you know, because it has been counted in already. Things like that…Not to great extent, but obviously in a building you need to understand it that some items pass through each other, become part of each other almost…*

Are you then would discuss about clash detection there?

Interviewee: *I don't discuss it in class at all. But at least they're developing some 3D sense. , Clash detection, I think it's is especially useful when you start to have a lot of building services and that's* *not treated in the course at all…with different disciplines…you know…we were building a hospital at some stage and there were all sorts of shoots, aircon ducts and fresh air ducts and electrical cabling and all sort of things, even kitchen equipment…depending on where you were. So, there at some stage just managing where all these should go, you know…for that it can be useful. But it's not a part of the course and I cannot see that it will become a part of the course. I think that's something that really somebody can learn for himself when they start to practice engineering out there. It's my opinion. It's not conceptual…*

It's not an issue just to discuss about and they will get the information.

Interviewee: *Yes.*

That's why we are thinking about applying BIM in some courses, for example Engineering Management, where they can discuss about it, they can play with the model and see how they can come through and how they can address that. But your course is more specialized in design aspects.

Interviewee: *Yes.*

Are you discussing about time for constructing the components?

Interviewee: *No, not officially, no…That's interesting that those are part of a BIM model. I never realized that. Are you connecting your BIM model to the project schedule?*

Yes, and it would be 4D model then, it can be extended to 5D model by adding the cost information.

Interviewee: *That is excellent….*

(Here, some part of the discussion is not mentioned as it was related to the software abilities and not related to the main subject.)

Are they informed about as-built information that they need to update drawings and provide reliable as-built drawings?

Interviewee: *The students, will they know this from the course? No, they don't. They don't know that. It's not included in the course at all.*

What about cost of the component of project elements? Something like BOQs…

Interviewee: *No, also not included in the course.*

For sure then you are not discussing about integrating information into a model, to explain it is not just a line and it got some properties…

Interviewee: *No, we are not discussing that at all. But that I mean, it is obviously quite useful and important to understand if you use Revit and things like that.*

What about collaboration and multidisciplinary approach? As we discussed, it would be bolder in something like clash detection, but at basic level they should know…

Interviewee: *No, very basic level they know that there is a consultant, then a contractor…they have a relationship, you know… and then we have done post tension design with them as well. So there even you have still specialist consultants like the post tensioning providers, because they typically come and post tension. So you quite often just give them a cable layout and the force that is required and then they provide that in whatever way they think the most appropriate. So, they are a little bit acting as a sub-consultant. So the main consultant would typically give them the central line of the force… where the cable should lie and the force that should be provided. But, then whether they supply that in ten / more cables or one big one that, you know, has an influence on the jack that you use and things like that…so, this thing is usually then done by them and also the quality control is often by done them…But as far as the course go, it's to a very limited…even this collaboration and multidisciplinary approach is very limited in this course. Just as part of a general discussion, it's not a formal topic of the course; just it may come out as part of explanations about other things*

So, it should be the same about optimizing productivity and performance, because these are more managerial aspects.

Interviewee: *Yes…correct. This is not treated at all. BOQs also not treated at all, cost estimation also not treated at all. Quality control…I mean, we talk to them about placing of steel, the importance of having minimum and maximum spacing requirements met, importance of cover, durability, curing… So, we treat a lot of quality control aspects or actually what are the things that should be there or checked and provided. But we are not talking to them about the quality control process, you know, the paper trails, or how often they should go to site or whatever. We are not talking to them about that at all; we're just really saying the things that should be there, and how it is controlled, that's not actually managed in the course.*

But are you willing to introduce BIM within your course while discussing about related issues?

Interviewee: *That will depend on how much time it will require. I am not up to speed with a use of Revit for example. I mean, it's going to require a bit of effort from me, you know, to teach myself the programme, which is ok, that's not a big deal. But then I would also not want to introduce something into the course that would take more time from the students, because they are already really struggling hard to manage everything that we're throwing at them. So, whatever I do, if it can add value without requiring more time, then I would be willing to consider to do it.*

And do you have any particular comment or idea about integrating BIM into the curricula?

Interviewee: *The only way that I could see is that we could possibly provide them with a BIM model, but a very basic one, not time and cost, just of 3 dimensional layout basically, of the structure that they are going to be analysing in the tutorial. That's the simplest way that I can think…Just to help them with 3D visualization pretty much…to help them see ok, it is how it ties in; ok the load are here, how does it transfer to the beams…*

But not working with the model?

Interviewee: *No, not really working with the model, not changing it to anything, just visualizing. That would be maybe what I would actually use it for. Maybe also in terms of bracing…They struggle to…the insight in terms of structure is braced in this direction but not in that direction, because of the shear walls and the layout of that. That might also be something that might be useful in 3 dimensions for them to see. It would have been more useful if the BIM model could also show the deflection of the structure in different directions…I think to a limited extent. I think in Advanced Design and management they might find it very useful.*

Interview no. 5 (Date and time: 29/10/2014, 12:00)

May I ask about your personal theoretical or maybe practical knowledge about BIM?

Interviewee: *Yes, well…not very much practical knowledge but I think I know probably more than most people what BIM is about. I did some for my own PhD research for example…yes… I was introduced to the subject or to the topic, when it was still called something else which was STEP by that stag, Standard for the Exchange Product Model Data. This was as far as I know, followed by something called the Industry Foundation Classes and then eventually, nowadays people talk about Building Information Modelling. So, my personal knowledge is on technical and research level more or less and not so much in the application of Building Information Modelling. I have spoken to many people about it but not really tried to, how can I say... apply any known standard of Building Information Modelling technically.*

About the course that you are lecturing at the moment, is it Engineering Informatics?

Interviewee: *Yes.*

May I ask about the topics you are discussing there?

Interviewee: *Yes, ok, there are two courses actually. The first course is just object modelling which is in my opinion, well…the technical basis of Building Information Modelling. I'm not quite sure that you can make any sense of Building Information Modelling if you don't understand object modelling, because the Building Information Model is a very extensive object model. So, I think object modelling, which is basically all I do on that first course, provides a very nice technical foundation for continuing in the direction of Building Information Modelling. But I don't mention it precisely; I don't think the students can really grasp it at that stage. They are second year students, second semester of second year…*

Almost half way through…

Interviewee: *Yes, almost half way through, but I mean they're still very naive about building stuff. I mean they think the courses is totally useless and they just find it very difficult…they struggle to pass it and they don't want to become programmers and they have all the excuses in the world why they do so badly in the course. But the point is the course is difficult because object modelling is a strange concept for them…and…it's abstract and it's technical and you have to be exact and you have to be correct and you have to really understand it to be able to do the tasks that get given…at that stage students don't like that…sort of discipline that involved in the subject. In the first semester of the third* *year, I essentially do the Finite element method from a mathematical point of view and then in the end we develop a Finite element object model, which may obviously eventually be part of a Building Information Model… The Finite element object model will be incorporated in any Building Information Model, when you really do it. But I mean again, I don't have much time and the technicalities of the method takes a very long times and we don't have much time to spend on the object model itself. But…I mean, I think these two courses provide some basis on which to build any future work concerning Building Information Modelling. I think without it, you have no chance. So, at other universities where they don't do this object modelling course and so on, I'm not sure that you can really…at university level, in my opinion, really address the issue of Building Information Modelling. At least not scientifically, may be just as a concept or as something that you use without understanding too much about it or whatever… I don't know. But you can't really address it technically; I think without the background that the students get in these two courses. So, I think we do a lot more than other universities already. I think the students do have a chance. It must be followed up in other courses and I don't think it really gets done. But I don't have more time. I mean, I had to over the years cut down the content of my courses already just to try and get the minimum done. So, I don't really have any more time to…Yes, I mean it would be nice but I think it's more for other courses to try and use the background that was provided, to build on the background and use it then. I think it may also help for the students in later on to say "oh, I can see why I actually did that course", but…it's not general but I think, in the class there is a big percentage of them that they don't see the point. So…*

Even on that year? Because if we can have some basic foundation for them, at the very first stage like first year while they are doing the engineering drawing…

Interviewee: *Yes, that may help to mention it there…Look, I mean the first programming course that I do is in a second semester of the first year and it's not object modelling. They just use procedural language C, so they get the basic concept of programming. But they don't do any object modelling in the first year. But I mean it doesn't to… start talking about Information Modelling and then when they get to the second semester of the second year, maybe they would have a bit more appreciation of what we are trying to do in that course. Because at the moment the students don't seem to see the point, so they think it is very difficult…Yes, I mean students everywhere in the world they are all the same…if course gets difficult, then they have to find some excuse why they do badly and then they have to find an excuse by saying "no, it's not important, so I don't care too much about it." And that's the way to get rid of your responsibility or explaining why you are doing badly in the subject or something. Because it takes a lot of hard work to master that subject and students don't really like that. It's just the way they are, it's always been like that…*

Are also discussing about parametric objects there?

Interviewee: *Yes, all the object modelling is parametric in a certain sense. You would say an object has attributes, for example a beam has a width and height and length and it has a material and using these parameters you can determine the mass of the beam, and if you can determine the mass of one beam, you can determine the mass of all the beams in the building, so you can model the building as a set of beams, and columns obviously, all the building frame there at least. I do examples like that when I model a building and a model for me is always a set of components which is the same concept that's obviously used in the Building Information Modelling. All the Building Information Models that exist… model is a set of components, and the components have attributes, parameters they have to find them, and they have methods with which they can do certain things like tell you what the stress in the beam is, or the bending moment or so forth… So, this modelling concept is really what I do. I mean, I model a building and we compute the mass of the building and the building comprises of beams, columns, slabs and stuff like that. And then, for example you work out with the mass of the concrete, something like this, something simple…yes.*

I think that nice…

Interviewee: *Well, I think it's really nice but I mean I don't think the students really appreciate that very much. For them it's just very difficult and a lot of hard work. But anyway, that's what we do.*

What about the software and tools that you are using?

Interviewee: *It is a basic modelling course, in other words we do the definition of the object classes ourselves and programming. So, we use Java object modelling language and then tools to do the programming… But it's not any BIM related software. That's really at basic level of all these things. I mean all the AutoCAD…*

It's behind the sense of it…

Interviewee: *Yes, it's behind the sense. They have object models based on Building Information Modelling standards and they use some sort of object language, like most of them use C++, I suppose…and then tools to create their software. I mean, I'm at the level of where you create the software not at the level where you use the Building Information Model…I show them how you build it…all the Information Model…what is it really, at the very basic level and that's why I say our students, if they understand that, they have a chance of understanding what Building Information Modelling really is all about. But you have to understand it at a certain level first. And that's what I'm trying to do…*

On that case, may be it would be helpful if they get some information about developed software based on this information and then they can use it …it would make sense for them then.

Interviewee: *Yes…I agree. I just think that it should be done in the courses that use these tools, for example the drafting courses. I mean if you say, I'm making a drawing of a building, you must try to teach the students that the drawing is not a set of lines, points and graphic objects that appear on a screen or on a piece of paper. These things that you see there, they represent beams and columns and slabs…*

They've got some properties…

Interviewee: *They have got properties and…that's what makes up the Building Information Model…and if you see it there, and you see it in the way I do it, then you can say "these two things are the same". I mean, that drawing program that I use, like AutoCAD or whatever, they must have a program like the programs I'm teaching them behind them. They must have these classes of objects with these properties and parameters to be able to do that. I mean somebody must tell them that, but it can't be me, because I've got my hands full with the other stuff. They have to…the people who use these tools in other courses must tell them that. I'm not sure if we've got that people that teach these courses, they really understand that…it's not that I think my colleagues did not know the stuff, they know a lot, but I don't think that they maybe understand that particular aspect of the things so well, because they don't have the background in object modelling.*

The fact is, the information is scattered…you are talking about some basic fundamental knowledge and then they are just putting it aside and will forget about that…and they cannot link them...

Interviewee: *Yes, they don't see the connection. It's a big problem. And it's not only in this particular course. I mean it's in all the courses. The students don't see the…because they don't use it directly; like…they fell "why I do have to know all this integration and stuff and differentiation". But it's the total technical basis of all the physical problems that we deal with. You have to…I don't know… they don't often see the point. So for me it's not a big surprise that they don't see the point of what I'm trying to do. But it has to be repeated…it has to be pointed out to them…But I can't do it, the other guys must do it. But I don't think it really happens. I think later only they do see it. I mean, I get often from guys in engineering practice questions about this. And then they say "oh, yes". Now they see we did the stuff and they can't believe that they should have to understand the tools they use in practice. And some of them even come back and do a master course or something to get this …but for the guys there, at second and third year level, for them it's just a big pain…I would be very glad if people can really point out to them that… that stuff is what is happening here now. What you draw there in*

AutoCAD, it is…you are creating a BIM, not just four lines or something…you have to teach them that.

Actually, the list of the question that I asked other lecturers is not really applicable in your course, as it is more about specific civil engineering issues. But through our discussion I'm getting to the point that this specific subject should be introduced to the students and through a suitable tool to help them understand it.

Interviewee: *Absolutely. It is in my opinion very important that this follow up will get done and pointed out. I really show them that this is the way it works now. And in their future it's not gonna get less, it's gonna get a lot more, like that…It's pretty soon it is going to be a situation where people are…the clients are gonaa specify that at the end of this project I want a full Building Information Model and if you can't provide that, I don't want to use you. And then you must be able to say I deal with this or no, I can't deal with it and sorry I can't do a job and this is coming…and this is really important I think.*

If we just ignore the shortage of time, do you think that you are also willing to introduce BIM also to the students?

Interviewee: *I would love to. Yes…I would really love to. I think I'm in a good position to introduce it in the way I think it should be done, and bring it to connection with what I have taught them. Because I mean, I know what I have taught them and I know how to build on that and to show them…because other people, they don't know exactly what I'm doing, so I can tell them and they can maybe…if they take enough trouble about it, they can look in detail what I'm doing. But usually people are also busy; they don't have time to worry about what the other guys are doing. They have to worry about what they are going to do. I don't blame them because I don't do it either. But I think I'm in a good position to give an introduction into Building Information Modelling, but then I need time, I need another course. Or I need to teach a course in which I can use it. But I don't want such a course…I have enough work…but I think I can do it, but as you say if we ignore the shortage of the time…yes, definitely.*

Besides, these issues that we discussed about, do you have any particular comment or idea about integrating BIM into the curricula?

Interviewee: *Do you mean make a specific proposal about where and how and so on?*

Actually when I'm talking about integrating BIM to the curricula, it is not be just for one course necessarily, I'm thinking about having it in all courses and in each course relevant subjects should be addressed through BIM.

Interviewee: *I agree with that point. I agree that that's the correct approach. I don't think that we can make a specific course about Building Information Modelling. I think it must be used continuously in all the courses somehow. It's difficult, it not easy to do that, it will need a lot of planning, but I think it can be done quite sensibly, I think it's possible to do it but it will need an integrated and coordinated effort from the department as a whole. We have to look at all our courses, we have to plan it carefully, and then we have to decide…what can be done in each of the courses and how it should be done. So that we don't get the conflicting messages…that everybody talk the same language about it, the correct one, not…you know, there is many times in academia…there is sometimes things people approach is different…and that is very confusing to students, because they are struggling to see through all these information, it's too much and… now if they get messages in different ways then it becomes even more confusing.so, I think it's possible to do it, but it needs a nice coordinated effort…to do it specifically, you know, you must plan to do it and how to do it correctly. But I think it is possible and I think it should be done.*

And do you think in this regard, lecturers also need some sort of training?

Interviewee: *Absolutely, they need will to be informed…really, I'm quite honest with you…I think there are very few people that they really understand what Building Information Modelling is all about and as a result you get weird statements about it and a lot of misunderstanding. I think to do it correctly, as I said would need planning, but you also really need to get all of the lecturers that are involved… will have to be told exactly what's it about so that they understand it. And then the message becomes a single message not all bunch of individual interpretations of what I think is Building Information Modelling…that this guy thinks like this and this guy thinks like that… Because it can be really causing a lot of damage if you do it incorrectly I think… If you don't do it correctly, you can spread a lot of conclusions.*

(Some part of the interview which was not directly related to the subject is not mentioned here)

I think you have a good understanding of students' willingness and ability to learn a tool or software, how do you think about their capability to being introduce to different tools?

Interviewee: *Students actually like to be introduced to tools, especially ones that they think they will be using in engineering practice. So, they respond very well to it and they are very capable, they learn really fast. But some of the tools are very difficult…the students struggle with it, but they do* *surprisingly well…But yes, they like to learn tools that they think they learn afterwards. They think it's important, so you do have a chance and I think, as long as you are going to use these tools anyway…you can just as well get this BIM message across at the same time. It's not so much extra effort to get this message also across as a part of the thing. It's not that you just making the drawing, you are trying to making a model…something like that… it makes a better sense eventually anyway. So I think that can definitely work.*

-Interview no. 6 (Date and time: 30/10/2014, 11:00)

May I ask about your personal theoretical or maybe practical knowledge about BIM?

Interviewee: *In terms of 3 dimensional models, I've had quite a lot of experience and exposure with it. I cannot build one myself, but… in structural steel work that is just about the way it gets done all the time, both for heavy steel structure and light steel frame construction. And, so…for example, just in terms of very practical exposure I'm just moving at the moment to a new house which we rebuilt from the ground up and that's made of hot rolled steel work at the bottom and light steel framing for the rest and all of that was done with 3 dimensional model; Tekla being most of it or at least for the hot rolled steelwork and for the purpose made thing for the light steel framing. And, so… as I say, and other issues relating to it also, for example, approval of shop-drawings which… to formulize that process, etc… We had a drafting school at the Institute of Steel Construction and there also I was the person involved in the teaching. But… at the end the kids were taught how to use Tekla, especially effectively for that purpose. Other issues relating to it, especially traceability of material is one thing for a steel element. Steel element gets made in the factory; it got the precise dimension, holes through this and other holes in the very specific places. And that specific element has into go to a very specific place in the structure, and in a specific time. Now, there is a number which has to be on it; that number has to be brought into the system and if you paint the thing or if you galvanize it…you know what happen to that number and to the whole traceability of the material and so on… our issues which I've actually been involved in quite a bit. Where it gets to the management side, and the financials, I've had really no personal experience. I've had…well except getting done things like Bill of Quantities and so on, a problem with…a few times which I had to help resolve… is that the quantity surveyor isn't sure of how much steel went into the project and we will tell him here is the precise print out of everything…all of the material and…added together or not, added together in categories and so on…here is the sum total of the areas which had to be painted and all that sort of things, you know. They first can't trust it; you actually have to convince him even though this information which comes from a contractor is still reliable information. And in fact there is a huge amount of information sitting in that model which can be obtained by various people who want to use it. I've been rather at various conferences in America, China, wherever issues around BIM for steel structure obviously, were discussed and new ideas and so forth. So, let say, I have exposer, but firstly not as somebody who is actually…it's a long time…fifteen years since I was involved in project myself as an engineer, as a consulting engineer. I've been, let say… in two consultants over long period and in the area of steel construction. So, that's why I say that my personal knowledge is not hands-on knowledge except for the house that I can speak of.*

At the moment you are busy lecturing Advanced Design for fourth year students. Are you using sort of models while you are lecturing to enhance their visualization ability?

Interviewee: *You know, we didn't and we just discussed, incidentally, you may want to speak to the other lecturer of Advanced Design…*

Actually, I had…

Interviewee: *We haven't and we actually, I don't know, if it was because after he talked to you…but in any case, we just agreed that in future we'll have to more of that. And actually I obtained quite a number of Tekla models, and for visualization I think, it is very important…We taught, we got messages across and so on and yet we seem to…falling short of what actually wanted to achieve. So, yes, in future most definitely we'll be using it. As I said that, it's physically sitting on my computer, the stuff that I obtained for that purpose. There is a lot of stuff to get through and methodology and still sort of fail in many instances…*

Are you discussing about providing information for reinforcing bar, like size and length and different properties that you need and do students learn to do it?

Interviewee: *Yes, they learn…bending schedules, what it is called…*

And do you think that they would be the opportunity to use something like a model, and then if it is applicable they can apply it there and use it meanwhile?

Interviewee: *Yes, I think actually we… there is a program called Procon which is used very much in South Africa. As far as reinforced concrete concern it is actually very good and detailing and so on…concrete in general is a lot easier to visualize, where steel structures are actually rather difficult to…it's really how things fit together and so forth. Visualization is more important with steel structures than it could ever been with concrete, and in fact I think the guys have really solved the problems to large extent.*

What about the geographical information of the building components? Is there anything in your course that students learn about it?

Interviewee: w*hat aspect of geographical information? What do you mean?*

The specific place of different components and how they are linking together that at the end may result to something like clash detection…considering the spaces and these sort of things.

Interviewee: *Yes, I know it's important of course. But I don't think in a certain undergraduate course… In an undergraduate course, I think there is no time to go to that point…It's sort of presumes that the guys have other knowledge of mechanical systems and so forth, for example. But, on a post graduate level, one tends to teach them sort of higher level things rather than more practical things, I mean. So, as I say, I think it's a level…I think it would be very good if graduating students have knowledge of… certainly they need knowledge of BIM and clash detection is one of the issues which can be addressed, and in fact there is thing like clashes, or with the potential for clashes. I think those are things people have to know. Constructability…especially with steel structure constructability I think is very important and it's part of visualization…and very difficult often…you know, how small is it the place when you can get your hand into, how bigger thing can you lift and how do you get that big thing between other things and so forth…*

So, you think that they don't need it in this stage. They should go and practice for a while and then come back again for more advanced courses?

Interviewee: *I'm not even sure how much we can actually teach at the university. That is my question, you know. It's a fast developing field; there is lot of software coming on all the time. There is lot of catching up, even to do it to get to the front of what there is, what already exist. I'm marking these final designs now, and I must say, I rather come to the conclusion that one has to be out there to learn to do design. And if I say design, I include with it lots of other things. You can't teach a person to draw. We gave them a, let say, like an empty drawing, with line thicknesses already determine and so on and just putting your things in there. That's about as much as you can expect from people. So, there is just so much time available. I thought rather different at the beginning of the year, because I was still quite optimistic in terms of what we can teach people and getting a feel for structures and so on…and behaviour and a framing system and…I've just come to the conclusion that you can…and I'm sure these students after all the trouble we have taken, they'll be a little be better than last years, they need to learn. They are just ready to start learning now, I'm afraid. You see, engineering educations is very different from our architectural training. Architects are trained, doctors are trained, engineers are educated, and that doesn't make them educated people but the process is an educational process, it's not a training process.*

(This part of the interview is not mentioned here, as it was not directly related to the subject.)

But I think it should be started from academia.

Interviewee: *The question is whether you are going to teach somebody a skill and so forth or whether you are going to just create awareness and the right attitude and so forth. We like to teach students things that you can examine and especially things that are based on mathematics…we tried with the* *design to let the people think conceptually, visualize…there is a big step which is a difficult thing that you have to firstly visualize, there is a building that looks like this and has made out of trusses or columns or... Then what are the loads acting on that thing, then feeding that into the computer to do the analysis or just do it by hands…doing the analysis of the forces in all the elements, designing the elements and designing the connections. And it is very difficult, for even post graduate students to do it…and I remember myself, when I started working that was a very difficult thing. It just took a while to understand this is the process. And things didn't actually fit together and we took a lot of trouble to try and make that things fit together…Even in doing the basic things, I mean teaching students just structures, there is a concept, geometry, the loads and analysis from which you do member design and connection design and you draw the whole thing. If you can achieve all of that, you are achieving a huge amount.*

Is it achieved at the moment with your current course?

Interviewee: *I think with many students we are successful…But I think…next year when we do this course again, we'll do it a little different..*

You are also discussing about cost and BOQ in your course, the students supposed to do some assignment and projects. If they learn to use a model for doing this calculation, do you think that would be enough for them to do it through software? And does it make a better sense for them?

Interviewee: *Yes, what we do at the moment is…there is something which are difficult to calculate…if you have a column let say, there are little things welded to the thing or bolted to it and so on… what we say: take the column, and add 10% f to weight just for those little things, you know. Versus, you work to feed it in a 3D model, it jumps up. Because, here if you give that out, as one little piece…half a kilogram here and quarter a kilogram there…we'll have BOQs which cover many many pages that you don't want. But they can combine those and it would be a very useful thing to learn.*

Are you talking about as-built information and how they can provide a reliable as-built drawing at the end and this sort of thing?

Interviewee: *I don't think we even mentioned as-built to them…*

But can it be a part of your curriculum?

Interviewee: *It should be mentioned. I don't think you…as I say; one has to limit your objectives. You can't teach students everything they need to know.*

Is it because of the time limitation?

Interviewee: *It is the time limitation. It's also…in a design situation, design office, you sit there and there is somebody who sit a few meters away from you all the time and who is your superior and who says no, what are you doing there? It is wrong or so forth…or you can ask how we do this and so on. Here we spend time with the students, but ultimately they work on their own. And so, if somebody is there all the time to tell you how to do things, you'll learn. And you learn about something very specific and limited.*

Back to the discussion we had, about practical learning and not just learning the concepts, what about if for example university has got some opportunity to send some students for vacation training to a company where BIM is applied? Then they are exposed to this technology while they are learning it at the university during their degree. Do you think that it is practical and helpful?

Interviewee: *That would determinedly be helpful. Actually if you can let the students concentrate on that almost specific to the places where they should work on this, that would be tremendously useful. Because there we can learn skills which we can build on once they come back here. There is no time to teach them everything from the beginning here. If they come here, already have a feeling of these, it would be tremendously useful.*

While they are doing something like drawing during the course, do you think they understand what their drawing is, and it is not a plain line but it has got some properties and information behind that which should be kept, which should be updated, which should be linked to other information they have?

Interviewee: *No, we haven't gone into more object oriented or whatever…I think they don't think of a drawing that much different from drawing a horse and adding some dimensions, and some even don't have the dimensions…*

What about discussing about collaboration and multidisciplinary approach? Are they exposing to that? Especially among civil engineering and architects…

Interviewee: *We speak about it a lot, but… There is no architectural department…even at other universities where there are architectural department in South Africa, they do not seem to work together at all. So, no, they have no cross discipline exposure.*

What about quality control?

Interviewee: *I really don't know. We teach them a little bit about the quality control of the design process, and at least presenting information in such a way that it can be checked, for example just saying where you store your files. Files these days can sit on even on the computer and so on and you never find them, unless somebody tells you where it is. Somebody else has to look at your things and you have to look at your things and so on. I think there is a great efficiency in it…I don't know what other guys teach them in terms of quality control, but we just talk to them about the quality control of the design process, and then only a little bit.*

I don't think that you would discuss about optimization of productivity or performance, as it is more managerial aspect of the design.

Interviewee: *There is firstly of curse structural optimization. They certainly got to understand that if you are designing structures, and you are making a living out of that, you have to the conclusion fairly quickly and you have to find an efficient way of doing your calculation, design, drawings and so on…how to play into the whole process and shop-drawings and etc…I think they exposed to commercial environment, we told them about that, I can say, the environment in which design happens…*

Generally do you think it is practical to integrate BIM into your course? Are you willing to do such a thing?

Interviewee: *I would say as a lecturing tool, most definitely. And when I say BIM, just mean 3D models not the whole thing, and maybe quantities. That's about as much as I can see that we can actually bring into the course. I can't see that we can let the students do the drawings using a 3D model; it would take too much time for them to learn this. Unless, using the example that you mentioned, if they can spend time at companies and there is a course in which they learn the software…*

Do you have any particular comment or idea about integrating BIM into the curricula?

Interviewee: *I think, they learn best when they are actually have to do it…they are on the pressure and so forth. But I would say…if one wants to talk BIM and not just as 3D model, then one would have to integrate the project management and the design…and how you do that is…an interesting question. Professor S. does this course for the second years and in a way that's already where things should start, I think. You are looking at second and third years and nowhere else you can fit anything in. What would be greatest if they…ok we design, but project is also should be built and managed and you bring it into the project management field…the practically of that look fairly complicated tome, if I say. That's your problem, there aren't so many hours in a day…and you have to cut things out to* *bring things in and you can't just add. People can't go faster that they do. But they can learn more useful things and then more effectively and I think…there is room. But there is not something which is such an obvious an easy idea to say "why didn't I think about it?". It is something which somebody would have to think deeply about, plan the whole thing, getting enthusiasm, go in and so on…and do the things in the right sequence so that for example when the students arrive in the final year design, you don't have to teach to draw still. They must come already with certain basic skills which can get developed while they're doing the design. Maybe the concept of sending them home, to do projects at home, is not such a good idea. Maybe the guys should actually…there should be studio type of situation where students spend their time, that's where they do their design.*

Appendix F- Tables related to BIM level of effectiveness on six areas which can be enhanced by using BIM based on contractual role of the company

Table F. 1: BIM effectiveness on personnel creativity based on company contractual role

Area of influence	Contractual role of the company	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Creativity in the project	Consultant/ Engineer	0	3	6	6	6
	Design-Build	0	0	2	1	0
	General Contractor	1	0	1	0	0
	Others:	0	0	1	1	3
	Sub-contractor	0	0	1	2	4

Table F. 2: BIM effectiveness on sustainability of project design based on company contractual role

Area of influence	Contractual role of the company	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Sustainability in project design	Consultant/ Engineer	1	2	9	8	1
	Design-Build	0	1	1	1	0
	General Contractor	1	0	1	0	0
	Others:	0	0	1	1	3
	Sub-contractor	0	0	2	3	2

Table F. 3: BIM effectiveness on quality improvement in project based on company contractual role

Area of influence	Contractual role of the company	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Quality improvement in project	Consultant/ Engineer	0	2	7	9	3
	Design-Build	0	1	1	0	1
	General Contractor	0	0	1	1	0
	Others:	0	0	1	0	4
	Sub-contractor	0	0	2	2	3

Table F. 4: BIM effectiveness on decreasing human resources based on company contractual role

Area of influence	Contractual role of the company	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Decreasing human resource in project	Consultant/ Engineer	3	7	6	3	2
	Design-Build	0	1	0	2	0
	General Contractor	1	0	0	1	0
	Others:	0	2	0	2	1
	Sub-contractor	0	1	2	3	1

Table 0F-5: BIM effectiveness on decreasing the cost of project based on company contractual role

Area of influence	Contractual role of the company	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Decreasing the cost of project	Consultant/ Engineer	0	8	4	7	2
	Design-Build	0	0	0	3	0
	General Contractor	1	0	0	1	0
	Others:	0	1	0	3	1
	Sub-contractor	0	1	1	4	1

Table 0F-6: BIM effectiveness on decreasing the time of project based on company contractual role

Area of influence	Contractual role of the company	Not Effective	Fairly Effective	Effective	Very Effective	Strongly Effective
Decreasing the time of project	Consultant/ Engineer	1	6	5	4	5
	Design-Build	0	0	2	1	0
	General Contractor	1	0	0	1	0
	Others:	0	1	1	2	1
	Sub-contractor	0	1	1	3	2

Appendix G- Tables related to the level of difficulty for different problems in implementing BIM based on the contractual role of the company

Table 0G.1: BIM implementation problem 1 based on company contractual role

Problem 1	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Lack of skilled personnel/ Employees' reluctance for learning a new technology	Consultant/ Engineer	1	3	10	7	0
	Design-Build	0	0	2	1	0
	General Contractor	1	0	1	0	0
	Others:	2	0	1	2	0
	Sub-contractor	0	1	4	2	0

Table G.2: BIM implementation problem 2 based on company contractual role

Problem 2	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Other parties' reluctance (Client, engineer, architects, contractors,...)	Consultant/ Engineer	1	3	14	3	0
	Design-Build	1	0	1	1	0
	General Contractor	0	0	2	0	0
	Others:	1	1	1	2	0
	Sub-contractor	1	2	3	1	0

Table G.3: BIM implementation problem 3 based on company contractual role

Problem 3	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Sharing the information/ Model with other parties	Consultant/ Engineer	1	6	10	4	0
	Design-Build	0	0	2	1	0
	General Contractor	1	1	0	0	0
	Others:	1	2	1	1	0
	Sub-contractor	3	0	4	0	0

Table G.4: BIM implementation problem 4 based on company contractual role

Problem 4	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Integrating company's system with BIM	Consultant/ Engineer	1	5	13	2	0
	Design-Build	0	0	2	1	0
	General Contractor	1	0	1	0	0
	Others:	3	0	1	0	1
	Sub-contractor	2	1	3	1	0

Table G.5: BIM implementation problem 5 based on company contractual role

Problem 5	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Lack of collaborative process and modelling standards	Consultant/ Engineer	1	3	11	6	0
	Design-Build	0	1	2	0	0
	General Contractor	1	0	1	0	0
	Others:	1	1	1	1	1
	Sub-contractor	0	1	6	0	0

Table G.6: BIM implementation problem 6 based on company contractual role

Problem 6	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Lack of contractual / legal agreements	Consultant/ Engineer	0	2	15	3	1
	Design-Build	0	1	1	1	0
	General Contractor	0	0	2	0	0
	Others:	1	1	2	1	0
	Sub-contractor	1	1	4	0	1

Table G.7: BIM implementation problem 7 based on company contractual role

Problem 7	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Waste of time	Consultant/ Engineer	4	5	10	1	1
	Design-Build	0	0	3	0	0
	General Contractor	1	0	1	0	0
	Others:	3	2	0	0	0
	Sub-contractor	4	0	3	0	0

Table G.8: BIM implementation problem 8 based on company contractual role

Problem 8	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Cost of software license and training	Consultant/ Engineer	1	1	10	9	0
	Design-Build	0	0	2	1	0
	General Contractor	1	0	0	0	1
	Others:	2	0	2	0	1
	Sub-contractor	0	0	5	2	0

Table G.9: BIM implementation problem 9 based on company contractual role

Problem 9	Contractual role of the company	Not a barrier	Ignorable problem	Solvable problem	Difficult	Impossible to get done
Compatibility issues between different software systems	Consultant/ Engineer	1	2	11	7	0
	Design-Build	1	1	1	0	0
	General Contractor	1	0	1	0	0
	Others:	2	0	2	0	1
	Sub-contractor	1	1	5	0	0