A STUDY ON THE BIM ADOPTION READINESS AND POSSIBLE MANDATORY INITIATIVES FOR SUCCESSFUL IMPLEMENTATION IN SOUTH AFRICA

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Building (Property Development and Management)

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the Degree of Master of Science in Building (Property Development and Management) to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.
I have followed the required conventions in referencing the thoughts and ideas of others.

I understand that the University of the Witwatersrand, Johannesburg may take disciplinary action against me if there is the belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words of others in my writing.

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ABSTRACT

Building information modelling (BIM) is one of many ways to automate construction processes and activities. Numerous projects in both the public and private sectors suffer from poor information management, resulting in time and cost overruns. BIM implementation is rapidly growing in western countries, as governments play key roles in devising strategies and mandating initiatives which increase its adoption. The purpose of this study is to determine possible regulatory initiatives towards BIM implementation in the South African Architectural Engineering and Construction sector (AEC) from the stakeholders' perspective. BIM implementation strategies that have been used in various countries are discussed in the study and a questionnaire survey of AEC professionals in South Africa was conducted to determine which government strategies or mandatory initiatives would be most effective. The obtained data were analysed using inferential statistics and hypothesis testing. The results reflect that the South African government's influence would be most valuable in mandating initiatives that promote BIM education and awareness, incentivising BIM usage by AEC stakeholders, modifying procurement practices to allow BIM usage and developing BIM libraries and data exchange frameworks.

Key words: Building information modelling, implementation, mandatory initiatives

To my beloved wife Tashmika, for all your unwavering support and motivation.

You are a real gem.

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1 INTRODUCTION

1.1 Background information

Building information modelling (BIM) is an information model of a building or construction project and consists of computer-based data and information such as function, materials used, economy, shape, etc. which is useful in managing and supporting all the lifecycle stages of the physical asset (McAdam, 2010). BIM also stands for the practice of building information modelling. It is therefore a combination of computer software applications, systems and processes about work practices used by Architectural Engineering and Construction (AEC) sector professionals and clients. These tools and systems help improve the efficiency of delivering construction projects and management thereof, during and after construction (Aranda-Mena et al., 2009). The functionality and data sharing capabilities of BIM enable it to be implemented on the whole spectrum of the construction and infrastructure projects. Lean architectural, engineering and cost management practices are associated with the efficiency brought by automating the building and management of activities using BIM (Arayici, 2011).

BIM is widely used in developed countries such as the United States of America (USA), Germany, Australia, Finland, Canada and of late in the United Kingdom (UK), and these countries are deemed to be leaders in using the technology (Mcauley et al., 2013). Although BIM is now extensively used in these countries, various challenges related to low adoption rates of the technology have been encountered during the initial implementation stages e.g. legal, institutional and financial barriers (Gu & London, 2010). Due to the successes achieved by these countries in BIM implementation and subsequent scale of usage, they are now regarded as being matured in BIM capability.

BIM was only introduced in South Africa around 2004 (Kotze, 2013). In comparison to the aforementioned developed countries, South Africa is less mature in terms of exposure and usage of BIM. Few projects have used BIM as a fully integrated system in South Africa. Examples of where BIM has been used are for the construction of the Nelson Mandela Bay and Mbombela stadiums for the 2010 FIFA World Cup. There is generally poor demand for BIM by private and public clients due to the high cost associated with implementing new tools and systems. This has resulted in a low rate of BIM adoption from the AEC sector. Although South Africa is starting to experience an increased uptake in BIM (Kotze, 2013), there is still inadequate demand from the public and private sectors to make BIM a viable mainstream technology (Booyens et al. 2013).

The South African construction industry is currently inefficient largely due to poor information management (Baloyi & Bekker, 2011; Talukhaba & Taiwo, 2009). The introduction of BIM to automate construction processes is thus deemed important to promote the chances of successful projects being delivered on time and within budget. However, based on experiences from more BIM mature countries, the implementation of BIM technology in South Africa poses many challenges that would affect its adoption from the AEC sector. Many strategies have been adopted around the world to overcome the challenges associated with BIM implementation (Booyens et al. 2013). One of the most important and commonly used strategies is the involvement of government or regulatory agencies to impose mandatory requirements for BIM usage on projects in the public and private sectors (McAdam, 2010; Wong et al, 2013). Some authors such as Migilinskas et al., (2013) and Wong et al. (2011) have claimed that the lack of governmental and regulatory support may lead to the failure of BIM adoption.

1.2 Problem statement

The delivery of construction projects in South Africa is increasingly becoming complex in terms of design, construction technologies being used and the need to manage produced information more effectively. Resources need to be managed efficiently so that construction projects can be delivered within set programme and budget parameters. Many recent studies have indicated that

BIM is one of the methods through which these inefficiencies in construction can be effectively managed. BIM is a parametric modelling technique that can be used to deliver construction projects efficiently. However, the adoption of the same in South Africa is limited. There are many initiatives and strategies reported in the literature for the effective adoption of BIM around the world. However, all those strategies were designed through the readiness of the industry and direct influence from governmental and regulatory agencies. *The unstructured ad hoc implementation of these technologies without considering the existing industry readiness or no supporting regulatory initiatives leads to irregular and inefficient adoption for the same.* Hence there is a need for understanding the industry readiness for BIM adoption along with the possible mandatory initiatives by the government. The current study is an effort to explore the same in South Africa.

1.3 Research questions

1.3.1 Main research question

What are all the possible regulatory initiatives that can be introduced by competent agencies in South Africa to promote BIM adoption in the AEC sector?

1.3.2 Sub research questions

1. What are the perceived benefits and challenges of using BIM?
2. What are the current industry readiness and the maturity level of BIM adoption in South Africa?
3. What are the possible regulatory strategies that have been used around the world to improve BIM implementation?
4. What are the possible regulatory strategies for BIM implementation that can be used in South Africa?

1.4 Research main objective

The main objective of this research is to explore the BIM adoption readiness and possible regulatory initiatives that can overcome the challenges towards BIM implementation in the South African AEC sector.

1.5 Research objectives

The four sub-objectives that contributed to the main objective are:

1. To assess the potential benefits of using BIM in South Africa.
2. To assess the existing information on the BIM maturity level in South Africa.
3. To explore the possible regulatory strategies adopted around the world to overcome BIM implementation challenges.
4. To explore the possible regulatory strategies that can be used in South Africa to overcome the identified challenges.

1.6 Rationale for the study and utility in domain

BIM research in South Africa is limited when compared with the developed nations, so this study contributes to the body of local knowledge. This work is therefore beneficial to the various industry stakeholders in the private and public sectors (see Figure 1) as it helps them to understand the specific barriers of implementing BIM in South Africa and the roles that each party plays for its successful implementation. The focal point of the research is to suggest possible strategies that may be initiated by the South African government and other regulatory agencies to promote BIM adoption. The study therefore helps public officials and decision makers referred to in Figure 1 to influence future policy making for supporting BIM technology usage in South Africa.

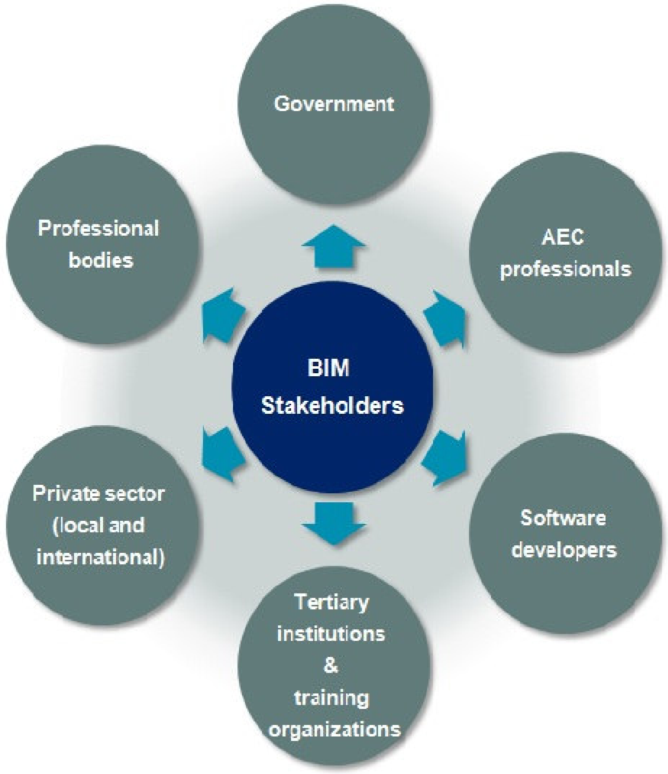

Figure 1: BIM stakeholders

1.7 Ethical considerations

The most important ethical consideration for this work was the need to adhere to the University of the Witwatersrand's Code of Ethics concerning research. As the study made use of quantitative research design through surveys, the informed consent of survey participants was required. It was made clear to participants of the study that the research undertaken was for the attainment of a Masters in Building qualification and in no way linked to any commercial gain or advertising purposes. Confidentiality of data and the maintenance of anonymity of participants were also very important. Once data was collected, the onus fell on the researcher to maintain the integrity of the data and to ensure that it was not compromised by, for example, altering results or responses.

1.8 Scope

The scope of the study covers the implementation of Level 2 BIM in South Africa to get the technology to a point where it becomes mainstream technology by replacing current methods of construction project delivery which are inefficient. With BIM being a relatively new technology on the global market, there is an appreciation of the fact that certain barriers need to be overcome in order to popularise the technology and make it viable for widespread usage. The review of existing knowledge on BIM in this study provides insights on the technology, thus being explanatory in nature. The study looked at possible regulations that may be imposed by the South African government and competent agencies to promote the adoption of BIM technology.

For purposes of this study the following terms are defined:

- “Implementation” – The introduction and usage of BIM technology.
- “Adoption” – Acceptance of BIM technology by government, clients and construction industry stakeholders to facilitate “implementation”.
- “Barrier” – Any factor that has a negative impact on the adoption of BIM technology.

1.9 Report outline

The research report contains five chapters with Chapters 2-5 presenting the researcher’s literature review, research method, findings and conclusion respectively.

2 LITERATURE REVIEW

The purpose of the literature review is to provide a detailed analysis of the academic literature on BIM that is relevant to the study. The application of BIM in the various stages of construction projects is considered as well as the purported benefits of BIM and challenges experienced around the world in implementing the technology. Numerous strategies have been used by stakeholders in the private and public sectors across the world to overcome the barriers towards BIM implementation. The review therefore further discusses these strategies and approaches by governments, statutory councils and policy makers in order to increase the uptake of the technology.

2.1 Building Information Modelling (BIM)

The exchange of information amongst professional team members in the AEC sector has been historically based on two-dimensional (2D) drawings. Recently, three-dimensional (3D) models have increasingly adopted by architects and engineers for design purposes. BIM, which is the practice of building information modelling, applies systems and tools that enable the modelling of buildings in 3D, allowing architects and engineers to coordinate design functions, share information and also assist with accurate quantity take-offs. In essence, BIM can be defined as a set of interacting policies, processes and technologies used to communicate information to project stakeholders throughout the project's lifecycle (Cerovskek, 2011).

While BIM incorporates 3D modelling, it differs from 2D drawings and 3D models in that it defines and applies intelligent relationships between all elements in a building model (Singh et al., 2011). Geometric (e.g. building dimensions and elevations) and non-geometric data (e.g. object attributes, specifications) are therefore contained in the same model. According to Singh et al. (2011), the benefit of using BIM over other technologies is that it significantly reduces the number of design errors and technical flaws.

2.1.1 BIM implementation maturity levels

Succar (2009) developed a conceptual framework that describes BIM implementation maturity levels. It basically consists of *stages* and *steps*. The relevant BIM stages detailed by Succar (2009) are summarised in Table 1:

Table 1: Conceptual framework for describing BIM implementation maturity levels (Succar, 2009)

BIM stage	Name	Description	Example/Application
Stage 1	Object-based modelling	Involves single disciplinary modelling expertise	Architect developing and sharing a Revit model with other AEC professionals
Stage 2	Model-based modelling	Multiple disciplines collaborate to produce a model with interoperable interchange.	Sharing of data between an architect and engineer
Stage 3	Network-based modelling	The development of interdisciplinary models which are significantly rich in model data and integration through dedicated model server technologies. At this stage models would comprise data.	Examples of data model data at this stage includes data on model intelligence, lean construction principles and, whole life costing, etc.

The main characteristics under each stage shown in Table 1 are that in Stage 1 modelling encourages "fast-tracking" from design to construction, in Stage 2 *the need* for collaboration instigates "fast-tracking" from design to construction whilst in Stage 3 the integration of various disciplines enforces "concurrent construction".

Figure 2 shows the three BIM fields or steps that need to be taken within each stage in order to implement BIM (Succar, 2009). These steps are represented as a venn diagram with *technology, process* and *policy* fields. These are the same fields described by Cerovskek (2011). Within the *technology* field there are software, hardware and network considerations to be made. In the *process* field there are leadership, infrastructure, human resources and products and services factors. The *policy* field includes contractual, regulatory and preparatory factors that need to be taken into account.

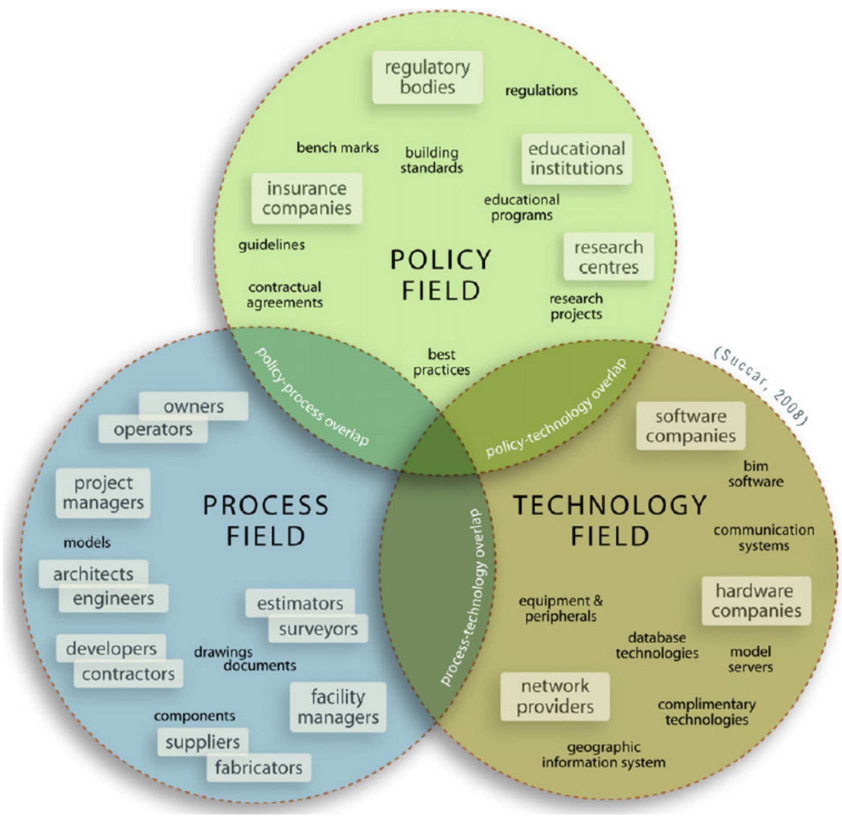

Figure 2: Venn diagram of the interlocking fields of BIM activity (Succar, 2009)

Succar (2009) also developed the matrix hereafter which shows a conceptual framework of BIM maturity as a network of stages (on the vertical axis) and steps (on the horizontal axis). The matrix is shown in Figure 3:

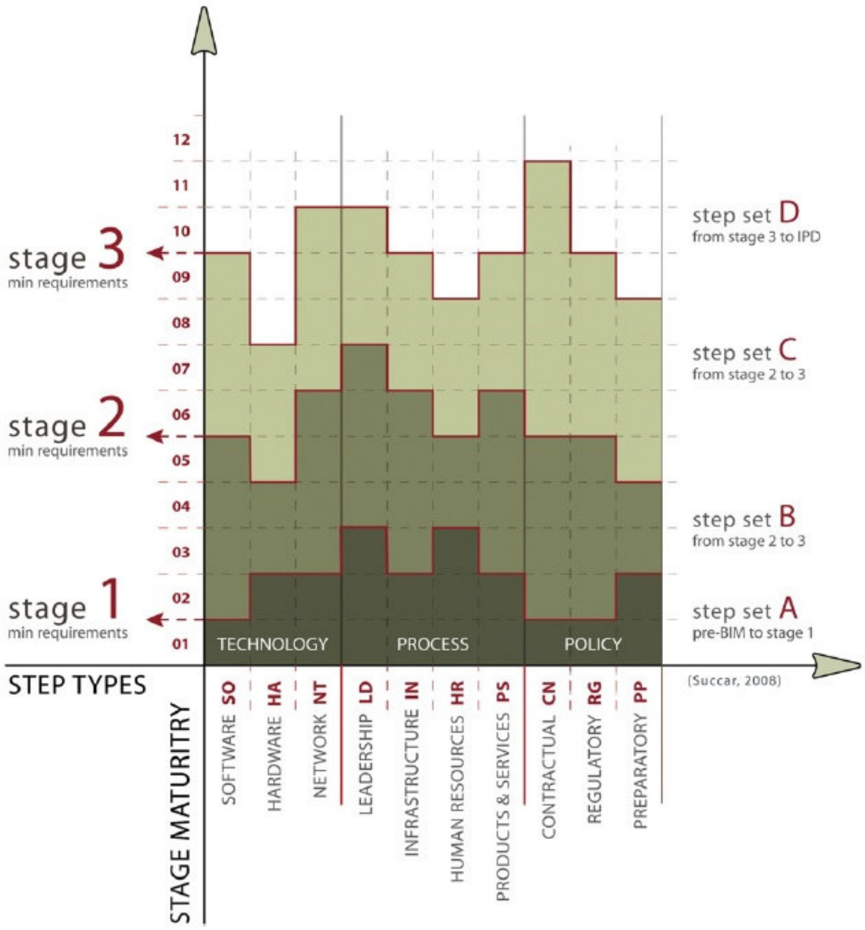

Figure 3: BIM stages and steps – matrix view (Succar, 2009)

This conceptual framework helps explain why a number of western countries are considered to be more BIM mature than South Africa. It is largely due to the fact that there are higher levels of collaboration between disciplines and complexity of data models produced (Stages 2 and 3) as well as progressions made in the implementation *steps* e.g. with more advance BIM implementation policies. Figure 3 shows the need for more technology, process and policy requirements for *step set A* in contrast to *step set B*. Architects mostly use tools like to Revit and ArchiCAD to produce models that can be shared with other

AEC stakeholders who have compatible software. These models are however, to a large extent, used to extract 2D drawings for use by other AEC stakeholders. It may therefore be said that South Africa is less BIM mature than western countries where BIM is being used.

For design and construction, BIM is more easily understood in terms of dimensions: 3D, 4D, 5D and 6D (Cerovskek, 2011):

- 3D – Design models and space programming tools, i.e. the use of spatial dimensions of width, length and depth to represent a model, which enables 3D visualisations and walkthroughs, clash detection and coordination, and item scheduling.
- 4D – This is 3D plus “time”. It refers to the ability to link the individual 3D parts or assemblies with the project delivery timeline, including the scheduling of resources and quantities, and modular prefabrication to assist tracking and project phasing. In addition to collaboration, 4D visualisations of the model function as communication tools to reveal potential bottlenecks. Both planners and contractors can use BIM onsite for verification, guidance and tracking of construction activities.
- 5D – This is 4D plus “cost”. This allows for the integration of design with estimating, and scheduling and costing, including the generation of material quantities and the application of productivity rates and labour costs.
- 6D – This is the information needed to use the model in asset operation, which includes specification, maintenance schedules and FM information, taking the asset right through to remodel or disposal.

As discussed, BIM usage in the construction industry is dependent on the level of maturity in the market (Porwal & Hewage, 2013). Another framework that describes BIM implementation maturity is that developed by the BIM Task Group developed under the UK’s Her Majesty’s (HM) Government Department for Business, Innovation and Skills (2011). This framework outlines three levels of BIM implementation maturity and reinforces the BIM stages and steps outlined by Succar (2009) as follows:

- Level 1 - Level 1 BIM involves the sharing of 2D computer aided design (CAD) files by AEC professionals. Drawings and other specifications are distributed electronically via electronic mail or other web-based file-sharing sites.
- Level 2 – Level 2 BIM involves “data” sharing as opposed to Level 1 BIM where there is simple “file” sharing. Level 2 BIM provides a single environment where data is shared and is accessible to all project stakeholders. The data files that are produced to integrate design, construction and operating instructions, and facilities management information.
- Level 3 - Fully open process and data integration enabled by ‘web services’ compliant with the emerging IFC/IFD standards and managed by a collaborative model server. Level 3 could be regarded as integrated BIM (iBIM), potentially employing concurrent engineering processes.

In short, Level 1 is current practice, flat drawings and paper exchange moving toward some 3D CAD working. Level 2 has individual models which are created in isolation and then exchanged and combined amongst project team members. In contrast, Level 3 is fully integrated with the model being created and managed in the same virtual space.

Figure 4 shows the different BIM maturity levels with examples of corresponding tools used at each level, as well as the envisaged outcomes.

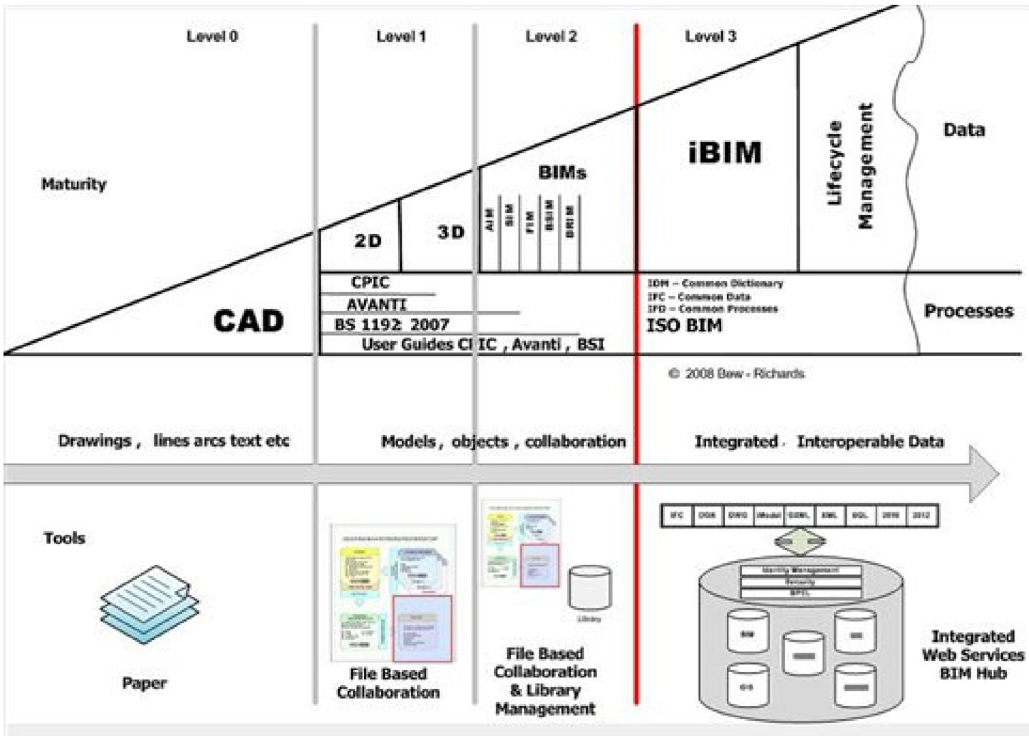

Figure 4: BIM maturity levels (Department of Business, Innovation and Skills, 2011)

Level 2 BIM is currently under-utilised in the South African AEC sector (Kotze, 2013). A significant amount of time and resources are wasted in sharing 2D files by AEC professionals which makes the planning and coordination of construction activities more difficult particularly on complex projects. There are better methods of working that are available via collaboration but these are currently under-utilised. Additionally, the adoption of Level 2 BIM in the South African AEC industry would result in innovative ways of working in terms of the collaboration of design teams, construction methodologies, development of BIM tools, software development, knowledge management and sharing, etc.

2.2 BIM implementation around the world and in South Africa

BIM has capabilities which can improve the efficiency of building output by providing price certainty and value for money (Mcauley et al., 2013). In addition. BIM has the capacity for increasing sector competitiveness to enhance activity and output (Fouche et al., 2011). One point of consideration is BIM's impact on the construction industry and the potential for economic growth. Saxon (2013) asserts that BIM implementation can lead to economic growth and argues that the UK government's BIM implementation strategy will lead to growth in both the import and export markets. According to Saxon (2013), the UK's built environment, which includes property, construction facilities and management sectors, contributes about 15% of the gross domestic product (GDP). Increased economic growth can thus be seen in terms of:

- added value to clients, reduction of costs and risks associated with the delivery of construction projects,
- digitisation of the built environment's asset base, leading to the development of a so-called 'smart economy' which can be managed more effectively in order to optimise performance,
- increase in construction activity through more competitiveness in the AEC sector, and finally
- development and sale of BIM products locally in order to reduce costs associated with the licensing of foreign BIM products (software applications) and technology implementation costs.

The South African economic industries where BIM can be applied are construction, real estate services and mining. These contribute approximately 25% of South Africa's GDP (Statistics South Africa, 2013). Although South Africa is yet to reach the maturity levels of the developed nations, Saxon's (2013) view that BIM implementation would lead to economic growth is logical. Fouche et al.'s (2011) show that technology management and improvements promote industry growth through increased competitiveness. The benefit of promoting BIM to the South African government would be improved levels of competition and efficiency in the AEC industry leading to better delivery of public and private sector projects.

BIM is a system that has been gaining much global support in terms of research and implementation (Wong et al., 2011). With the aid of government support, BIM is now widely used in countries such as the UK, Australia, Hong Kong and Canada (Porwal & Hewage, 2013). The technology has the capability to assure numerous advantages in terms of “efficient” project delivery. The scope of efficiency relates to improving communication and interaction within professional teams (Manderson et al., 2012), but it also improves inter-project participation between team members.

From the study undertaken by Talukhaba and Taiwo (2009), it may be inferred that BIM has the capability of improving knowledge management functions for construction projects. The term *knowledge management* is used by these authors to refer to processes and technologies used to efficiently deliver projects. Construction activities generally involve big teams with a rapid exchange of information across various disciplines. Good knowledge management would thus lead to the implementation of best practices in projects, good retention of data and transfer of knowledge and skills to beneficiaries.

Barlish and Sullivan (2012) also highlight the benefits that may be derived from using BIM, which include reduced capital expenditure on construction projects. They also provide empirical evidence to show that BIM is quite useful as it generates higher margins of return on investments over a number of years, fewer change orders during the construction phase, and a reduction of project delays due to high levels of design detailing prior to the commencement of construction.

2.3 Challenges encountered in implementing BIM

Despite the numerous purported benefits of using BIM, AEC sectors around the world have experienced a number of challenges to the implementation of this technology. According to Succar et al. (2012) and Rekola et al. (2010), barriers to the implementation of BIM are generally classified into three typical categories, namely process, technology and people factors. Barlish and Sullivan (2012) admit that although BIM has many advantages, one of the biggest threats is that professional teams do not really understand the technology. According to Succar (2009) the reason for the lack of understanding of this technology may be attributed to the fact that in most cases, the scope of BIM research and the definition of capabilities are either too broad or unclear. This then causes confusion amongst some academics and the public (Succar, 2009). Lee and Jeong (2012) also support this view by stating that BIM technology continually faces the risk of being rejected by industry practitioners and clients due to the system not being well understood.

While it is true in theory that one of the most important benefits of BIM is the interoperability of the technology (Rekola et al., 2010; Singh et al., 2011), this is not very practical in most cases because, due to different types of software packages available on the market, it is very difficult to synthesise or integrate various engineering disciplines, as well as architectural and quantity surveying functions (Manderson et al., 2012).

At the initial stages of BIM implementation, the costs of introducing the technology may be prohibitive and could affect the financial viability of construction projects (Olatunji, 2011). Financial viability performance indicators, such as yield (or return on investment) in the first year of operation, internal rate of return (IRR) and return on equity (ROE), could be lower than the expected levels of investment.

Concerns about the high cost of investment in the technology and low rates of return or profit margins have, to an extent, resulted in the adoption of the technology being relatively slow compared to when 2D computer aided design was introduced to the AEC sectors around the world (Rekola et al., 2010). Slow uptake or adoption of new technology is always a problem due to unfamiliarity and the subsequent learning processes required for successful implementation and use of the new product. Also linked with slow adoption of the technology is the lack of support from the private sector (Wong et al., 2009).

Another hindrance to the successful implementation of BIM has been that the forms of contract, e.g. International Federation of Consulting Engineers (FIDIC), Joint Building Contracts Committee Principal Building Agreement (JBCC PBA) and New Engineering Contract (NEC), make it difficult to use BIM (Manderson et al., 2012). Due to this, the procurement and management of construction contracts potentially become considerable challenges in terms of design liability, ownership of data and the delegation of work functions (Gu & London, 2012). Olatunji (2011) also supports this, arguing that the use of BIM presents risks to members of professional teams; i.e. existing professional services contracts do not ideally cater for the use of BIM as there are no clauses in the respective contracts on how risks can be apportioned across teams.

BIM obstacles are greater in small markets where design and construction companies are small and have limited resources to obtain and maintain BIM software tools (Migilinskas et al., 2013). However, such companies are also of the opinion that the development of BIM products alone does not automatically lead to improved BIM implementation. Rather, firms in the AEC industry should change work practices, staff skills, relationships (communication) with clients and project delivery participants, and contractual arrangements (Migilinskas et al., 2013).

In general terms, barriers to the successful implementation of new technology exist which minimise the chances of the widespread adoption of new ways of working. Theories can be applied to show how new technologies can be successfully implemented. Such theories, which are relevant to BIM, are highlighted in section 2.4.

2.4 Theories of innovation and their possible application to BIM adoption

BIM innovation is important due to the fact that design management and project delivery are challenging and complex processes in terms of planning and coordination (Senthilkumar et al., 2010). Slaughter (2000) identifies five different types of innovation found in the construction industry, namely incremental, architectural, modular, system and radical. BIM is a system that links different AEC professions in such a way that it ultimately changes traditional project delivery methods and may, therefore, be classified as a combination of architectural, system and radical innovations.

According to Bossink (2004), the importance of innovation is to improve the speed of project delivery and economic efficiency on fast track projects. There are various threats to the growth of innovation in the construction industry. These include architects and engineers being time pressured by clients to produce detailed designs for fast track projects, inadequate finance support, and a lack of expertise and communication within project teams (Blaise and Manley, 2004).

Innovation has been applied in the development of the Design Structure Matrix (DSM) and subsequent modifications leading to design interface management systems (diMs). According to Senthilkumar and Varghese (2013), diMs form the drawing DSM (DDSM) which is based on a *system* approach and structured process. The disadvantage of DSM methodologies and tools is that it is difficult to implement on complex construction projects due to the difficulty in identifying and implementing interdependencies across AEC disciplines (Senthilkumar & Varghese, 2009; Senthilkumar et al., 2010). In place, diMs can be used on complex projects. BIM is a system approach to design which creates dependencies and allows for better collaboration and innovative ways of working between designers and engineers.

Academic researchers have identified many theories that describe how barriers to the implementation of BIM were overcome, leading to the increased adoption and growth of the technology. Table 2 summarises theories identified, providing brief descriptions and application to BIM studies undertaken in the past.

Table 2: Theories used in addressing challenges to BIM implementation

Theory	Author/s that used the theory in BIM context	Brief description of theory	Application to BIM study
Acceptance Theory	Lee and Jeong (2012)	Authority does not depend on the person giving orders but rather on the willingness of those who receive orders to comply.	The acceptance of BIM technology is ultimately determined by people's attitude to change.
Reward Theory	Oti and Tizani (2010)	Looks at how people are motivated. It states that people will react positively if rewarded.	Collaboration between the public and private sector is vital for BIM development. The two sectors will engage beneficially with each other if compensated accordingly.
Systems Theory	Succar et al. (2010)	Provides for a systems thinking approach to solving problems.	BIM consists of three interacting fields (Succar, 2009). A systematic approach must be used

Theory	Author/s that used the theory in BIM context	Brief description of theory	Application to BIM study
			for developing BIM frameworks. The standardisation of certain workflows helps define the content of policy documents by outlining the desired deliverables.
Diffusion Innovation Theory	Succar et al. (2010); Kale and Arditi (2010); Linderoth (2010)	This theory attempts to explain how and why new technologies spread, as well as the rate at which this takes place.	BIM adoption rates are affected by different factors. In the context of this study, if the barriers to implementation are overcome, then the rate of adoption of BIM will increase.
Technology Acceptance Model	Succar et al. (2010); Lee et al. (2012)	Acceptance models are frequently used in information technology (IT). These models show stages of acceptance of new technology by users.	The acceptance of BIM is based on internal and external factors. Acceptance models need to be done for every market in which BIM is deployed.
Complexity Theory	Succar (2009); Succar et al. (2010); Singh et al. (2011)	This model studies "complex systems".	BIM is a complex system which requires multi-disciplinary collaboration from professional team members. Where

Theory	Author/s that used the theory in BIM context	Brief description of theory	Application to BIM study
			frameworks or guidelines are developed for the implementation of the system, they must simplify the process of utilising the system.

2.5 Strategies and policies to increase BIM adoption

Many benefits and drivers for BIM implementation are understood from a theoretical point of view through literature on the subject, but there is limited quantitative data available with which to evaluate and rank the order of importance of the drivers for BIM implementation (Eadie et al., 2013). Eadie et al. (2013) observes that the drivers for BIM implementation change from adoption at the initial stages to after experience has been gained in using the technology. In the initial stages, pressure from clients, e.g. the government, to use BIM is a key driver. This view is supported by, for example, the UK government's mandate that centrally procured construction projects in the public sector are to be delivered using Level 2 BIM by 2016. After BIM has been initially adopted, the drivers for its growth depends on individual organisational requirements, e.g. improving design quality, cost savings through reduced work and design clash detections. The Diffusion Innovation Theory highlighted in Table 2 can be used to explain the adoption and growth of technology.

Slaughter (2000) proposes a systematic approach to implement as the use of new technologies becomes available in the market place. BIM implementation requires a "technological paradigm shift" flowing though these stages:

- Evaluation of current methods and proposed tools.
- Identification of the type of technology (such as BIM) and software to use.
- Commitment through investment in new technology.
- Detailed preparation prior to implementation of new tools.
- Actual use.
- Post-use evaluation.

There are different views amongst scholars and public authorities about the relationship between regulations and innovation in the built environment. According to Migilinskas et al. (2013), regulations are sometimes deemed to be burdensome and a hindrance to innovation and development.
Strict enforcement of BIM guidelines and standards by the government is essential in implementing new technology. Migilinskas et al. (2013) is of the opinion that government intervention in the development or implementation of guidelines for BIM usage is required due to the industry's (private sector's) failure to invest in new technologies. They argue that distinctions need to be made between the content of standards and the process of administering them. Performance standards are generally good for encouraging a systematic technological change (Migilinskas et al., 2013).

An element of risk sharing between the public and private sectors is required in order to implement new technologies such as BIM (Singh et al., 2011). While the government may be instrumental in developing frameworks and policies for BIM deployment, the private sector must show willingness in adopting new work practices. Such willingness may be induced to the private sector through incentives being provided by governments. This notion is supported by Mcauley et al. (2013).

BIM regulations or standards are used in different developed countries with the support of their respective governments. Various organisations have developed and defined national standards and regulations which need to be adhered to for effective BIM implementation (Glema, 2013). Such government agencies include the General Service Administration (GSA) in the USA, Statsbygg in Norway, the Danish Building and Property Agency in Denmark, and Senate Properties in Finland (Glemma, 2013). To elaborate further, in the USA, the GSA mapped a way of enhancing BIM capability by moving from a document based to a model-based delivery of designs (US GSA, 2014). In 2003, the *BIM Guide Series: National 3D-4D BIM Program* was developed to support 3D and 4D BIM implementation (US GSA, 2014). In addition, according to Glemma (2013), national and international standards for digitisation or modelling of buildings have also been documented by professional agencies such as the American Institute of Architects (AIA) in the USA, the Construction Industry Council (CIC) in the UK, and Fiatech and BuildingSMART (bSI) with the aim of improving the exchange of information in the AEC industry.

2.6 Public-private sector collaboration for BIM implementation strategies

One of the most important factors that would contribute towards the success of BIM in South Africa would be the development and implementation of national BIM guidelines. Wong et al. (2011) provide steps on how governments can implement BIM programmes via the development of policies/strategies for each life cycle phase of a project or level of maturity of the construction industry. Therefore, it would be expected that the type and size of BIM-related problems encountered would vary from time to time.

McAdam (2010) argues that government support is needed to formulate the legislative framework required for BIM implementation. He contends that the use of BIM requires collaborative partnering between the government and the private sector. It is such links that Oti & Tizani (2010) deem necessary to incentivise so that deep level of interaction between the two groups will be promoted. The roles of the private sector include developing new business processes and opportunities, creating partnerships and cooperating with researchers, while the role of the public sector includes initialising the implementation of BIM in public sector projects and policy creation (Succar, 2009).

The importance of a sound legal framework is also highlighted by Olatunji (2011) who posits that even if governments initiate the usage of BIM to complete public sector construction projects, the use of the technology will ultimately fail without a framework supported by the government. Part of the value provided by frameworks and guidelines for usage and implementation is to reduce the occurrences of poor coordination, and errors and risks associated with traditional contractual arrangements (Porwal & Hewage, 2013).

Although BIM frameworks are important tools to overcome barriers to the implementation of BIM, problems have been encountered when “non-coherent” or too generic guidelines have been used (Succar, 2009). In addition, Succar (2009) determined that, in most cases, it is difficult to assess the overall benefits of BIM because there are very few or no comprehensive measuring tools included in frameworks which allow for the systematic investigation or quantification of the benefits of using the technology.

In another study, Succar et al. (2012) argue that BIM is a set of “interacting circles” between policies, processes and technology whose benefits in each of the interacting circles should be ascertained by users of the system in order to evaluate whether project objectives are being met. Barlish and Sullivan (2012) and Jung & Joo (2011) are proponents of measureable target areas being included in BIM implementation frameworks and standards. An essential measurable target is financial performance, thus looking at whether a project is delivered within budget and calculating the return on investment through use of BIM technology (Barlish & Sullivan, 2012). Another important area that should be measured is productivity which impacts on on-time project completion and quality of output (Jung & Joo, 2011).

BIM standards used in one country should not however be used automatically in another country (Howard & Bjork, 2008). Succar (2009), for example, explains how different countries or regions will have varied levels of maturity which determines how to use BIM and technology advancement. Regardless of the varying maturity levels, BIM guidelines also need to conform to international standards (Cerovsek, 2011).

Some of the leading western countries in developing BIM implementation standards are the USA and UK. The General Services Administration (GSA) in the USA has developed a series of guidelines for its BIM implementation programmes (GSA, 2014). According to the GSA (2014), the following guides have been published and applied to over 100 projects in the USA since 2003:

- Series 1 – 3D-4D BIM overview.
- Series 2 – Spatial program validation.
- Series 3 – 3D Laser scanning.
- Series 4 – 4D Phase.
- Series 5 – Energy performance operations.
- Series 6 – Circulation and security validation.
- Series 7 – Building element.
- Series 8 – Facility management.

In the UK, BIM implementation guidelines were published by the British Standards Institute (BSI) in line with the National Building Specification (NBS) requirements. According to BIM Talk (2014), the following standards are essential in implementing Level 2 BIM:

- PAS 1192-2 which specifies requirements for achieving Level 2 BIM by focusing on the project delivery phase.
- BS 1192-4 which details how information for design models should be developed collaboratively in order to meet client requirements.

It is therefore important for the relevant South African AEC stakeholders to understand how BIM standards and guidelines have been developed so that they can develop their own set of local guidelines or frameworks with the aim of promoting successful BIM implementation based on current maturity levels.

As discussed, the creation of BIM guidelines is one of the most important factors to promote the success of implementation of the technology. Government initiation alone will not guarantee the success of the technology without the necessary framework to support it. With the South African market being “immature” in terms of BIM utilisation, it is most likely that the same problems as those highlighted above will be experienced. This assumption is based on the study done by Porwal and Hewage (2010) which assumes that when new technology is introduced, it will encounter problems related to the low absorption rate of the implemented system. AEC industry adoption rates vary significantly from country to country due to factors such as levels of education or training and the extent or types of initiatives instituted by industry stakeholders (Gu & London, 2010).

Slow absorption rates may be attributed to unwillingness to change work practices, rigid organisation structures, and non-dynamic team structures. To overcome these BIM implementation barriers, it is very important that the South African government support the introduction of the new technology. This would follow examples set in countries such as Australia, Hong Kong, Canada, UK and the USA which have led to widespread use and acceptance of the technology by AEC professionals in these countries (McAdam, 2010; Wong et al., 2011; Porwal & Hewage, 2013). The UK government has, for example, planned a five year phased programme which would make it a legal requirement to use BIM tools and techniques by 2016 (Mcauley et al., 2013). Macauley et al. (2013) further add that in support of this initiative, a BIM academy has been established to ensure that the 2016 target is met.

As outlined above, one of the biggest challenges to BIM adoption is the lack of knowledge and training. The role of government is therefore quite important in setting up bureaus of research to improve BIM knowledge (Howard & Björk, 2008). This may be encouraged by incentivising collaboration between universities and the private sector using the Reward Theory as advocated by Oti & Tizani (2010). This would build up the body of knowledge in the AEC sector, improve education and increase peoples' willingness to accept new technology.

One of the most important strategies by governments around the world in implementing BIM in their respective markets has been initiating usage of the technology in public sector projects (Wong et al., 2011). Macauley et al. (2012) also support this view. In South Africa, spending on infrastructural projects is critical for balanced economic development, unlocking economic opportunities and promoting job creation, amongst other benefits. During the period 2013/14 the South African government, through the National Infrastructure Plan, intended to spend R827 billion on building new and upgrading existing infrastructures. The New Growth Path (NGP) was prepared by the South African government to improve the nation's economic performance as well as accelerate technological change. The government is targeting a reduction in unemployment by increasing output in key sectors, thereby improving economic performance (Economic Development Department, 2011). The construction industry is one of the key sectors identified to improve economic performance through the construction of public sector property and relevant development.

BIM is potentially a useful tool to achieve desirable spending and growth targets by enhancing planning capabilities. Infrastructure programmes can be delivered on time and within budget constraints. Should the government make BIM a requirement for the delivery of public sector projects, it forces AEC practitioners to adopt the new technology so as to get work from the government as a client.

2.7 Summary and conclusion

This chapter fundamentally described the levels of BIM implementation maturity. The literature reviewed shows that there are three levels of BIM implementation maturity and that the steps within each stage need to be observed in order to successfully implement BIM (Succar, 2009; Department of Business, Innovation and Skills, 2011). It was also established that South Africa has a low level of BIM implementation maturity compared to some western countries. This is evident from the higher levels of collaboration and more developed systems and tools as well as defined BIM policies that are in use in the AEC sectors in countries such as the USA, UK, Canada, Germany and Finland. South Africa currently has Level/Stage 1 BIM implementation maturity whereas the more BIM markets are at Level/Stage 2. Traditional methods of construction project delivery used in South Africa often result in a vast amount of revisions during the design and implementation stages which results in time and cost overruns.

Automation of construction and innovation though BIM generally results in lean efficiency gains for the delivery of construction projects in terms of eliminating waste, improvements in decision making, communication and speed of delivery (Arayici et al, 2011). Although BIM has a lot of potential benefits for users and clients, there are many challenges to its implementation, particularly in South Africa. Various strategies for BIM implementation that have been used around the world were discussed. Government implementation used in strategies where BIM is used more effectively were also reviewed.

Figure 5 was summarises the literature reviewed. It shows BIM implementation strategies that can be used in the AEC sector that follows a methodical approach from identifying problems and benefits to final implementation.

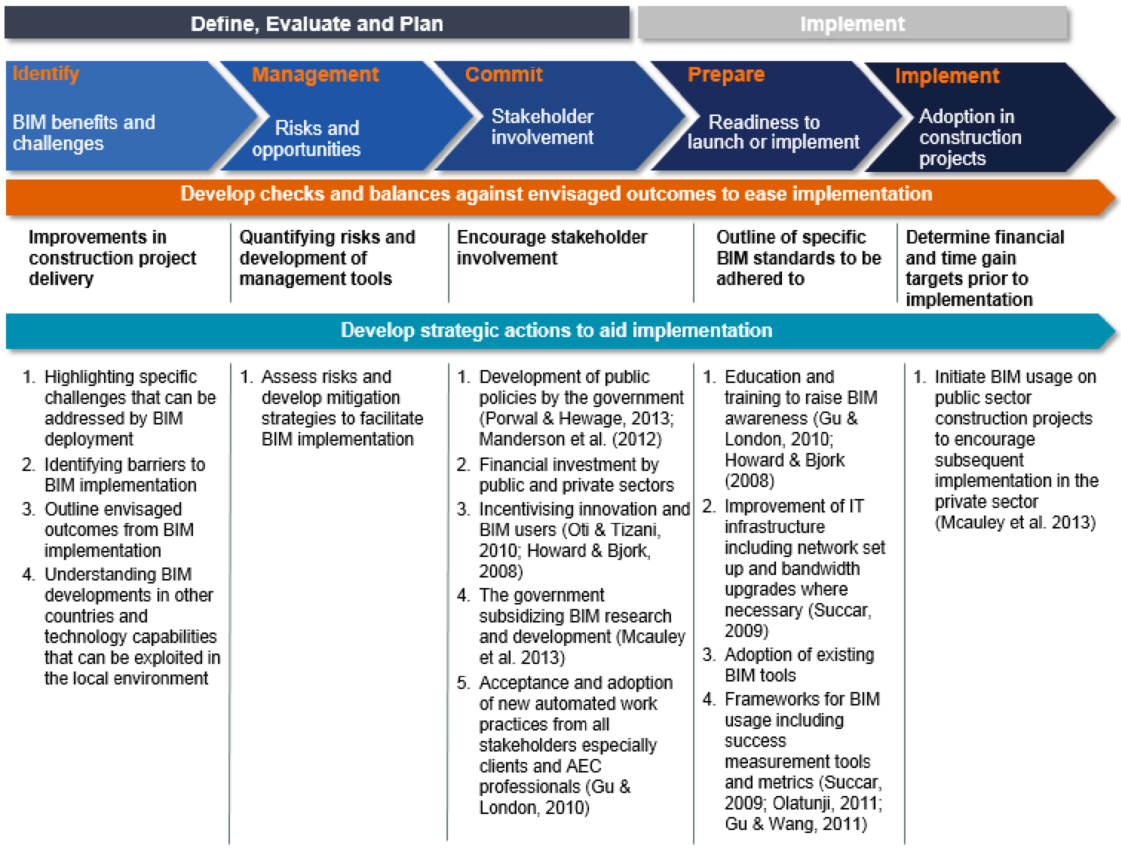

Figure 5: BIM implementation strategies from the reviewed literature

Additionally, based on the literature reviewed, BIM challenges are summarised in Table 3, as well as government intervention strategies to ensure successful implementation of the technology.

Table 3: Summary of BIM challenges and implementation strategies

Challenges	Strategies	Government intervention
Unwillingness from AEC professionals to change current work practices (Gu & London, 2010).	Understanding drivers for BIM implementation that apply to the market (Eadie et al., 2013).	Mandating BIM usage requirements (Mcauley et al., 2013; Gann et al., 1998).

High costs associated with implementing new technology systems (Olatunji, 2011a).	Developing, adapting or adopting systematic flow processes for BIM implementation from markets that are similar in nature and maturity to South Africa (Succar, 2009; Slaughter, 2000).	Developing and driving BIM procurement and implementation guidelines (Mcauley et al., 2013).
Standard forms of contract are not drafted to take into account BIM usage within professional teams where aspects such as design liability, data ownership and delegation of work functions are important (Manderson et al., 2012).	Developing regulations that conform to ISO standards (Cerovsek, 2011).	Initiating usage on public sector projects.
Low levels of training and lack of knowledge from users in BIM capabilities (Gu & London, 2010; Talukhaba & Taiwo, 2009).	Incentivizing BIM users (Oti & Tizani, 2010). Private sector involvement through development of BIM tools, e.g. software (Wong et al., 2009).	Developing legislative frameworks, and developing state bodies or agencies that oversee compliance with BIM standards (Manderson et al., 2012; Cerovsek, 2011; McAdam, 2010).
Poor commitment from clients to use the technology (Talukhaba & Taiwo, 2009).	Encouraging development of BIM professional bodies that encourage professional development of AEC practitioners and BIM research (Glema, 2013).	Subsidising research and development costs of BIM tools in South Africa. Development of government mandates for BIM implementation (Porwal & Hewage, 2013).

3 RESEARCH METHOD

There are numerous approaches to research. The choice of the most appropriate research methodology depends on the type of data that is being sought (Saunders et al., 2012). This chapter presents four key methodological elements that were chosen so as to obtain data to meet the research objectives, namely research philosophy, approach, methodological choice and ultimately the strategy used to gather data.

3.1 Research philosophy

The research philosophy fundamentally looks at the application of the "research onion" as developed by Saunders et al. (2011). According to Saunders et al. (2012), research philosophy is *"the development of knowledge and the nature of that knowledge"*. At global level, BIM studies and research are varied, ranging from policy creation, system benefits, and challenges of using the technology to academic proposals of how to implement the technology.

Current methods of delivering construction projects in South Africa are inefficient from a time and cost perspective. One way of reducing these inefficiencies is by automating construction activities through BIM implementation. However, there are numerous challenges and barriers to BIM implementation that have been experienced around the world that would also affect South Africa. Governments around the world where BIM has been implemented have taken lead roles in getting the technology implemented in their respective AEC sectors. Therefore, this study contributes to the development of BIM knowledge in South Africa by gaining an understanding of the possible mandatory initiatives that can be instituted by the South African government for successful implementation of BIM technology. Possible strategies for BIM implementation by the public sector are drawn up based on attitudes and opinions of industry experts, including contractors, architects, quantity surveyors and engineers.

Evaluation of the research and sub-research questions

The epistemology (i.e. what constitutes acceptable knowledge in the field of study) influences the philosophy. With regard to the epistemology, the positivist philosophy was chosen for this study, as it enables the views and methods of gathering data presented to be objective and independent of "social actors" (Saunders et al. 2012).Positivism looks at only observable phenomena that can provide credible objective facts (Saunders et al., 2012). In order to successfully implement BIM in South Africa, it is believed that credible facts based on observations of the BIM phenomenon need to be obtained so as to gain full support from all BIM stakeholders in the AEC sector.

According to Saunders et al. (2012), observations have to be quantifiable leading to suitable statistical analysis when using a positivist philosophy. The research philosophy adopted in this work leads to the research methodology being quantitative and highly structured in nature.

3.2 Research approach

An inductive research approach was most suitable for the study as it showed the appropriateness of the chosen approach (Saunders et al., 2012). Levin-Rozalis (2010) states that induction is used in instances where there are empirical generalisations and phenomena whose range of variances is already known. However, given that there is very little academic literature on the utilisation of BIM in South Africa, which is in this case the “phenomena” under investigation, the benefits and barriers to implementation are not so well known from a South African context. The inductive research approach was therefore used to meet the research objectives, as the study looked at BIM adoption readiness in South Africa and the specific attributes that act as promoters or hindrances of the BIM phenomenon in the local market.

3.3 Substantiation of methodological choice

Based on the review of the research philosophy (section 3.1) and approach to be adopted in the study (section 3.2), quantitative research methods were deployed. Quantitative research methods were used on a sample population in order to deduce the general perception of South African AEC professionals on BIM adoption readiness and possible mandatory initiatives for its successful implementation.

The characteristics of quantitative research, as well as how these were applied to the study, are outlined in Table 4.

Table 4: Characteristics of quantitative research and application to BIM study

Characteristics	Application to the BIM study
It helps develop a conceptual framework.	To provide a conceptual framework for the deployment of BIM in South Africa.
Research process may be interactive.	The main research tools to be used in gathering data was a questionnaire.
Researchers normally depend on communication with respondents.	Communication with respondents was important in order to administer the questionnaire and to make sure that all respondents understood or interpreted questions in the same way.

3.4 Nature of research design

This study was explanatory in nature due to BIM being a relatively new concept in South Africa. Explanatory studies help review existing knowledge and provide insights about topics of interest which, in this case, is BIM.

3.5 Research strategy

There are two types of research strategies associated with quantitative research i.e. survey and experimental research strategies (Leung, 2001). The survey method was employed to meet the set out objectives because this technique is commonly used for explanatory research. The main research tool used for data collection was a questionnaire as it supported the positivist philosophy which was adopted.

Characteristics of the questionnaire

Leung (2001) explains that questionnaires are a commonly used instrument for observing data from a distance, which reduces costs and time for associated with researchers travelling to all correspondents. He explains further that questionnaires often have standardised answers that make it simple to compile data. There is a likelihood that the standardised answers may frustrate users so to avoid this Kennedy (2006) and Leung (2001) outline the main guidelines for setting up a questionnaire. They emphasize that the language should be clear and concise so as to obtain the exact information that the researcher is looking for. Good questionnaires are highly structured to ensure that respondents answer questions in the same way and to allow for the data to be analysed quantitatively and systematically (Leung, 2001).

Ordinal data was gathered using the Likert scale (strongly disagree, disagree, neither agree nor disagree, agree and strongly agree). The researcher assumed that ordinal scale from the questionnaire could be used as an interval scale by assigning an equal variance of one between each Likert item. Converting ordinal data scales into intervals has been applied in previous BIM studies by authors such as Ahmad et al. (2014). They conducted an exploratory study on the key factors that can enhance a designer's role when designing flexible spaces in healthcare facilities in the UK with the use of BIM. They used a questionnaire survey to gather data from a sample that consisted of architectural firms and academics in the built environment. The questionnaire collected both quantitative (closed questions) and qualitative (open questions) data. For the closed questions, the respondents were requested to rate their agreement with statements using a five-point Likert scale. Ahmed et al. (2014) converted the ordinal scale into an interval scale by assigning and equal difference of one between each Likert item. The quantitative data were then analysed statistically.

A similar approach to that used by Ahmad et al. (2014) in their BIM study was used in this research to enable the researcher to statistically analyse the data.

Disadvantage of quantitative research methods

The main disadvantage of using questionnaires (survey technique) as part of a quantitative research methodology is that there is a limit to the number of questions that the questionnaire can contain before data becomes prejudiced or compromised. The number of the survey questions was therefore set to nine questions split into four sections.

Selection of participants for the study

The selection of the study sample/s is very important to ensure the credibility of results obtained. Non-probability sampling comprising a purposive (heterogeneous) population group was chosen for the study. The sample chosen was representative of all the AEC disciplines found in South Africa. Non-probability sampling allowed for generalisations about opinions and beliefs with regard to the BIM implementation strategies that need to be developed. Subjective judgement was used to select the respondents which, in turn, enabled the purposive research questions to be answered (Saunders et al., 2012).

3.6 Summary

The research philosophy, research approach, methodological choice and research strategy applicable to this study were reviewed in order to meet the research objectives. A positivist research philosophy was adopted as this allows for quantifiable observations to be made, thus leading to suitable statistical analysis. An inductive research approach was adopted by the researcher and a quantitative research method using a highly structured questionnaire was also employed.

The justification for the methodological choices was that quantifiable data provides a better understanding of South Africa's readiness for Level 2 BIM adoption. More insight was also gained in possible mandatory initiatives that can be deployed to overcome the barriers to BIM implementation in order to successfully implement the technology.

The *"research onion" (*Saunders et al., 2012) was applied to this study to depict the methodological choices made for this study. The concept of the research onion is summarised in Figure 6.

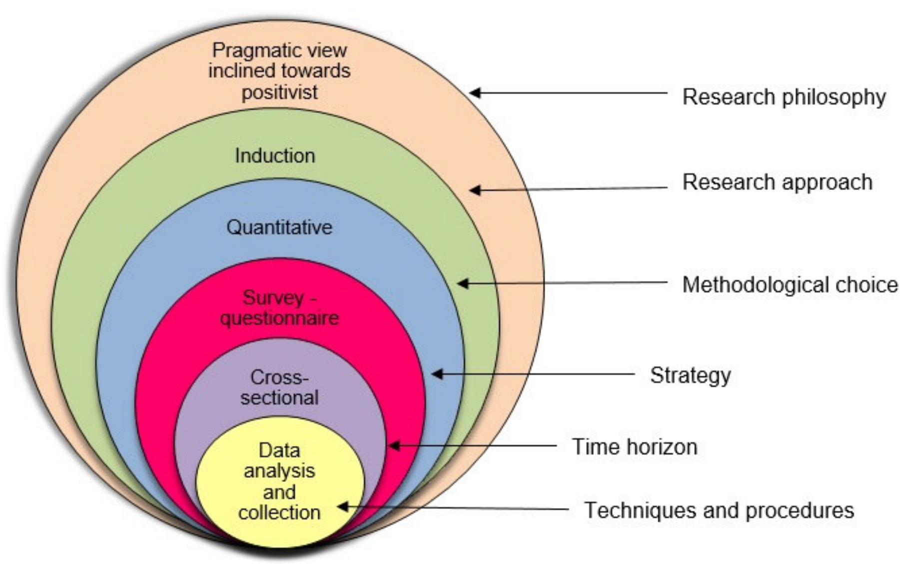

Figure 6: Representation of the research method

Finally Table 5, summarises the research objectives, strategies and techniques applied to this study to meet the objectives, as well as data and ethical considerations applied to this study.

Table 5: Application of the research design

Research objective	To assess the potential benefits of using BIM in South Africa.	To assess the existing information on the BIM maturity level in South Africa.	To explore the possible regulatory strategies adopted around the world to overcome BIM implementation challenges.	To explore the possible regulatory strategies that can be used in South Africa to overcome the identified challenges.
Research strategy	Survey	Survey	Survey	Survey
Research techniques	Quantitative	Quantitative	Quantitative	Quantitative
Population	AEC professionals, software developers, engineers	AEC professionals, software developers, engineers	Architects, engineers, software developers	AEC professionals, software developers, engineers
Sampling plan	Non-probability sampling –	Non-probability sampling – purposive	Non-probability sampling – purposive	Non-probability sampling –

	purposive sampling (heterogeneous population)	sampling (heterogeneous population)	sampling (heterogeneous population)	purposive sampling (heterogeneous population)
Data collection	Questionnaire	Questionnaire	Questionnaire	Questionnaire
Data Type	Ordinal	Ordinal	Ordinal	Ordinal
Aspects of validity and reliability (possible threats)	Participant error – e.g. timing of administering questionnaires	Participant error – e.g. timing of administering questionnaires Participant bias – e.g. location of where interviews are conducted	Research bias	Participant error – e.g. timing of administering questionnaires Participant bias – e.g. location of where interviews are conducted
Ethical considerations	Informed consent and confidentiality	Informed consent	Informed consent, confidentiality of data and maintenance of anonymity of participants	Informed consent and confidentiality

			Not altering data collected – maintain responsibility in the analysis of data obtained.	

4 DATA ANALYSIS AND DISCUSSION OF RESULTS

This chapters evaluates the data that was gathered using the questionnaire. The analysis is divided into four sections based on how the sub-research questions and questionnaire were developed. Two methods of data analysis were applied. These were:

1. Statistical inferences to analyse data on the benefits of using BIM, barriers to BIM implementation and the BIM adoption readiness of the South African AEC sector.
2. Descriptive statistics and significance testing using one sample one-tailed testing were used to analyse data on the possible mandatory initiatives that can be used to introduce BIM in South Africa.

The last part of the questionnaire invited the respondents to provide any further feedback on how BIM can be implemented in South Africa. Less than 20% of the respondents provided feedback on this section. Due to the low response rate to this part of the questionnaire, this data did not form part of the statistical analysis and results discussed. The exclusion of this section did not affect the final results of the study as data gathered in the preceding sections of the questionnaire was fully completed and was used to answer the research questions.

<u>Restatement of the research questions</u>

The purpose of the study was to evaluate the BIM adoption readiness and possible mandatory initiatives for successful BIM implementation in South Africa. To answer the research questions outlined in Chapter 1, it was important to understand the immediate benefits that could be enjoyed in South Africa from the implementation of Level 2 BIM. Additionally, the researcher also wanted to understand the current barriers to BIM implementation in South Africa, as these barriers vary from one location to another due to BIM maturity levels

(Migilinskas et al., 2013). An understanding of BIM implementation strategies successfully used by western countries was gained from the literature reviewed and this was useful in assessing how similar strategies can be adopted in South Africa.

<u>Summary of responses</u>

The questionnaire was issued to 41 BIM stakeholders consisting of property developers, architects, engineers and quantity surveyors. 32 valid questionnaires were returned by architects and engineers only. This suggests that BIM is predominantly used in the architectural and engineering fields in the South African AEC sector.

4.1 General observations

The questionnaire respondents were requested to indicate their years of experience in using BIM. 50% of the sample had less than five years of BIM experience. The remaining 50% of the sample was equally split between six to ten years and more than ten years of BIM experience. This is graphically shown in Figure 7.

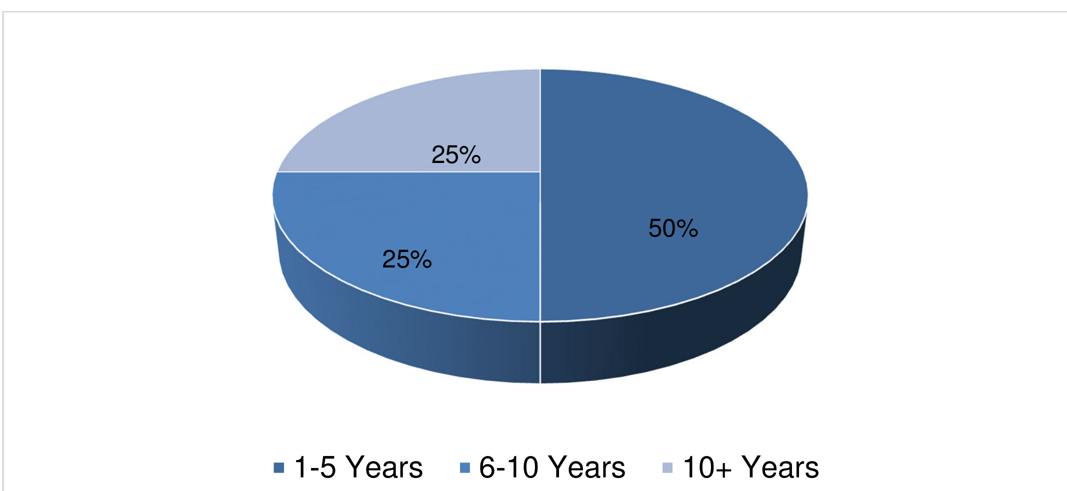

Figure 7: Years of experience of BIM users

The years of experience in using BIM suggests that BIM-based products have been used in South Africa for at least five years in the design fields by architects and engineers. This is notwithstanding the possibility of some AEC practitioners having either gained BIM experience whilst working for international firms outside South Africa before deploying skills in South Africa, or they may be currently working on international projects whilst based locally. Nonetheless, the experienced BIM users are currently based in South Africa and acquired skills are available for application on local projects.

4.2 Benefits of implementation in South Africa

The South African AEC sector predominantly uses 2D and 3D CAD based technologies as a medium of managing project information. It was important to understand what the respondents believed would be the immediate benefits of implementing Level 2 BIM locally.

Using a five point scale where one represents “strongly disagree” and five represents “strongly agree”, the researcher calculated the mean scores and standard deviations of the questionnaire responses. Table 6 summarises the results on the benefits of using BIM in South Africa.

Table 6: Mean scores and standard deviations of benefits of BIM implementation in South Africa

Description	Mean	Standard deviation
Better design management through quick detection of design clashes	4.28	0.46
Providing clients with better value for money	4.78	0.42
Evaluating proposed construction methodologies in terms of practicality and ease of construction	4.00	0.44

Improved communication within project delivery teams (professional consultants and contractors)	4.75	0.44
Better storage of design data throughout the entire built asset's life cycle	4.50	0.88
Ease in outlining project material and resource requirements	4.50	0.51
Better planning of projects prior to construction on site	4.25	0.44
Replacing traditional methods of construction project delivery which are deemed to be inefficient and give rise to time and cost overruns	3.75	0.44
Providing price certainty in delivering construction projects	4.00	0.72
Promoting competitiveness of construction activity in South Africa and subsequent growth of the AEC sector	3.47	0.51

The information detailed in Table 6 is graphically summarised in Figure 8.

Figure 8: Mean scores on the benefits of using BIM in South Africa. Mean scores for each category shown at the end of each bar

Based on the results shown in Table 6 and Figure 8, it is evident that the South African AEC sector would vastly benefit from using BIM to deliver construction projects. Eight out of the ten BIM benefits that were evaluated each had a mean score greater than four. The standard deviations for all potential benefits were less than one. The mean scores and standard deviations show that the levels of agreement were considerably high with minimal variability of the mean scores. Providing clients with value for money, improved communication or collaboration within project teams and better design management were perceived as the most important benefits of implementing Level 2 BIM.

4.3 Barriers to BIM implementation in South Africa

As outlined in the reviewed literature, barriers to BIM implementation vary from one country to another based on the BIM implementation maturity levels (Succar, 2009). It was important to understand the specific challenges South Africa faces in implementing Level 2 BIM.

Using a five point scale where one represents "strongly agree" and five represents "strongly disagree" the researcher calculated the mean scores and standard deviations of the questionnaire responses. Table 7 summarises the results on the barriers to BIM implementation in South Africa.

Table 7: Mean scores and standard deviations for the barriers to BIM implementation in South Africa

Description	Mean	Standard deviation
IT infrastructure limitations such as low bandwidth and data connection speeds	2.75	0.88
Lack of BIM experience and education/training	4.50	0.51
High costs of implementing the new technology	3.19	1.52
Legal and contractual risks to AEC professionals, such as design liability and delegation of work functions in a collaborative setup due to unavailability of professional services contracts that apportion risk amongst BIM users in a team	3.50	0.51
Low levels of commitment from public sector clients	4.00	0.72
Reluctance to change current work practices	4.25	0.44
Unawareness of BIM benefits	2.00	0.5
Limited BIM tools (software packages) available on the South African market	2.5	1.14

Figure 9 graphically shows the mean scores and standard deviations of the eight barriers to BIM implementation investigated in the study.

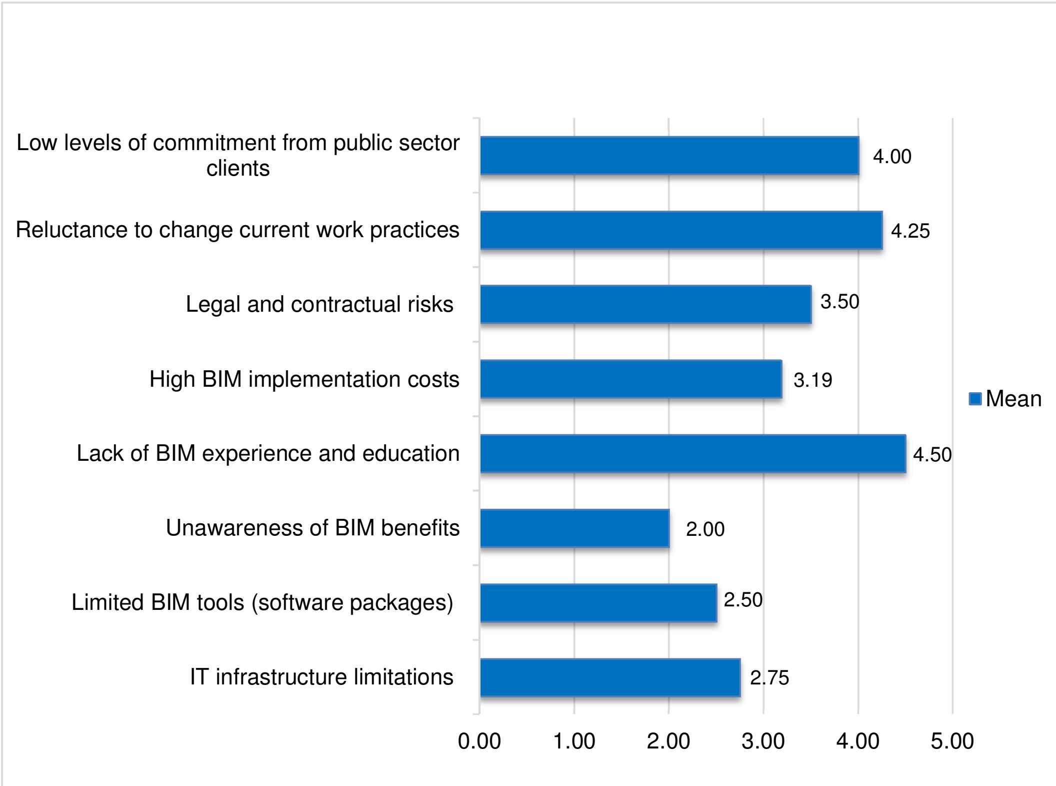

Figure 9: Mean scores of the barriers to BIM implementation in South Africa. Mean scores for each category shown at the end of each bar

Three barriers to BIM implementation had mean scores greater than or equal to four, namely lack of BIM experience and education, reluctance to change current work practices and low levels of commitment from public sector clients. The respective standard deviations were less than one, showing high levels of agreement of responses of these three barriers. Based on the results, the researcher can look at these three barriers to BIM implementation in South Africa and infer that low levels of commitment from public sector clients and the lack of BIM experience, education of training lead to the reluctance to change current work practices and thus a low adoption rate of BIM. The evaluation of this inferred cause and effect relationship is however beyond the scope of this study.

The technology barriers to BIM implementation such as the lack of BIM tools or infrastructure limitations like low bandwidth or data connection speeds cannot be considered as hindrances to BIM implementation. These factors had mean score less than three. This suggests that there is an adequacy of BIM products and supporting systems in South Africa. The unawareness of BIM benefits had a mean score of two, showing disagreement that this cannot be deemed to be a barrier to BIM implementation. This is consistent with the results from section 4.2 which shows that the benefits of using BIM are well known.

The high costs of implementing BIM as well as legal and contractual risks to AEC professionals associated with using BIM had mean scores of 3.19 and 3.50 respectively. Both of these factors had mean scores greater than three which suggests that they cannot simply be ignored as barriers to BIM implementation in South Africa. In other words, these two factors could potentially be very significant depending on the size and financial strength of the firm intending to use BIM.

4.4 BIM maturity and readiness in South Africa

BIM implementation and adoption are dependent on the stakeholders' willingness and readiness to use the technology (Howard and Bjork, 2008). The rate of adoption is also affected by the level of implementation maturity (Succar, 2009). The lower the level of BIM implementation maturity, the lower the adoption rate. The questionnaire gathered data on BIM adoption readiness in terms of current availability of systems and tools to support BIM implementation, and the actual readiness of BIM stakeholders in terms of skillsets, motivation, adequacy of standard forms of contract to use BIM, demand from clients to use the technology, etc.

Table 8 shows the mean scores and standard deviations of the questionnaire responses on the BIM adoption readiness factors for the implementation of BIM technology in South Africa.

Table 8: Mean scores and standard deviations of BIM adoption readiness factors in South Africa

Description	Mean	Standard deviation
Availability of suitable hardware and software technologies to be able to fully take advantage of BIM capabilities	4.25	0.44
Affordability of BIM tools in South Africa	3.75	1.11
Existence of necessary BIM knowledge to aid development of BIM models and data management	3.50	0.88
Adequacy of information technology infrastructure such as bandwidth and BIM servers to support Internet usage of the technology	3.0	1.24
Awareness about BIM	3.75	0.44
Awareness of the benefits of BIM	3.00	1.02
Tools to measure the benefits of using BIM	2.50	1.14
Awareness about the challenges of using BIM	2.75	1.31
Personal motivation to adopt BIM	2.75	0.84
Companies' motivation to use BIM	2.50	0.51
Demand from clients for usage of BIM	2.25	1.11
Support and encouragement of other AEC stakeholders for the adoption of BIM	2.50	1.14
Availability of university graduates with requisite BIM training knowledge	3.00	1.61
Readiness through regulatory mandates	3.00	0.72
Adequacy of standard forms of contract for use with BIM	2.75	0.44
Existence of strategic initiatives for BIM adoption	3.00	0.84

Insistence of statutory approval which mandate the usage of BIM	2.25	0.42
Promotion of BIM awareness through conferences and workshops	3.50	0.88
Existence of standard BIM implementation documents or guidelines prepared by statutory or regulatory authorities	2.75	1.08
Availability of higher education courses in BIM	2.50	1.52

Figure 10 is a graphical summary of the mean scores of BIM adoption readiness factors.

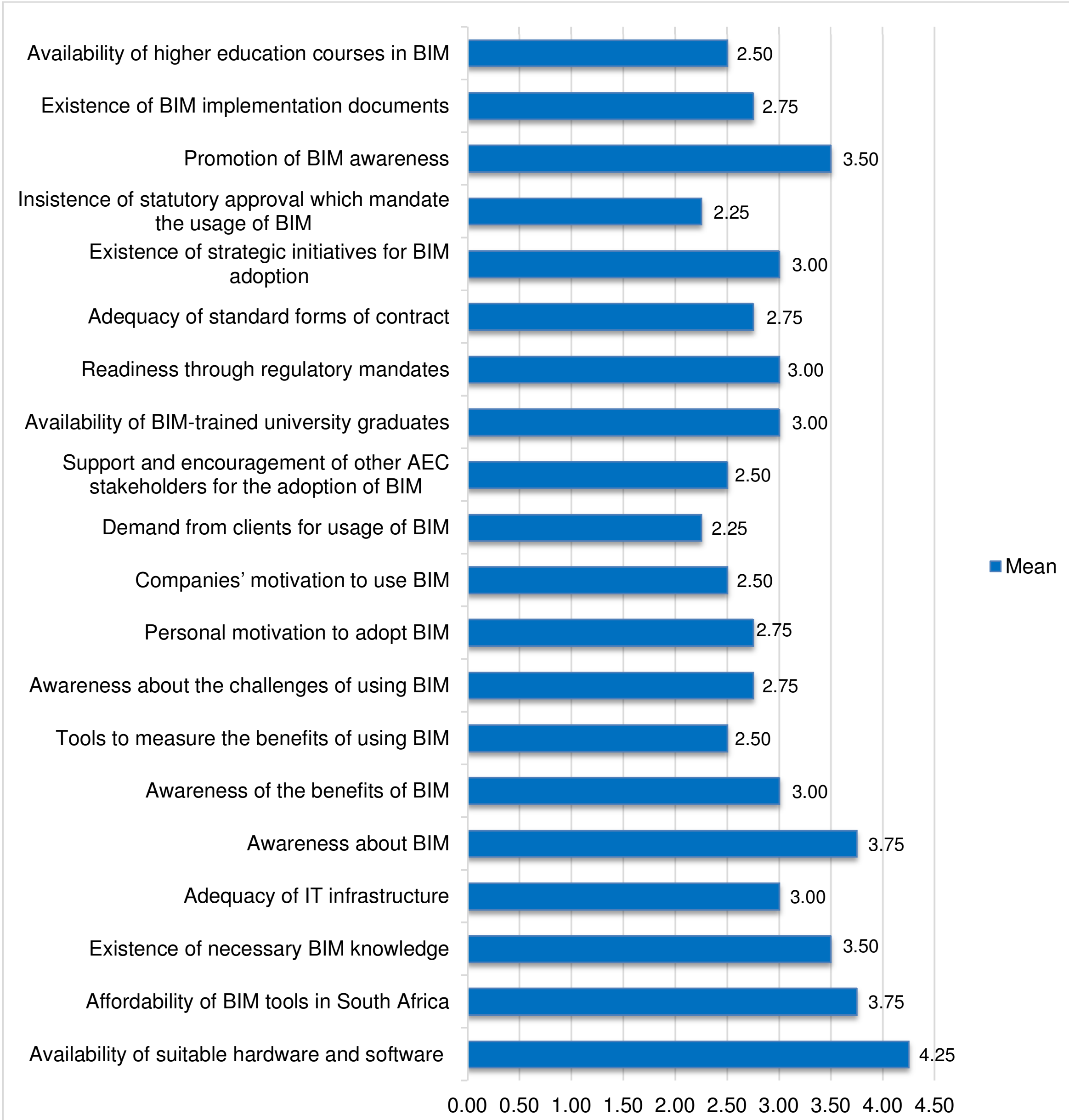

Figure 10: Mean scores of the BIM adoption readiness factors in South Africa

Unlike the results for barriers and benefits of BIM implementation, the mean scores of BIM adoption readiness were mostly between two and four. Consequently, a mean score greater than three was used to evaluate agreement on South Africa's readiness for BIM adoption. The results shown in

Figure 10 and Table 8 highlight that the local AEC sector is only ready in five out of 20 factors. South Africa is currently ready insofar as promotion of BIM awareness, existence of BIM knowledge, affordability of BIM tools, availability of suitable software and awareness of BIM benefits are concerned. These findings are consistent with the results from the preceding sections of this data analysis which showed that people understood the benefits BIM (section 4.2), there is general awareness and expertise in using BIM (section 4.1) and availability of suitable BIM software (section 4.3). However, the South African AEC sector shows signs of non-readiness for BIM adoption due to the high number of factors with mean scores equal to or less than three. Gu et al. (2010) categorised BIM adoption readiness factors in terms of technology, process and people related factors. The non-readiness factors from the gathered data can all be linked to the aforementioned categories. Therefore any mandatory initiatives to promote the successful implementation of BIM must address the barriers to BIM implementation observed in section 4.3 and increase the levels of adoption readiness for all the factors that had mean scores equal to or less than three.

4.5 Possible mandatory initiatives for BIM implementation in South Africa

Mandates for successful BIM implementation can be enforced by regulatory authorities such as the Council for the Built Environment (CBE), professional councils in the built environment, Construction Industry Development Board (CIDB) and Construction Education and Training Authority (CETA). In order to determine the best suited strategies within the South African context, ten BIM implementation strategies were presented in the questionnaire as possible initiatives that can be mandated in South Africa. Based on the literature reviewed, these strategies were considered by the researcher to be important for successful BIM implementation in South Africa and it was anticipated that the respondents would be agreeable with the proposed strategies.
For each possible mandatory implementation strategy, the questionnaire respondents were required to rate each one in terms of importance of being

able to result in successful BIM implementation in South Africa. Each BIM implementation strategy was tested with a cut off value of three. A value greater than three showed agreement thus considered by the respondents to be important for successful BIM implementation in South Africa. The converse was taken to be true for any values less than three, which were interpreted as being not important by the respondents. The researcher therefore hypothesised that the respondents would be agreeable with the strategies proposed in the questionnaire such that the mean rating would be greater than three. Statistically speaking, it was believed that the null hypothesis (H_0) - which is what a researcher tries to disprove (LeMire, 2010) - was that the mean (μ) for each possible implementation strategy was less than or equal to three i.e. H_0: $\mu \leq 3$; and that the alternate hypothesis (H_1) was that the mean was greater than 3 i.e. H_1: $\mu > 3$.

In order to determine which strategies the respondents believed would lead to successful BIM implementation in South Africa, one-tailed one sample *t*-tests were conducted to the data collected. The one-tailed *t*-tests were conducted to a 5% level of significance. The *p-value* that was calculated using statistical analysis software tells us whether to accept or reject H_0 in favour H_1. According to Saunders et al. (2012) and McCrum-Gardner (2008), if the *p-value* is less than 0.05, H_0 is rejected and if it is greater than 0.05 H_0 is accepted.

Table 9 shows the mean score, standard deviation and *p-value* for each possible BIM implementation strategy.

Table 9: One-tailed test results for BIM implementation strategies

BIM implementation strategy	Mean	Standard Deviation	*p-value*	Accept / Reject the null hypothesis
Introduction of BIM implementation studies	4.25	0.84	8.79E-10	Reject
Development of a government centrally led BIM implementation strategy	3.25	1.32	0.15	Accept
Formulation of BIM implementation task groups	2.67	1.27	0.11	Accept
Accreditation mandate in the allied courses at universities	4.00	0.72	3.45E-09	Reject
Administering BIM conferences to increase awareness	4.50	0.51	2.36E-17	Reject
Contractual mandates on governmental projects	4.00	1.02	2.11E-06	Reject
Providing incentives to BIM software users	3.75	0.44	3.78E-11	Reject
BIM training to small to medium enterprises (SME's) and other organisations	3.75	0.84	9.68E-06	Reject
Modifying procurement practices to make best use of BIM technology	3.75	0.84	9.68E-06	Reject
Development of BIM libraries and data exchange frameworks	4.50	0.51	2.36E-17	Reject

From the results obtained, the null hypothesis ($H_{0:}\ \mu \leq 3$) was rejected for eight BIM implementation strategies in favour of the alternate hypothesis ($H_{0:}\ \mu > 3$). This shows statistical significance and that the questionnaire respondents agreed that these eight strategies would lead to increased adoption of BIM and successful implementation of the technology. The lower the *p-value* for a BIM implementation strategy, the stronger the statistical significance (McCrum-Gardner, 2008; Kennedy et al., 2012; LeMire, 2010) and hence the level of agreement of the importance for successful BIM implementation in South Africa. Based on the *p-values*, the following strategies are deemed to be *essential* for successful BIM implementation in South Africa:

- Administering BIM conferences to increase awareness
- Development of BIM libraries and data exchange frameworks
- Providing incentives to BIM software users
- Introduction of BIM implementation studies

A government centrally led BIM implementation strategy and the formulation of BIM implementation task groups were not deemed to be currently important for successful BIM implementation in South Africa. The null hypothesis was accepted for both of these possible strategies hence showing statistical insignificance and disagreement from the questionnaire respondents.

Merely looking at the mean score and standard deviation for each possible BIM implementation strategy would have led to the researcher concluding that nine out of the ten strategies could lead to successful BIM implementation as they had mean scores greater than three. It was therefore necessary to use stronger statistical analysis using the one-tailed one sample *t*-test to show which BIM implementation strategies the respondents agreed would be important for successful BIM implementation in South Africa.

4.6 Chapter summary

Data were gathered from a sample size of 32 questionnaire respondents. Statistical frequency analysis and hypothesis testing were used to analyse the data. The ordinal scales from the questionnaire were used as interval scales. The questionnaire respondents heavily agreed that the South African AEC sector would benefit from Level 2 BIM implementation. However, in saying so, the analysis conducted showed that the respondents believed that the existence of barriers to BIM implementation affected its adoption and widespread usage. The lack of BIM experience or training and reluctance to change current work practices by BIM stakeholders were shown to be key barriers to BIM implementation. The respondents believed that the South African AEC sector showed readiness to adopt BIM in only five out of 20 factors. The respondents' mean scores on the South Africa's BIM adoption readiness were low and also exhibited a high degree of polarization. This obviously shows that BIM implementation in South Africa would not be successful unless suitable strategies to address the barriers to BIM implementation are introduced.

A parametric method of statistical analysis using one-tailed one sample *t*-testing evaluated the possible BIM implementation strategies. The test results showed that the implementation of Level 2 BIM would be successful if the South African government instituted:

- the introduction of BIM implementation studies,
- the development of accreditation mandates in the allied courses at universities BIM conferences to increase awareness,
- contractual mandates on governmental projects,
- provision of incentives to BIM software users,
- BIM training for small to medium enterprises (SME's) and other organisations,
- modification of procurement practices to make best use of BIM technology and development of BIM libraries and data exchange frameworks.

These strategies are supported by many academics e.g. Oti & Tizani (2010), Manderson et al. (2012), Cerovsek (2011), McAdam (2010) and Glema (2013) whose work was reviewed in Chapter 2.

5 CONCLUSION

The aim of this study was to explore the BIM adoption readiness and possible regulatory initiatives that can overcome the challenges towards BIM implementation in the South African AEC sector. Various BIM implementation maturity models have been developed by many academics. The researcher thoroughly discussed a model developed by Succar (2009) which highlights that different barriers to BIM implementation are prevalent depending on a country's level of BIM maturity. Implementation strategies that address the relevant barriers need to be developed in order to facilitate the successful adoption of the technology. The results of the study show that the introduction of BIM implementation studies, development of accreditation mandates in the allied courses at universities, increasing BIM awareness through conferences, initiating contractual mandates on governmental projects, providing incentives to BIM software users, providing BIM training to small to medium enterprises (SMEs) and other organisations, modification of procurement practices to make best use of BIM technology and development of BIM libraries and data exchange frameworks would result in successful adoption and widespread usage of Level 2 BIM in South Africa.

As reflected in the literature that was reviewed, government support has aided the widespread acceptance of BIM in countries such as the UK, Australia, Hong Kong and Canada (Porwal & Hewage, 2013). The results of the research predict a similar outcome from a South African perspective. In understanding where most of barriers to BIM implementation lie i.e. in respect of lack of BIM education or awareness and unwillingness to change work practices, BIM implementation strategies that will address these barriers need to be mandated.

5.1 Benefits and barriers to BIM implementation in South Africa

South Africa currently has Level 1 BIM maturity. 2D and 3D CAD based technologies are commonly used by architects and engineers for design work. A majority of the sampled population believes that the most important benefit of using BIM in South Africa would be improvements in design management through quick detection of design clashes. This is an area where most wastage is currently experienced in terms of repeated work on site which ultimately jeopardises the timely delivery of construction projects. The research findings demonstrate that another key benefit of using BIM in South Africa is that it would lead to improved communication and collaboration within professional teams. Increased collaboration leads to increased efficiency in delivering construction projects (McAdam, 2010).

The benefits of using BIM are well documented in the literature that exists on this subject. BIM implementation in South Africa has also been undermined due to a lack of demand and knowledge from clients. One of the consequences of lack of knowledge is that BIM staff are not regarded as being important; they are merely seen as CAD technicians and there exists a general lack of understanding from the AEC sector that the knowledge required to implement full BIM is substantial. BIM professionals are undervalued and not adequately rewarded.

5.2 Possible mandatory BIM implementation strategies

Government intervention will increase the chances of successful BIM implementation (Wong et. al., 2011). The research findings indicate that eight of the ten BIM implementation strategies that were evaluated in the study would lead to successful Level 2 BIM implementation in South Africa. These strategies are related to the promotion of BIM education and awareness, incentivising BIM usage by AEC stakeholders, modification of procurement practices for BIM usage and development of BIM libraries and data exchange frameworks. The BIM implementation strategies fall into the technology, process and policy fields outlined by Succar (2009) in the literature reviewed. Based on the statistical significance of the data analysed showing high levels of agreement from the sample population, four of these BIM implementation strategies may be deemed to be essential and would therefore need to be prioritised by the South African government in order to introduce Level 2 BIM. The four essential strategies are administering BIM conferences to increase awareness, development of BIM libraries and data exchange frameworks, providing incentives to BIM software users and introduction of BIM implementation studies.

Statutory agencies such as the CBE, CETA and CIDB need to support BIM training programmes that would help increase BIM awareness to all BIM stakeholders. Accredited higher learning qualifications must be introduced in order for the BIM profession to grow and be fully recognised in the AEC sector. In addition, there are many small to medium enterprises in the South African economy that would require BIM training to ensure that BIM adoption is not only limited to big private businesses but also to the wider economy.

Many researchers such as Eadie et al. (2013) outline that in the initial stages of BIM implementation, pressure from key stakeholders such as the government leads to successful BIM implementation. The results of the study are further proof of the assertions made by these academics.

5.3 Recommendations for future study

This study focused on using BIM in construction projects. BIM technology can be used across different sectors and because of this, the researcher recommends that the study be extended to infrastructure and mining projects, as well as to the provision of facilities management services.

As outlined in the literature review, BIM adoption rates are affected by different factors. According to the diffusion theory which is applied in the Succar et al. (2010) study, if the barriers to BIM implementation are overcome, then the rate of adoption will increase, leading to widespread growth of the technology. The researcher recommends that a study be conducted to measure the BIM adoption rate in South Africa over a period of time once government intervention has been initiated through a centrally led programme.

Barriers to BIM implementation evolve (Wong et. al., 2011). This means that implementation challenges that exist in the initial stages change when the technology (Level 2 BIM) is in use. The researcher suggests that the same study be conducted after a period of time once the South African government initiatives have been introduced. It is conceivable that barriers to BIM implementation will change after a period of time, therefore requiring new mandatory initiatives to be instituted to overcome the challenges.

A study that looks at the South African government's growth targets in respect of technology usage in South Africa would be beneficial to BIM stakeholders. It could possibly drive the development and introduction of frameworks and systematic flow processes for use with the technology.

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APPENDICES

APPENDIX 1: QUESTIONNAIRE

QUESTIONNAIRE

Title of research project: A Study on the BIM Adoption Readiness and Possible Mandatory Initiatives for Successful Implementation in South Africa

Section 1: General

1. Which role best describes your current job?

☐ Client representative
☐ Consultant
☐ Researcher
☐ BIM software developer
☐ Contractor
☐ Other (please specify):

____

2. Does your firm use BIM?

☐ Yes
☐ No

3. How many years' experience do you have in using BIM?

☐ Nil
☐ 1 – 5 years
☐ 5 – 10 years
☐ 10+ years

<u>Section 2: Benefits and Barriers to BIM Implementation in South Africa</u>

<u>Benefits of using BIM</u>

Please rate how strongly you agree or disagree with the following BIM benefits as being mostly applicable to the South African Architectural, Engineering and Construction (AEC) sector:

Benefit of using BIM	**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
Providing price certainty in delivering construction projects					
Providing clients with better value for money					
Promoting competitiveness of construction activity in South Africa and subsequent growth of the sector					
Improved communication within project delivery teams (professional consultants and contractors)					
Better design management through quick detection of design clashes					
Better storage of design data throughout the entire built asset's lifecycle					
Ease in outlining project material and resource requirements					
Evaluating proposed construction methodologies in terms of practicality and ease of construction					
Better planning of projects prior to construction on site					
Replacing traditional methods of construction project delivery which are deemed to be inefficient and give rise to time and cost overruns					

<u>Barriers to BIM Implementation</u>

Please rate how strongly you agree or disagree with the following barriers to BIM implementation as being mostly applicable to the South African AEC sector:

Barrier	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Technology Barriers:					
IT infrastructure limitations such as low bandwidth and data connection speeds					
Limited BIM tools (software packages) available on the South African market					
Knowledge / Awareness Barriers:					
Unawareness of BIM benefits					
Lack of BIM experience and education/training					
Financial Barrier:					
High costs of implementing the new technology					
Other Barriers:					
Legal and contractual risks to AEC professionals such as design liability and delegation of work functions in a collaborative setup due to unavailability of professional services contracts that apportion risk amongst BIM users in a team					
Reluctance to change current work practices					
Low levels of commitment from public sector clients					

Section 3: BIM Implementation Readiness

Readiness based on adequacy of the BIM technology and knowledge

Please indicate how strongly you agree or disagree on whether BIM can be viably implemented in South Africa based on the following technology and knowledge factors:

Technology and knowledge factor	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Availability of suitable hardware and software technologies to be able to fully take advantage of BIM capabilities					
Affordability of BIM tools in South Africa					
Existence of necessary BIM knowledge to aid development of BIM models and data management					
Adequacy of information technology infrastructure such as bandwidth and BIM servers to support Internet usage of the technology					

<u>BIM readiness of AEC stakeholders</u>

Please indicate how strongly you agree or disagree whether the South African AEC sector stakeholders are ready to adopt and implement BIM based on the following factors:

Readiness factor	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Awareness about BIM					
Awareness of the benefits of BIM					
Tools to measure the benefits of using BIM					
Awareness about the challenges of using BIM					
Personal motivation to adopt BIM					
Companies' motivation to use BIM					
Demand from clients for usage of BIM					
Support and encouragement of other AEC stakeholders for the adoption of BIM					
Availability of university graduates with requisite BIM training knowledge					
Readiness through regulatory mandates					
Adequacy of standard forms of contract for use with BIM					

Existence of strategic initiatives for BIM adoption					
Insistence of statutory approval which mandate the usage of BIM					
Promotion of BIM awareness through conferences and workshops					
Existence of standard BIM implementation documents or guidelines prepared by statutory or regulatory authorities					
Availability of higher education courses in BIM					

Section 4: Possible BIM Implementation Strategies

Possible regulatory authorities who can influence BIM adoption are Council for the Built Environment (CBE), professional councils in the built environment, Construction Industry Development Board (CIDB), Construction Education and Training Authority (CETA) and Government Agencies of South Africa. Please tick in the appropriate boxes below to rate the importance of the following possible BIM implementation strategies that can be instituted by these agencies:

Possible BIM implementation strategy	**Not important**	**Somewhat important**	**Important**	**Very much important**	**Essential**
Introduction of BIM implementation studies					
Development of a government centrally led BIM implementation strategy					
Formulation of BIM implementation task groups					
Accreditation mandate in the allied courses at universities					
Administering BIM conferences to increase awareness					
Contractual mandates on governmental project					
Providing incentives to BIM software users					
BIM training to small to medium enterprises (SME's) and other organisations					
Modifying procurement practices to make best use of BIM technology					
Development of BIM libraries and data exchange					

Please add any further comments you may have about the implementation of BIM in South Africa in respect of benefits, challenges and possible regulatory strategies to promote adoption of the technology.