A framework for advanced construction techniques used in the construction of nuclear projects in South Africa

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ABSTRACT

This research study is an investigation into advanced construction techniques opportunities for usage in nuclear construction in South Africa and to produce a framework to be used by all stakeholders. This study will concentrate on the construction phase of the construction project management lifecycle. There are numerous models that identify the best practice for Construction Project Management. These models are analysed and compared to the requirements of the nuclear industry. Furthermore, the investigation identifies the advanced construction methods used in nuclear projects globally, the best practise for advanced construction management and the key requirements. These construction technologies include modularisation, building information modelling (BIM), additive manufacturing (3D printing), robotics, augmented reality, Blockchain, artificial intelligence, autonomous equipment, advanced materials and internet of things. The output from this research will be a framework for advanced construction technologies that will be used for nuclear construction projects in South Africa. The framework will provide a guideline to assist in transforming practitioners performing nuclear projects to successfully plan and deliver a nuclear new build project in South Africa.

Keywords: nuclear project management, advanced construction, modularisation, building information modelling (BIM), additive manufacturing (3D printing), digitalisation, framework.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABWR	Advanced Boiling Water Reactor
ALARA	As low as reasonably achievable
APMI	American Project Management Institute
AP	Advanced Passive
APR	Advanced Pressurised Reactor
BWR	Boiling Water Reactor
CGNPC	China Guangdong Nuclear Power Corporation
CPR	Chinese Pressurised Reactor
CII	Construction Industry Institute
DOE	Department of Energy
EPR	European Power Reactor
FFD	Fitness for duty
GE	General Electric
IAEA	International Atomic Energy Agency
IRP	Integrated Resource Plan
KEPCO	Korea Electric Power Corporation
MBE	Model Based Engineering
PPE	Personal Protective Equipment
PWR	Pressurised Water Reactor
SCWE	Safety Conscious Work Environment
VVER	Water-Water Energy Reactor
WEF	World Economic Forum

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CHAPTER ONE: OVERVIEW AND INTRODUCTION

1.1 INTRODUCTION

South African government under the auspices of the Department of Energy (DOE) has developed the Integrated Resource Plan for Electricity 2010-2030 (IRP2010) detailing the energy mix for development (Department of Energy, 2011). Included in the plan is to add a further 9600 MWe of baseload nuclear energy to the grid by 2030, with the first unit commissioned in 2023. The revised IRP gazetted in October 2019 has decreased the requirement from 9600 MWe to 2500 MWe. The preparations for the 2500 MWe must occur at a pace and scale that South Africa can afford without stipulating any timelines. Therefore, the need to develop the framework for advanced construction technology for nuclear construction in South Africa remains.

South Africa has previously, through the Department of Energy (now the Department of Mineral Resources and Energy), completed the preparatory phase for the nuclear new build programme by signing inter-governmental framework agreements with seven nuclear vendor countries. Key requirements of these agreements are the industrialisation of the country, re-development of the local nuclear industry, the creation of jobs, development of skills and technology transfer. These countries and the associated technologies provided are summarised in Table 0-1.

Table 0-1: Technology Vendors in agreement with South Africa

(Reproduced from DOE, 2014)

Vendor Country	Vendor	Reactor Name / Type
Canada	Atomic Energy of Canada Limited (AECL)	Candu / PHWR

China	China Guangdong Nuclear Power Corporation (CGNPC)	CPR 1000 / PWR
France	Areva	EPR / PWR
Japan	General Electric-Hitachi (GE-Hitachi)	ABWR / BWR
Russia	Rosatom	VVER 1200 / PWR
South Korea	Korea Electric Power Corporation (KEPCO)	APR 1400 / PWR
United States of America	Westinghouse	AP 1000 / PWR

Nuclear can make a significant contribution to reducing greenhouse gas emissions while delivering energy in the increasingly large quantities needed for growing populations and socioeconomic development (IEA, 2015). However, the key issue that nuclear new build faces is the large amount of time required for planning and construction. This creates significant pressure for South Africa to meet the reduction in greenhouse gas emissions and deliver new nuclear plants as per the plan.

In addition to the time constraints, global nuclear events have added further pressure required to construct a nuclear plant. The accident at the Fukushima Daiichi nuclear power station that resulted from the devastating earth-quake and Tsunami of March 2011 was both a catastrophic disaster and a serious event in terms of Japanese and global energy security (Hayashi and Hughes, 2012). The accident had an impact on projects under construction and commencement of the construction of new plants globally. The accident also saw stricter regulations of nuclear power plants being introduced around the world and are expected to cause longer construction times and increased interest burden (International Atomic Energy Agency, 2011). To address the challenges within the energy sector, there is the need for the South African government

to construct a new nuclear plant in the shortest space of time and with the lowest cost. To achieve this, there is the need to establish a programme that integrates the critical attributes into the overall project (IAEA, 2011).

Nuclear construction projects globally are increasingly adopting advanced construction techniques and technologies (i.e. steel-plate reinforced concrete structures, advanced concrete admixtures, robotic welding, 3D modelling, prefabrication, preassembly, and modularisation and cable splices) as part of the process to deliver the project within time, cost and quality (Buongiorno, Corradini, Parsons & Petti, 2018; Wright, Cho & Hastak, 2012). The speed and scope of technological change as a result of the onset of the fourth industrial revolution creates tremendous opportunities for the use of advanced construction techniques in the construction industry. The nuclear construction industry has not fully embraced the latest technological opportunities that have radically transformed many other industries (Zachiang, 2017; Mutesi & Kyakula, 2011). Nuclear construction industry seems to lag behind almost other industry in the adoption new sophisticated technologies despite an onslaught of technological advances and opportunities in the industry. The nuclear construction industry can benefit from improved productivity and efficiency thanks to digitalisation, innovative technologies and new construction technologies. The fourth industrial revolution has ensured that technology and tools developed during the digital revolution have now gained maturity and will play a major role in the future of the construction industry. Innovation has also created many emerging technologies that will impact nuclear construction projects immensely.

In order to do this a proper understanding of the advanced construction techniques that are available is required. The World Economic Forum (WEF) has commenced a study on the future of construction. In this study, the following technologies have been

identified: modularisation, digitalisation, additive manufacturing, advanced building materials, building information modelling, autonomous construction and augmented reality and virtualization. Further emerging technologies like Blockchain, artificial intelligence and Internet of things can also add vast value to the construction process. A key facilitator in implementing these capabilities is a set of company-wide software tools such as building information modelling. These tools will help in connecting islands of information, making information easily available and simplifying actual project management (by providing support for scoping, scheduling or costing) (WEF, 2016).

This research study will produce a framework that can be used for new nuclear project construction in South Africa. The requirements for the nuclear new build (NNB) to have some localisation effort must be taken into consideration during the entire lifecycle. NNB has been steadily progressing since the year 2000, with the construction of 94 new reactors as well as 56 finished reactors connected to the grid (Horst, Cometto, Kim, Sozoniuk, Rothwell, Thompson, Savage, Mancini, Leigne, Bickford & Crozat, 2015). In South Africa, two reactors which are located at Koeberg nuclear power station account for around 5% of South Africa's electricity production. The NNB is part of the 2010 Integrated Resource Plan (IRP), which envisages building 9,600 MWe of new nuclear power capacity by building between six and eight new nuclear reactors by 2030. In the years 2016, an updated draft RIP was realised by the government which set a much lower nuclear target due to lower demand projections and increased costs of capital. The new nuclear build will be a game changer as it will provide construction firms with the opportunity to move away from designing paper reactors towards building demonstrations. The construction phases such as the preparation and planning required to adopt advanced construction will ensure a successful project saving time and money as a lot of activities and preparations go into these phases.

1.2 Problem Statement

The experience gained over the last forty years has shown that the *construction phase* is one of the most critical phases for the success of the project (International Atomic Energy Agency, 2011). Recent power generation mega projects undertaken by State-Owned Enterprise Eskom Holdings have had major time and cost overruns and some major quality issues. This performance should be avoided in the construction of a nuclear plant as the construction period is approximately seven (7) years (IEA, 2015). Further time delays and resultant cost impacts can be detrimental to the delivery of the project. It is envisaged that South Africa will embark on a nuclear new build project in the future and needs a framework on how and when to use advanced constructions technologies in the construction phase.

In order to be successful in the construction phase, there are requirements that must be considered in the front end planning phase of the project. Currently there is no single framework document that details advanced construction techniques, such as, modularisation and digitalisation. A framework will collate all vital information to be considered to assist in decision making and alignment for the successful delivery of the project. Figure 0-1 illustrates the cost of changes in the construction life cycle. It is easier and cheaper to make changes in design in the front end planning stage than the construction phase. A framework will ensure that the front end planning takes advanced construction technologies into consideration as changes to the system and processes later in the lifecycle results in cost increase and time delays. A framework will assist decision makers in the front end planning of the project and will ensure design and procurement includes advanced construction techniques.

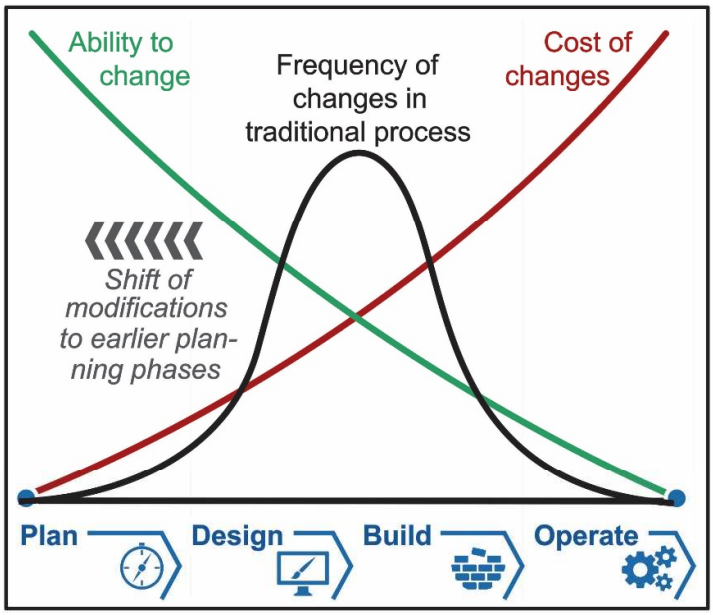


Figure 0-1: Cost of Changes in the Construction Life Cycle (Reproduced from WEF, 2016)

In order to develop the framework, the following key questions need to be addressed:

- What advanced construction technologies are available for conventional and nuclear construction globally?
- What are the benefits and challenges of these advanced technologies experienced globally?
- What are the requirements for successfully implementing the advanced construction technologies for nuclear construction in South Africa?
- What is South Africa's capability to meet the requirements of the framework for advanced construction in nuclear?

1.3 Aim and Specific Objectives

The aim of this research is to determine the key factors that are required to ensure that advanced construction technologies are used successfully in nuclear new build projects in South Africa. This information will result in the development of a framework for the

nuclear industry. Although the International Atomic Energy Agency has produced a document on the construction technologies for nuclear power plants (IEA, 2017), the advent of the Third Industrial Revolution has created further technologies that will be dealt with in this study to supplement the available information.

This framework will provide a better understanding of the tools and processes for designers, skills required by owners and project stakeholders, benefits and challenges that advanced construction technologies application and implementation involves. The objective is to provide the knowledge and experience such that the construction industry can plan and organise for proper implementation.

The specific objectives for this research study are as follows:

1. Identify the advanced construction techniques used in construction globally
2. Determine the benefits and challenges the technologies provide from experience and good practice from global projects
3. Provide a best practice process for implementation.
4. Verify the framework by testing the developed model in the nuclear construction environment

1.4 Scope of Work

This research identifies and investigates the experience of advanced construction technologies application in global projects and provides a framework to aid in implementation within the South African nuclear new build project. The following key items will be discussed:

- Nuclear Safety Culture
- Nuclear Quality
- Pre-fabrication and Modularisation construction

- Open top method
- Building information modelling
- 3D printing and additive manufacturing
- Augmented reality and visualization
- Big Data and predictive analytics
- Wireless monitoring and connected equipment
- Cloud and real-time collaboration
- Artificial intelligence
- Autonomous construction, including robotics
- Advanced materials
- 3D scanning and Photogrammetry.

1.5 Work Excluded

This research study will only focus on construction related activities. The areas that are impacted by advanced construction technologies are discussed. Although other areas in the project management process are also important for the delivery of the project, the following are not discussed as it makes the study too broad and will difficult to complete:

1. Site survey and environmental assessment
2. Site selection and evaluation
3. Nuclear Licensing
4. Investment Studies
5. Operation and Maintenance
6. Nuclear Fuel Cycle
7. Community Infrastructure development
8. Legal and Organisational framework
9. Power system planning

The framework is not a comprehensive guide on how to implement advanced construction management but presents the key elements that would form part of the system. The details of the acquisition, configuration and detailed implementation are not part of this study.

1.6 Outputs and Deliverables

The key deliverable will be a framework that will be developed to assist construction practitioners, owners, suppliers and other stakeholders to have a better understanding of the benefits, challenges and requirements for advanced construction technologies associated with the nuclear new build construction projects within South Africa. Although focusing on the construction phase, the framework will assist owners to make early decisions to adopt the technologies as part of the project and provide all the resources to gain maximum benefits and efficiencies from the implementation. Suppliers can gain benefit by identifying areas to add value. The overall benefit is to increase confidence in the delivery of the project.

The framework is not a comprehensive guide on how to implement advanced construction management but presents the key elements that would form part of the system.

1.7 Structure of the Report

The research report is divided into six chapters with dedicated appendices and references.

Chapter 1 sets out the overall need for the research study and consists of a problem statement, aim and specific objectives, the scope of work, work excluded and outputs and deliverables.

Chapter 2 consists of the literature review detailing the advanced construction techniques employed by vendors in construction globally. This chapter presents a critical look at the requirements and experiences of advanced construction technologies globally.

Chapter 3 details the research methodology and process undertaken in this study.

Chapter 4 contains the presentation of the results.

Chapter 5 analyses and interpretation of the results received from the sample population.

Chapter 6 concludes and makes a recommendation for the future use of the framework

1.8 Chapter Summary

This chapter provided an overview of the study setting out the rationale for the research. It contained the background of the study focusing on advanced construction techniques and technologies. The research aims and objectives are also presented in this chapter. The structure of the research is also presented in this chapter. The proceeding chapter contains the review of literature on the subject matter.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The literature review will discuss the construction project management frameworks available. These frameworks will form the basis of developing the framework for advanced construction technologies. The current knowledge base on this topic is found in research work done by the Construction Industry Institute, the International Atomic Energy Agency and experience documented by Vendors during execution of various projects. The advanced construction technologies used in conventional and nuclear project will be defined together with their advantages and disadvantages. The key requirements for advanced construction techniques will be identified and will result in the development of a framework.

2.2 Future Construction Technologies

The World Economic Forum compiled a report in 2016 detailing the future of construction. It has identified ten technologies that will play a key role in the future of construction. These technologies are shown in Figure 0-1 and will form the core of the advanced construction technologies framework.

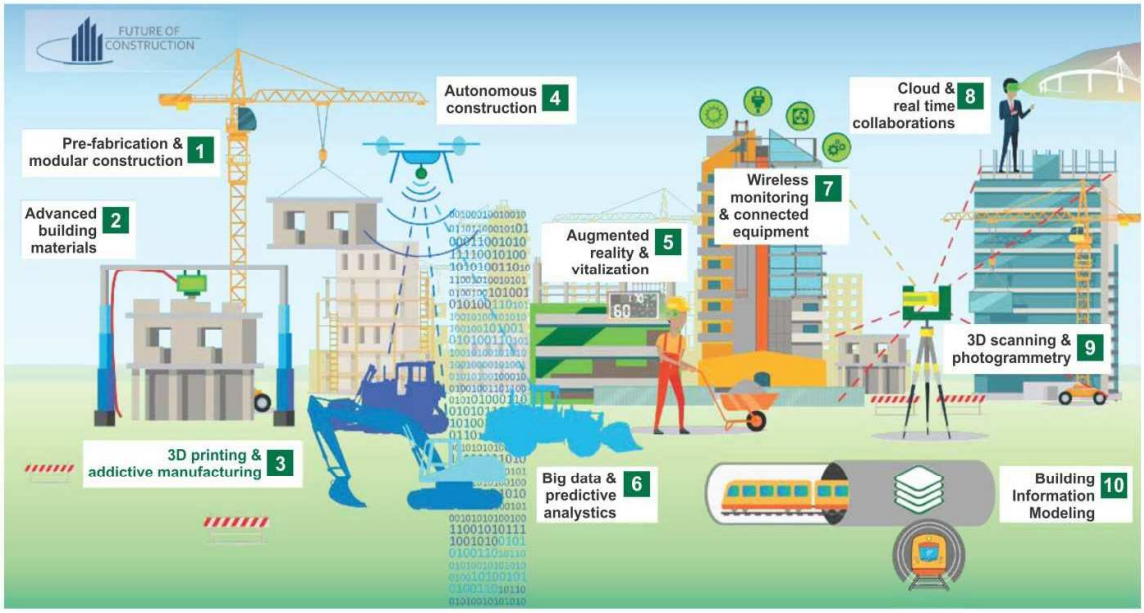


Figure 0-1: Ten technologies to improve construction productivity

(Reproduced from WEF, 2018)

The ten technologies as shown in Figure 2-1 are prefabrication and modular construction, advanced building material, 3D printing and additive manufacturing, autonomous construction, augmented reality and visualisation, bid data and predictive analytics, wireless monitoring and connected equipment, cloud and real time collaboration, 3D scanning and photogrammetry and building information modelling" (WEF, 2018).

2.3 Construction Management Frameworks

There are many construction and project management organisations that have models, best practices and knowledge repositories to assist deliver a project successfully.

2.3.1 American Construction Project Management Institute

The American Construction Project Management Institute developed a model that describes the processes required for the successful completion of an industrial project.

It is shown in Figure 0-2. The model shows the construction lifecycle and highlights the key items that must considered for implementation. This framework is very unique given the fact that it provides a step-by-step approach to how a project can be executed starting from planning phase to the completion phase. Another significance of the American construction project management framework is that it contains the input required to successfully execute construction project including the project team, system, methods and resources. One critical success factor for project management is that the project manager should be knowledgeable in each component of the project. This framework is useful given the fact that it explains the types of knowledge (explicit and tacit knowledge) required by project managers and team members to successful execute a project. Jung, Joo and Kim (2011), in their study, noted that advanced information and communications technology have contribute to increase in productivity in all industry sectors including the construction sector. Thus, the utilisation of information system in the construction industry has the potential to generate competitive advantage for construction firms as well as increase effectiveness of construction projects throughout their life cycle and across different construction business functions. The framework/model is a useful tool for construction firms as it contains information on construction management information system required to successfully completed a construction project. This model will be used as the basis to develop a framework of advanced construction techniques that can have positive impacts on the outcome of a project.

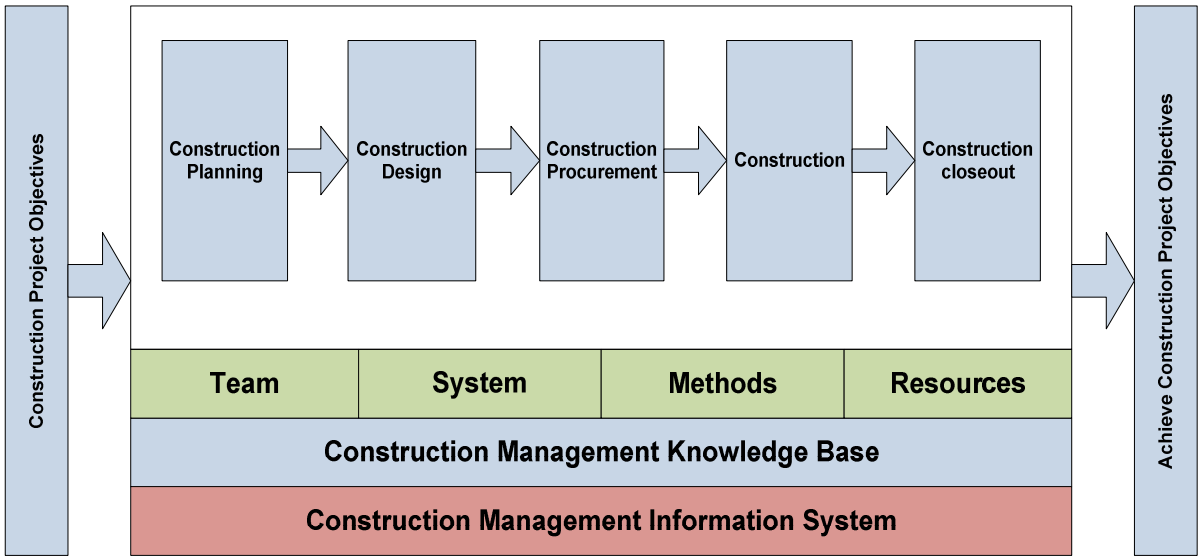


Figure 0-2: Framework for American Project Management Institute (Reproduced from APMI, 2012)

2.3.2 Construction Industry Institute

The Construction Industry Institute (CII) project management model is described in Figure 0-3. The key difference to other models is the emphasis on front end planning. The focus on the feasibility, concept and detail scopes add confidence to the ability to deliver a successful project. Furthermore, through research, the organisation has produced many best practice guidelines that are in use industry-wide. The organisation has performed research on advanced construction technologies, in particular, modularisation. This information will be incorporated into the framework for advanced construction technologies.

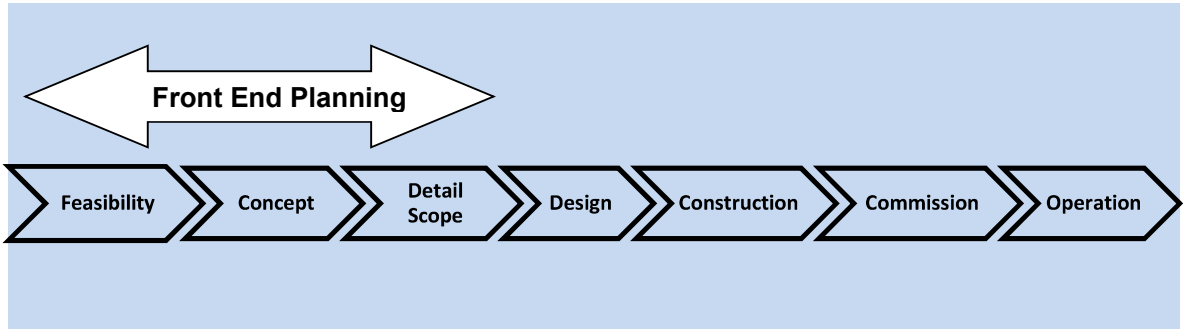


Figure 0-3: CII Model (Reproduced from CII, 2013)

Having compared the two conceptual models presented in Figure 2.2 and 2.3 respectively, the model developed by the American Construction Project Management Institute will be the most suitable to the adopted by nuclear and conventional project experts in South Africa. The APMI framework will serve as a useful to for construction projects in South Africa because it contains detail information about the phases a project should go through starting from planning to the completion phase. It provides project managers, contractors, project team members and other stakeholders the tasks to be undertaken at each phase of the project. In this way, it will help to ensure the timely execution of construction projects. Compared to the latter model, the APMI model may be a useful tool for construction firms in South Africa as it contains the necessary input, knowledge and information required to successful complete a project. The model when adopted by nuclear and conventional construction industry in South Africa will enable them to increase efficiency, save costs, execute construction project on timely basis and increase productivity.

2.3.3 Nuclear

Nuclear projects are unique because of the presence of radioactivity and radioactive materials (Devgun, 2013). Nuclear projects have three key areas that make nuclear projects different from other types of projects. These areas are:

- Radiation protection
- Nuclear Safety Culture
- Nuclear quality -(Devgun, 2013).

2.4 Nuclear Safety Culture

It is well recognised in the industry that the safe operation of a nuclear site requires not only the proper design and operation of the safety systems but a safety-conscious attitude of the workforce (Devgun, 2013). The fundamental safety objective is to protect people and the environment from the harmful effects of ionising radiation (IAEA, 2015). Cooper (2000) explains safety culture as a sub-facet of organisational culture, which is thought to affect member's attitudes and behaviour in relation to an organisation's ongoing health and safety performance. According to Misnan, Mohammed, Mahmood, Yusoff, Mahmud and Abdullah (2008), the nature of accidents and injuries at construction recurrent and serious shows that the construction industry is unique. It is suggested that an efficient safety management system should be based on the safety awareness that should become a culture in the construction industry involving all the stakeholders. Also, promoting safety culture in the construction industry should focus on providing key skills and knowledge and training that can be used to encourage and modify behaviour and attitudes of workers (Misnan et al., 2008). According to Jamal Khan, Chew Abdullah and Yusof (2005), one important measure that can be adopted to create a good or better image of construction industry is to provide safe working environment. Misnan and Mohammed, (2007) suggest that efforts to improve occupational safety and health at work will only be effective if occupational safety and health culture is improved. Misnan and Mohammed (2007) recommend that the promotion of safety culture within the construction industry should include, namely: leadership support, employee participation and involvement, employee training,

communication, motivation, setting up health and safety committee, work environment and policy and safety planning.

Devgun summarises the following key attributes of a nuclear safety culture site:

- Site management cultivates and promotes Safety-conscious work environment (SCWE).
- Each worker is personally responsible for safety.
- Encourage a questioning attitude at all levels of the workforce and provide adequate training.
- Encourage safety culture in every task to be performed
- The organisation demonstrates a strong commitment to safety.
- Workers can raise safety concerns without fear of reprisal.
- Safety is the highest priority in decision making.
- Safety training is provided and continually updated.
- Apply lessons learned from industry experience.
- Nuclear sites contain radiation hazards, thus nuclear sites have unique training requirements.
- In addition to the safety of workers, the safety of the public near the site is given proper consideration.
- Open (and free of reprisal fear) flow of information on safety-related issues.
- A formal process is established for Differing Professional Opinions (DPO).

The key elements of a safe nuclear work site are shown in Figure 0-4. In order to achieve this, advanced technologies can play an important role.

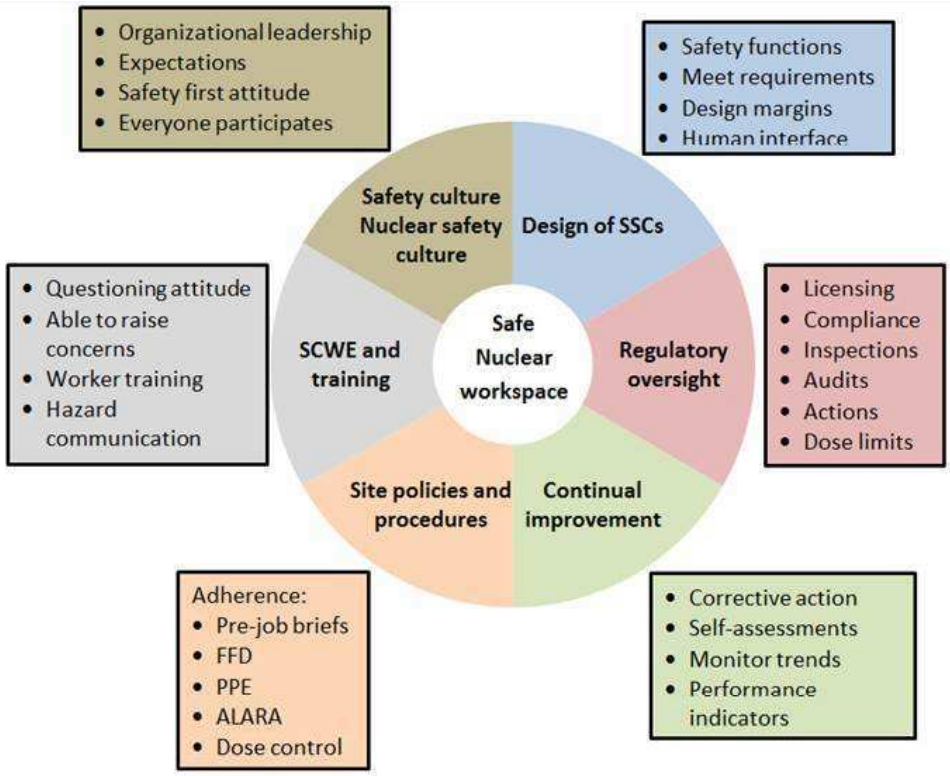


Figure 0-4: Key Elements for Nuclear Safety Culture (Reproduced from Devgun, 2013)

From the Figure 2-4, the abbreviation SCWE stands for safety conscious work environment, FFD (fitness for duty), PPE (personal protective equipment) and SSCs (structures, systems, and components).

2.5 Nuclear Quality

Nuclear quality control and assurance is intended to provide adequate confidence that a structure, system or component will perform satisfactorily in service (Chen et al, 2014). In South Africa, the requirements for nuclear quality is regulated by the National Nuclear Regulator (NNR) and found in the document titled Quality and Safety Management for Nuclear Installations in South Africa, commonly referred to by its document reference number RD0034.

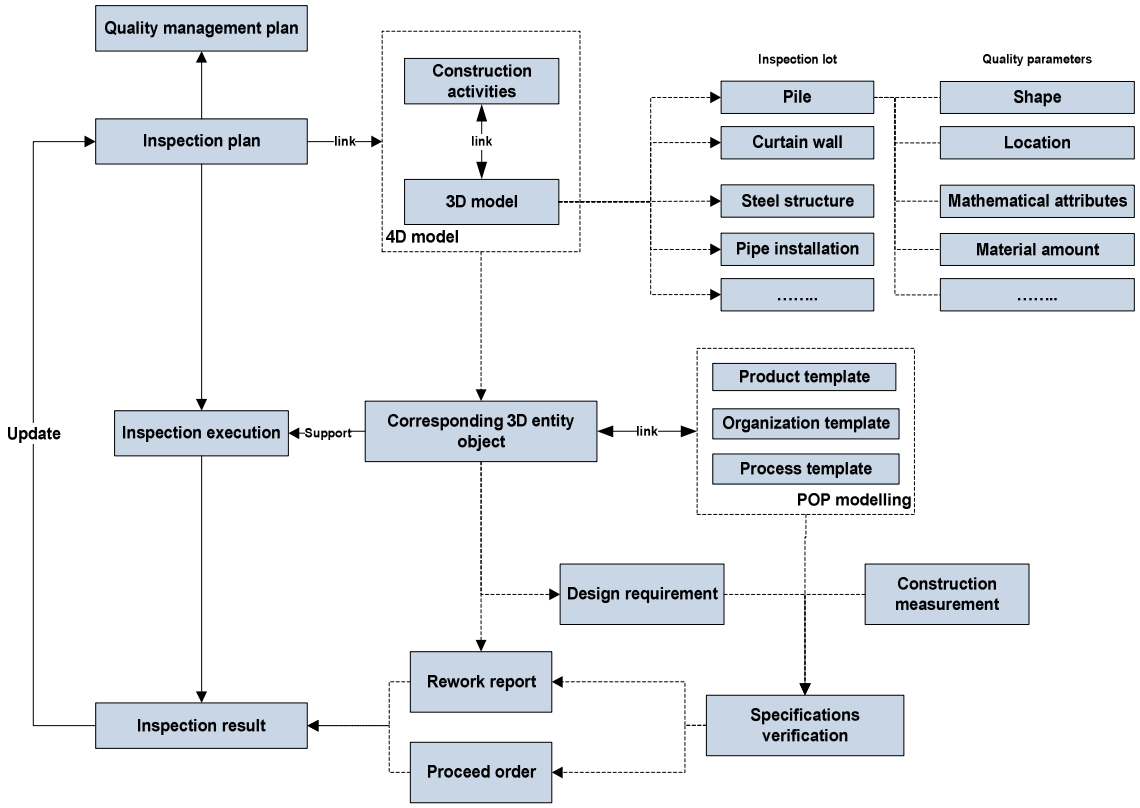


Figure 0-5: Construction quality using building information modeling (BIM) (Reproduced from Chen et al, 2014**)**

The significance of BIM in construction project is that it offers a virtual repository that allows easy access to and sharing of information and knowledge in real time (Fadeyi, 2017). Another significance of the BIM model in construction industry is that it provides a platform for project experts to work in an integrated environment at any stage of the building delivery process. As shown in the Figure 2.5, the model explains how nuclear quality can be improved, particularly within the construction sector taking into consideration the inspection processes and producers. The Figure 2.5 also explains the construction activities and technologies required to achieve nuclear quality. One usefulness of BIM in construction projects is that it increases the information quality

required to make critical design decisions to evaluate a building's environmental impact. BIM offers the following benefits to construction firms, namely: faster delivery; improved productivity; reduced wastages; creates opportunities for revenue generation and business; reduced construction costs and improved quality of project (Diaz, 2016)

In the construction of nuclear installations, traceability of items provides an important tool through the lifecycle from the initial design through construction and then to commissioning and later during operation and maintenance. traceability is achieved by the collection and storage of records that the owner and the regulatory body NNR needs. These records include: Construction quality using BIM

- As-built drawings
- Manufacturing and assembly details
- Inspection reports
- On-site traceability records including marking and tagging
- Construction and test records (to be used as baseline data)
- Design calculations
- Documentation of design changes and non-conformance
- Details of equipment qualification.

Advanced construction technologies like BIM can support these requirements for traceability by providing a central repository to store and retrieve all information instantaneously. For instance, BIM repository has the potential to improve building delivery productivity by providing improvement to several tasks that take place across building delivery stages. These tasks may include teamwork, risk aversion and business development; change management; scheduling, logistic planning, cost

estimation, constructability analysis, data analysis, prefabrication, design and construction co-ordinations and material management (Fadeyi, 2017).

2.6 Advanced Construction Technologies

A study by Bechtel Power Corporation in 2004 highlighted that standardised plants and advances in construction techniques promise to reduce construction costs and schedule in nuclear power plant construction. A summary of these technologies is listed in Table 0-1. Many of these technologies can be found in the mature phase in the technology lifecycle today. Many new technologies are added in present-day as the digital age progressed.

Table 0-1: Advanced Reactor Construction Technologies – 2004

NO	Description	Recommended for Advanced Reactor Implementation
Sufficiently mature with proven economic benefits		
1	Concrete composition technologies	Yes
2	High deposition rate welding	Yes
3	Robotic welding	Yes
4	3D modelling	Yes
5	GPS application in construction	Yes

6	Open top installation	Yes
7	Pipe bends versus welded elbows	Yes
8	Precision blasting / Rock removal	Yes
Show promise but further technical development needed		
9	Prefabrication, preassembly, modularisation	Yes
10	Cable pulling, termination and splicing	Yes
11	Steel plate reinforced concrete structures	Yes
12	Advanced information management and control	Yes
Not Recommended		
12	Fibre-reinforced polymer rebar structures	No

Advanced construction technologies adoption in nuclear construction is gaining momentum as the best practice to improve plant design, ensures the quality of construction and reduces the time taken to construct the plant. For example, concrete constitutes the largest manufactured material globally and accounts for more than 6 billion metric tons of materials annually (Shah, Gohil, Chavda & Khediya, 2012). Over fifty years ago, there have been notable improvements made in concrete technology. The advancement of chemical admixtures has revolutionized concrete technology in recent times. For instance, the use of air entraining admixtures, accelerators, retarders, water reducers and corrosion inbitititors are commonly used for bridges. Applying the

advanced concrete technologies in modern methods of concrete structures production improved efficiency within construction firms.

Silva, Ferraresi and Scotti (2000) suggest that given the level of competition among construction firms, it is important to select the most suitable fabrication process to a specific situation, among them welding, considering the technical and economic viability. It is suggested that submerged arc welding (SAW) is considered one of the one of the most cost-efficient processes for welding thick steel plates (Layus, Kah and Gezha, 2018). The SAW is the most commonly used welding tool in the shipbuilding production and construction work as it provides high productivity and delivers superb weld quality (Kiran, Basu & De, 2012).

Since the advent of industrialisation around 1960s, the development of robotised welding has been truly remarkable. Robot welding is mainly concerned with the application of mechanised programmable technologies, known as robots, which completely automate a welding process by both performing the weld and handling the part (Hong, Ghobakhloo, and Khaksar, 2014). Robots are quite versatile and are able to perform different welding types including resistance welding and arc welding.

In recent times, 3D scanners have become a standard source for input data in many application areas, but image-based 3D modelling still remains the most complete, economical, portable, flexible and widely used approach. 3D modelling is advanced construction technology which converts a measured pointcloud into a triangulated network or textured surface (Remondino & El-Hakim, 2006). There are different types of 3D modelling, namely: simple polygons, 3-D primitives – simple polygon-based shapes, such as pyramids, cubes, spheres, cylinders and cones and spline curves. The 3D modeling, does not only speeds up the design process, but also enables architects and designers play around with different ideas and identify potential design problems before

they become actual issues. Another relevance of 3D modeling in construction is that it allows animation (Thompson, 2017).

Global Positioning System (GPS) is a satellite based navigation system which consists of a network of 24 satellites placed into orbit by U.S. Department of Defense (Kumar & Mahajan, 2013). GPS is mostly used to monitor ground objects with respect artificial satellites launched in space. Given the benefits of GPS, many construction firms continue to use it in their filed works as it enables them to collect, store and reuse field data accurately and timely. One primary benefit of using GIS as a data base for transportation data is the fact that it integrates the spatial data and display the attribute data in a user-chosen format.

The challenges of installing major components inside the reactor and containment building may have significant impact on the construction schedule. In the last decades, walls of the reactor and containment building were constructed with temporary openings to allow the entry of large equipment. In open top installation, the reactor and containment building is built with a temporary roof with an opening through which major pieces of equipment, such as the reactor vessel and steam generators, can be lowered into position using very heavy lift cranes (Jung, Kang & You, 2010). Open top installation has been applied successfully with modularization to reduce schedules in construction projects. For example, during the construction of Tarapur-3 and -4 in India, open top installation was used to position more than 50 pieces of equipment including the steam generators moderator heat exchangers, , pressurizer, calandria primary circuit headers and fuelling machine (Jung et al., 2010).

Pipe fittings are piping component that assists s in changing the direction of the flow such as elbows and tees. There are several types of pipe fitting used in piping including elbow, tee, reducer, union, coupling, cross, cap, swage nipple, plug, bush, expansion

joint, and adapters. However, elbow is commonly used than any other pipe fittings. Elbows offers flexibility to change the pipe direction. Long radius pipeline bends are used in fluid transportation line which required pigging. Due to their long radius and smooth change of direction, pipe bend has very less pressure drop, and smooth flow of fluid and pig is possible. 3D and 5D Pipe bends are commonly used in construction works.

Fiber reinforced polymer (FRP) composites are used in a wide range of applications in construction ranging from rehabilitation of existing structures to the full-scale use for new projects because of the benefits they provide over conventional building materials (Zaman, Gutub & Wafa, 2013). These benefits include lightness, high mechanical performance and possibility of production in any shape, ease of installation and lesser requirement for supporting structure and controlled anisotropy. However, FRP composites are not recommended in most construction projects due to their bottlenecks such as vulnerability to static fatigue, ultraviolet radiation and alkaline environment (Uomoto, Mutsuyoshi, Katsuki & Misra, 2002).

Advanced construction technologies are designed around the equipment found in a nuclear power plant and innovative ideas have created better ways of delivering the construction. The equipment types are summarised in Table 0-2.

Table 0-2: Equipment comprising a pressurised water reactor

Mechanical Equipment	• HVAC Ductwork	• Distributed Control System (DCS)
• Pressure Vessels	• Cranes	• Transmitters
• Tanks		• Gauges/Indicators

• Valves	**Electrical Equipment**	• Sensors/Elements
• Pumps	• Generators	• Transmitters
• Compressors	• Transformers	
• Fans (HVAC)	• Motors	**Civil Works**
• HVAC (Chillers, Heating Coils)	• Switchgear	• Civil Concrete
• Heat Exchangers	• Motor Control Centres (MCC)	• Forms
• Filters	• Electrical Panels	• Rebar
• Ion Exchangers	• Cables	• Tendons
• Turbines		• Structural and Reinforcing Steel
• Pipes	**C&I Equipment**	• Containment Assemblies (Electrical Pen, Piping Pen, Hatch Assemblies)

A cost-conscious design and project planning will ensure that operating and maintenance costs are minimised if they are determined early on, during the design and engineering phase shows the project lifecycle and when advanced construction technologies are involved from planning, the necessary requirements can be incorporated in the procurement process. This knowledge is possible if there is a framework that provides the guidance.

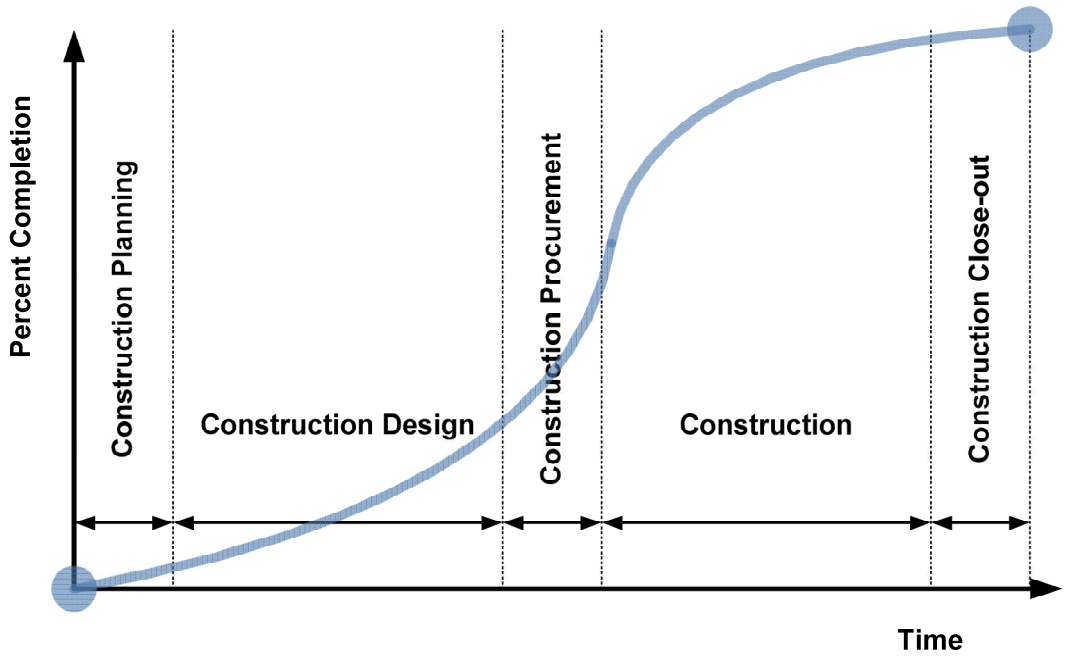


Figure 0-6: Construction project lifecycle (Reproduced from APMI, 2012)

2.7 Modularisation

Modularization entails the large-scale transfer of stick build construction effort from the job site to one or more local or distant fabrication shops/yards, to exploit any strategic advantage (CII, 2013). According To Wrigley, Wood, Stewart, Hall and Robertson (2018), although modularisation has been utilised in nuclear to reduce costs, however, more work needs to be done to create effective modules. Markovitch and Willmot (2014) discovered that digitalisation reduced costs by up to 90 percent and turnaround times improved by several orders of magnitude. Moreover, it was found that the real-time reports and dashboards on digital-process performance allow managers to solve problems before they become critical (Markovitch & Willmot, 2014). There are three levels of modularisation, defined as follows:

- Pre-fabrication – joined materials to form a component part of a final installation;

- Pre-assembly - joined component parts to form a subunit;
- Module – joined subunits to create an installation unit or assembly (IAEA, 2011).



Figure 0-7: Sanmen CA20 Module Installation (Reproduced from Ray, 2011)

In the United of States America, largest module has been installed at the Vogtle 4 nuclear construction project at Georgia. The A20 module and sub-modules were assembled from prefabricated wall and floor sections within the modular assembly building at the Vogtle site. The installation lasted for 3 hours with the help of the world's largest crawler crane to hoist the module into position. The CA20 module is usually used to comprise plant and equipment for used fuel storage, transmission, the heat exchanger and waste collection, among other things.

2.7.1 Benefits of Modularisation

Modularisation as a construction technology has many benefits in the successful delivery of a project. These benefits include lower capital costs, improved schedule performance, increased productivity, higher overall quality, increased safety performance, reduced waste, better environmental performance and reduced site-based permits (CII, 2013). Choi (2014) summarised these benefits and details as shown below in Table 0-3.

Table 0-3: Benefits of Modularisation (Reproduced from Choi, 2014)

Measurement Category	**Benefit Area**
Lower Capital Costs	• Offsite labour costs reduced • Onsite accommodation costs reduce • Material delivery cost reduced • Onsite crane usage minimised
Improved Schedule performance	• Workshop fabrications prevents weather delays • Parallel fabrication and construction reduces schedule time
Increased Productivity	• Reduced onsite labour numbers • Increased labour productivity • Highly skilled labour workforce
Higher Overall Quality	• Improved quality control • Improved working environment

	• Reduced Failure rates
Increased Safety Performance	• Safety risks reduced in controlled shop environment • Reduced exposure to hazardous conditions • Improved work environment
Reduced water and better Environmental Performance	• Reduction in material waste • Reduction in noise, air and water pollution • Reduced energy usage
Reduced site based permits	• Reduced rigging and working at heights • Reduced permitting process due to parallel work

2.7.2 Challenges of Modularisation

The research conducted by the Construction Industry Institute identified barriers to modularization. These include cost barriers, Coordination barriers, Engineering Design barriers, procurement barriers, logistics barriers expertise and culture barriers. These challenges associated with the use of modularisation can also be applicable within the South African context given the fact that modularisation is a common advanced construction technique used in almost all construction firms across the globe. In South Africa, the common challenges affecting the use of modularisation in construction projects include planning and coordination, transportation restraints, negative perception, and flexibility to make changes onsite (Lawson, M., Ogden & Goodier, 2014; Lu Na, 2007; Blismas, Pasquire & Gibb, 2006). These challenges can be addressed through creating positive awareness of the need to use modularisation in construction projects, proper project planning, finding suitable means of transporting the equipment and training project team members on how to use the equipment.

Table 0-4: Challenges to Modularisation (Reproduced from Choi, 2014)

Measurement Category	Challenge Area
Cost	• Increased transportation costs due to bigger crane and large ships • Complete Engineering required earlier • Investment required earlier
Co-ordination	• Increased Engineering is a challenge to the resources
Engineering Design	• Project scope must be well designed and frozen early
Procurement	• Modules manufactured in parallel will require large equipment to be procured early
Logistic	• Insufficient supply of heavy and mega lifts resulting in the construction of smaller modules • Minimal storage space on site for modules • Module size constrained by transport restriction
Owner and Contractor Capability	• Methods and benefits of modularisation are unknown to Owners

2.7.3 Design and Engineering

A multidisciplinary effort is required early on in the process to ensure success with modularization. The use of 3D models and virtual design tools to design and also

simulate the equipment in the field has great benefits. This equipment is then load into the materials program and managed on a single platform to see the effects of late delivery or to determine when the equipment is required.

The plan for manufacturing is critical to ensure that when equipment are required as per plan that they are manufactured and available. Modularisation allows manufacturing to take place off site in workshops. The logistics to then transport these items to site is also important.

According to Department of Defence (DOD) (2018), Through increased computer speed, storage capacity and processing capabilities, digital engineering has empowered a paradigm shift from the traditional design-build-test methodology to a model-analyse-build methodology.

2.8 Advanced Construction Methods

Advanced construction methods are techniques that are beneficial as a result of modularisation. The two methods are open top construction and parallel construction.

2.8.1 Open Top Construction

Open Top construction takes place in the reactor building and containment area. In the open-top installation sequence, part of the reactor and containment wall is built (IAEA, 2011). Heavy equipment such as the Reactor Pressure vessel, containment vessel, steam generators, emergency diesel generators, heat exchangers, overhead cranes, condensers and feedwater heaters are lifted using very heavy lift cranes into place and then the rest of the construction continues.



Figure 0-8: Module installation at Sanmen Unit 1 using open top method (Reproduced from Ray, 2011)

2.8.2 Parallel Construction

Modularisation allows the application of parallel construction techniques whereby civil, mechanical and electrical can proceed for the most part in parallel (IAEA, 2014). A qualitative schedule is shown in Figure 0-9 of the conventional method of construction compared to modularization. In order to get maximum gain on the schedule, a different strategy needs to be adapted to the procurement, scheduling and module installation. The key factors are:

- Early procurement of equipment for module fabrication;
- Advanced accessibility and transportation plans;

- Extra ground surfaces allocated for heavy lifts and long lift radii;
- Extra laydown space for module handling;
- An integral module/construction management approach.

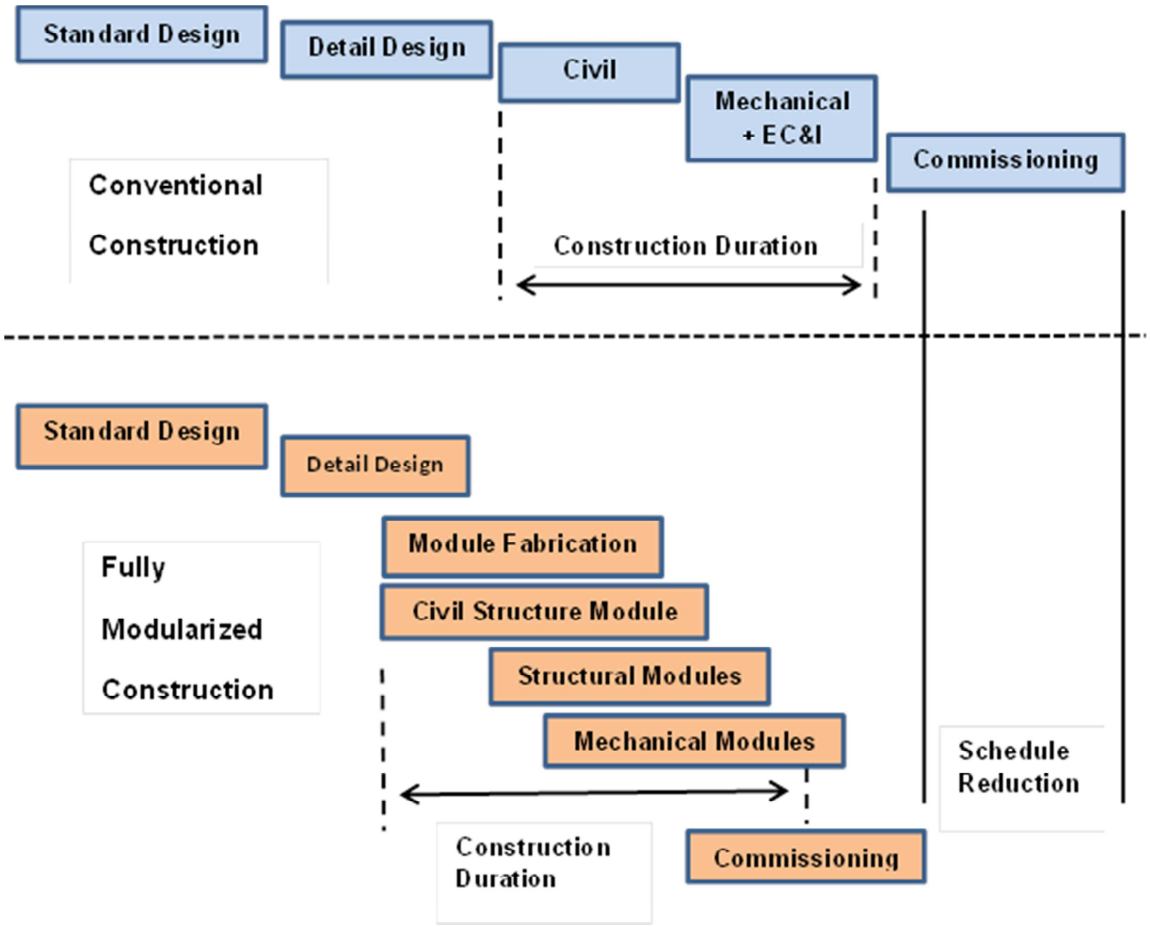


Figure 0-9: Gain in time from parallel construction (Reproduced from IAEA, 2014)

Parallel construction involves the execution of two or more activities that would normally follow after each other in a concurrent manner and thereby reduce the time required to deliver the area under construction. This technique is combined with modularization to

be effective. While the construction is progressing, the mechanical manufacturing of the module occurs concurrently.

2.8.2.1 Civil

The civil works is the longest activity on the critical path in the construction phase of the schedule (IAEA, 2014). One of the time consuming activity for the civil construction is the rebar installation. This is usually done in-situ, but for advance construction technique, prefabricated rebar modules are used. These modules are manufactured off site and then lifted into position prior to the concrete pour. Rebar is required in the base mat, containment wall and containment dome and structural walls of the reactor and turbine building.

2.8.2.2 Mechanical

Mechanical modules usually contains a number of process components, a selection of any equipment combinations of pumps, compressors, motors and control centres, heat exchangers, fans, air ducts valves, interconnecting piping, instruments, cables, cable trays and wiring (IAEA, 2014). These modules can be fabricated and assembled in a factory environment offsite and then transported and installed into its correct position. Welding is a key activity in a nuclear project and the advanced techniques used include trying to avoid welding, moving the welding off site and automating the welding.

2.8.2.3 Electrical

Cable tray supports have been improved by removing the support on one side. This reduces the amount of temporary scaffolding required and thus prevents congestion and providing better access to the multidisciplinary work areas. The use of electronic cable and racking routing will improve the cable routing system.

2.8.2.4 Control and Instrumentation

The use of multi-core cable, fibre optic cables and bus systems have created benefits by reducing the number of cables and racking required and thereby reducing the cost of cabling. The further use of 3D systems allows for advance detection of cable clashing and better planning for access to the work area. The Control system has now progressed to Distributed Control Systems which has the flexibility to be available early in the construction process to assist in functional testing of the plant and the control logics.

2.9 Digitalisation

Digitalisation is the development and deployment of digital technologies and processes in the transformation of industries (WEF, 2016). It is described as the increased interaction and convergence of the digital and physical worlds. A study conducted by Sabbagh, El-Darwiche, Friedrich and Singh ((2012) reveals that digitalisation allows managers and other stakeholders to operate with greater transparency and efficiency. Experience from the UK, USA, France suggests that digitalisation has potential to simultaneously solve several of the current challenges of nuclear power thereby increasing operational efficiency. The use of digitalisation can help build capacity in efficient management of nuclear information and resources and improve skills and competences of nuclear facility personnel. The digital has three fundamental elements:

- Data – digital information
- Analytics – the use of data to produce useful information and insights
- Connectivity – exchange of data between humans, devices and machines (including machine to machine), through digital communication network (IEA,2017)

Digitalization is the adoption of Information Technology tools and systems and combining them on a single platform to assist in delivering a project on time and on budget. These tools and system are used through the entire lifecycle of the project as shown in Figure 0-10.

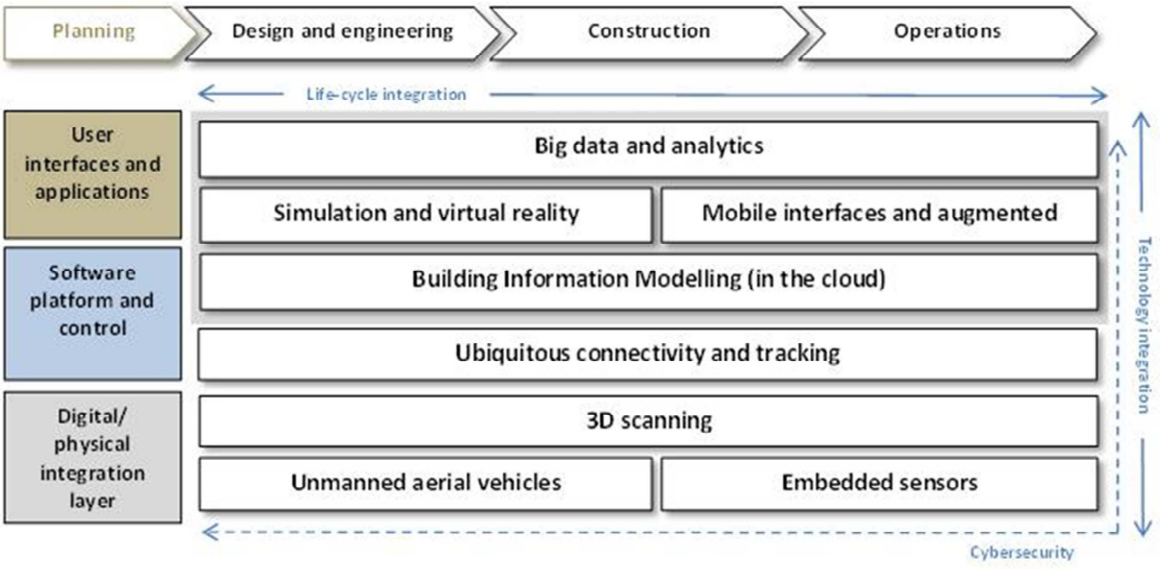


Figure 0-10: Digital tools and systems in the project lifecycle (Reproduced from WEF, 2018)

The South Korean nuclear vendors have used 4D, which is the combination of 3D technology and linking it to the planning software. The Russians have used 7D or Multi-D to successfully deliver nuclear new build projects. The system includes the 3D model, planning, costing, material management and resource management (Kim, Ma, Baryah, Zhang & Hui, 2016).

The Fourth Industrial Revolution is characterised by the fusion of technologies that is blurring the lines between the physical and digital. The timeline of the industrial revolutions is shown in Figure 0-11, indicating the future that we must prepare for and understand.

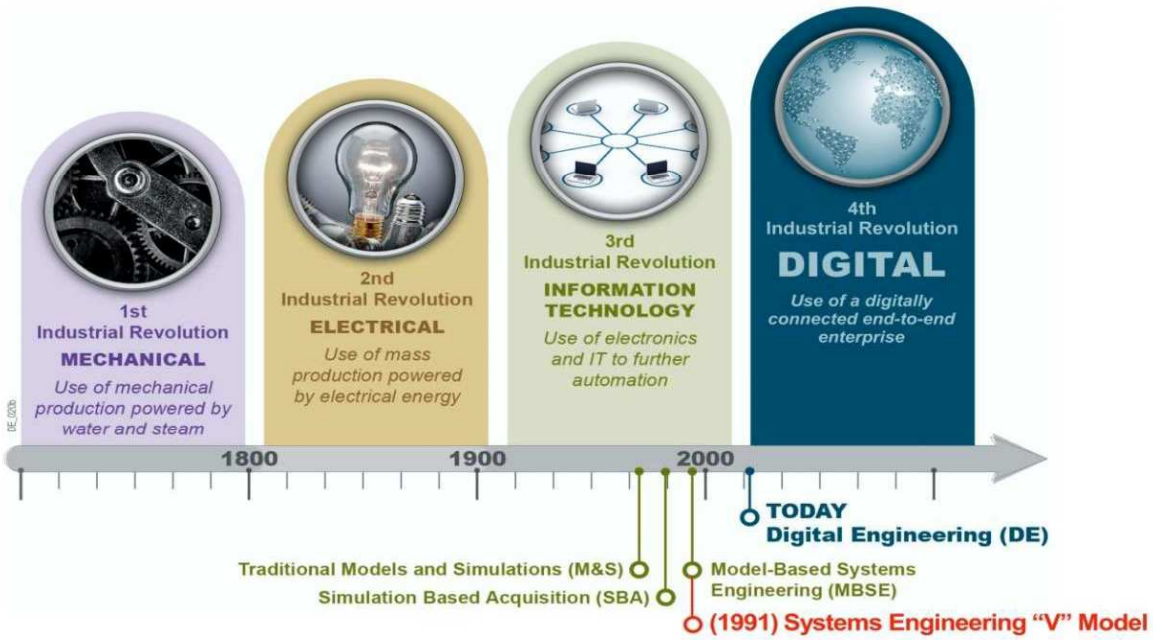


Figure 0-11: Timeline of the Industrial Revolutions (Reproduced from DOD, 2018)

One of the key systems in digitalisation is Building Information Modelling. It is an integrated platform where individual technologies provide data and when combined with other digital technologies add significant benefits to the project. These individual technologies are shown in Figure 0-12.

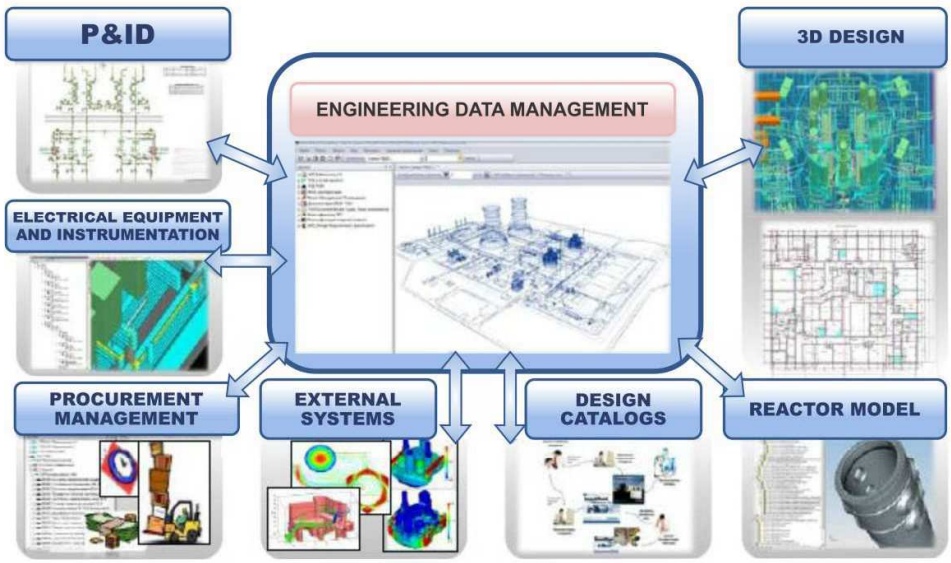


Figure 0-12: Building Information Modelling (Reproduced from Rosatom, 2015)

2.9.1 Building Information Modelling

Building Information Modelling is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from the earliest conception to demolition (Eynon, 2016).

BIM is based on object-based parametric Technologies Corporation in the 1980s as described by Hardin (2009). It became commercially available to the construction industry in the 1990s with the availability of computers with sufficient processing capability for #D CAD models. Autodesk's acquisition of Navisworks in 2007 served as a catalyst for BIM adoption among contractors due to its ability to integrate multiple BIM file types. This largely took place during the third industrial revolution. From 2007 to 2012, BIM has moved to the late majority phase of the technology adoption lifecycle".

BIM stores and provides 3D object data, shared information on scheduling (4D), cost (5D), sustainability (6D) and operations and maintenance (O&M) (7D).

A University of Maryland study showed that BIM can reduce the design phase of a project by 30% and its cost by 8%. It can also cut 10% from a project's construction phase and 3% from the construction costs (WEF, 2018)

Russian nuclear Vendor Rosatom developed the Multi D system for BIM. It has 3D object data, shared scheduling (4D), cost (5D), sustainability (6D) and operations and maintenance (7D).

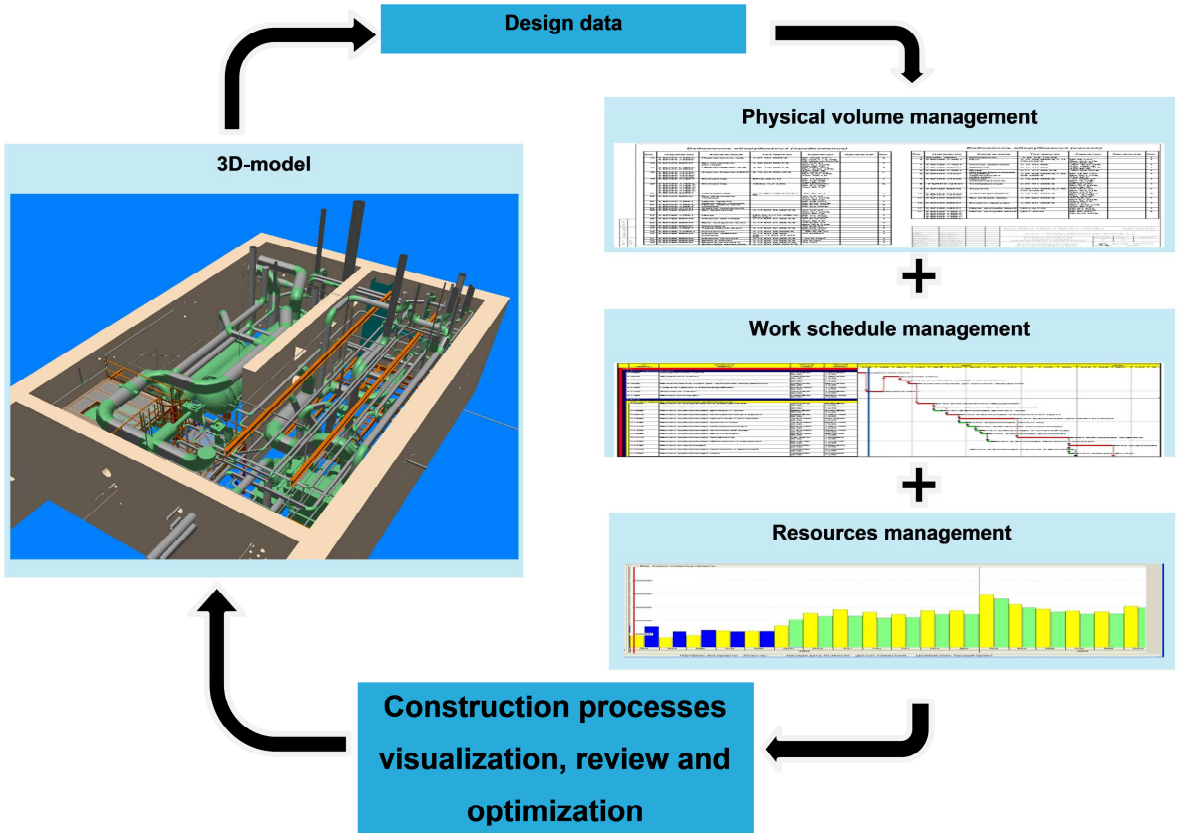


Figure 0-13: Multi D Technology used by Rosatom (Reproduced from Sachik, 2015)

2.9.1.1 Application of BIM

- **Coordination of Construction –** Documentation and installation coordination are traditional methods used in construction to ensure quality structures are delivered. Without this poor quality is the result of issues during construction and also during operations. The tools used in construction for sequencing, safety, logistics, material storage, deliveries, quality control, equipment management and reporting still operate in silos. By using BIM these two coordination processes can be aligned thus resolving clash detection on the elements or systems. BIM's integrated tools are interconnected and consolidated allowing for better-informed decisions and to respond to information more effectively.

- **Constructability –** Prior to construction commencement, constructability is used as a technique to identify roadblocks, constraints and potential issues. BIMs' use as the best practise in spatial coordination is the key reason for its rapid adoption in construction for conflict resolution between systems. BIMs real-time clash detection prevents failures in the design process.

- **Controlling scheduling –** Model elements and systems are linked to the schedule to animate the sequence of work looking at logistics of construction for efficiencies, safety and during the construction phase to justify contractor payments for work completed. Main scheduling platforms such as Asta and Primavera are used. Field BIM on tablets are used on-site to record progress and later synchronised with BIM to have an up to date view of progress.

- **Controlling Costs** – The costs are linked to the schedule and animation of the sequence of work such that owners have a clear understanding of the cost

forecast as work progresses. The model is also used to extract quantities of materials and associated costs to estimate and measure work completed for payment purposes.

- **Facilities management –** Eighty percent of the life cycle costs of a structure or building are operating and maintenance (Azhar, 2011). The 80 percent expenses often reach three times of a building initial construction cost. This figure suggests that the construction firm is operating at a loss. Thus, the costs will have a profound impact on a building's financial outlay. Nevertheless, these costs could be reduced and performance optimised by encouraging facility professionals to provide input during the design phase of the project. Additionally, it is imperative to discuss the operations and maintenance costs at the beginning of any construction activity to optimise the life-cycle of a building. Model-based facilities management focuses on leveraging the model information to reduce the owner's costs. Elements details in the model have information such as serial numbers, manufacturer, warranty information, specifications, purchasing instructions and training videos that are all available at a click of a button.

- **Analysing Data in BIM –** BIM has the ability to store a large amount of data and information as construction projects are complex. New analytics tools are available to mine through all the large amounts of data and provide information like safety reports, material inventory, subcontractor performance, schedule updates, accounting and quality that is useful in managing the project. Analysis tools provide meaningful metrics assisting construction management teams to become more productive, safer and connected.

- **Closeout –** Project closeout is the final inspection and submission of a project that includes the facility itself, supporting documentation and concluding payment per contract documents (Hardin et al, 2015). BIM has the ability to transfer linked and more meaningful closeout information digitally much earlier than traditionally done in projects.

The application of Building Information Management through the entire project lifecycle is shown in Figure 0-14. Benefits are realised throughout the lifecycle. The ability to have one system from the front end planning, until handover and through operations creates a seamless process with huge impact.

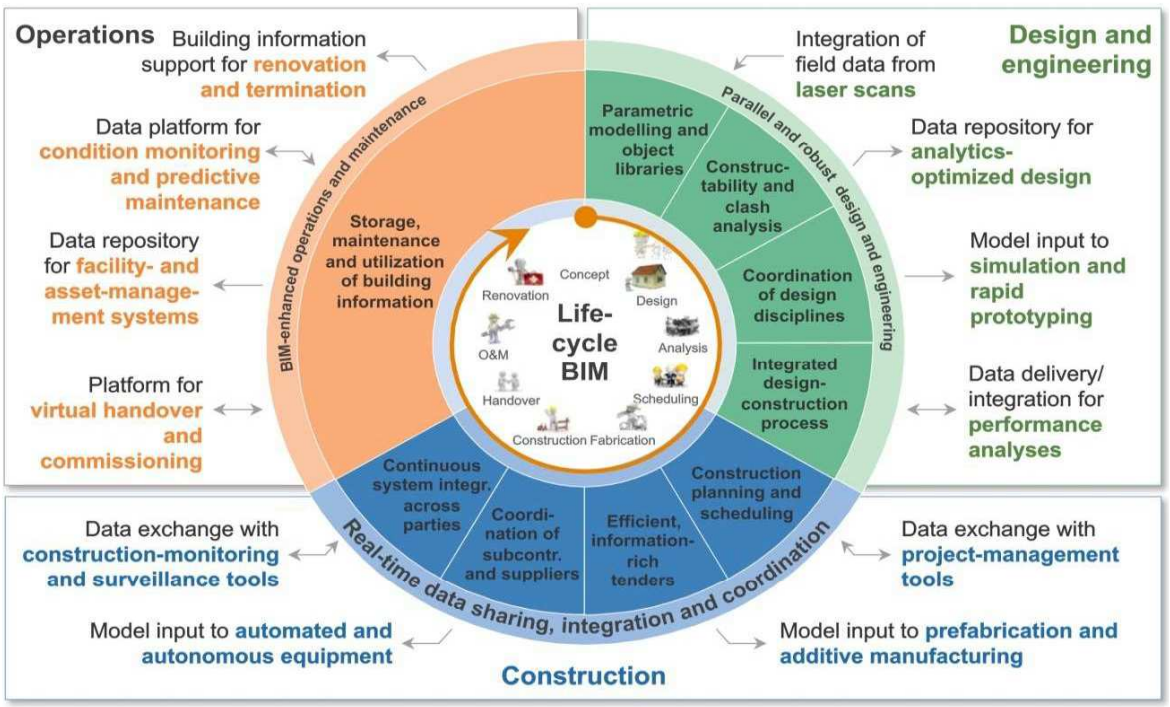


Figure 0-14: Application of Building Information Management (Reproduced from WEF, 2018)

2.9.1.2 Integration of Individual systems

Organisations globally are using digital technologies that have added value to organisations and made many activities easier and faster. These technologies are used to perform individual tasks currently on projects. The individual systems are shown in Figure 0-15. By using a common integration platform, all the technologies are integrated and linked creating a powerful tool for nuclear construction practitioners.

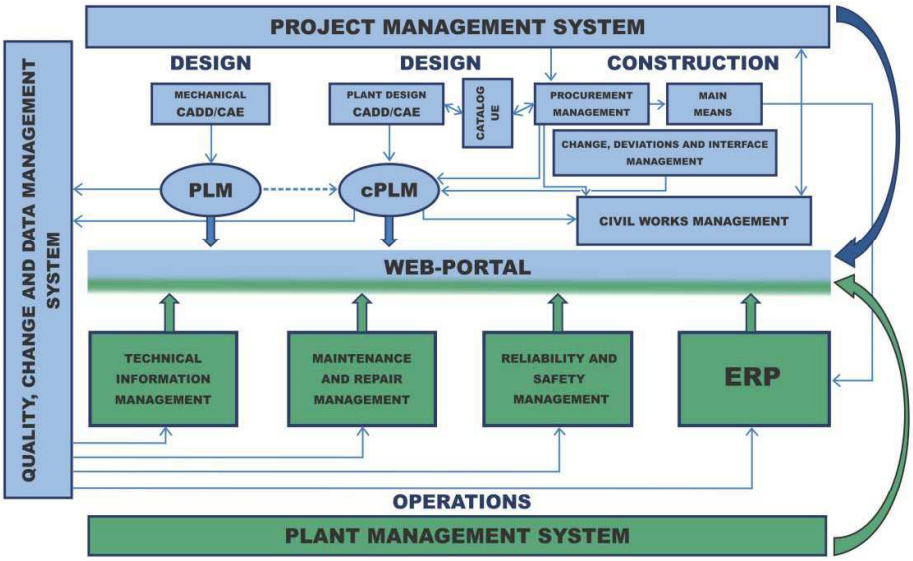


Figure 0-15: Systems integration in BIM (Reproduced from Rosatom, 2015)

2.9.1.3 Benefits of BIM

The implementation of any technology in an organisation must provide benefits realisation that makes the investment justifiable. The benefits of BIM by category and the area of benefit are shown in Table 0-5.

Table 0-5: Benefits of Building Information Modelling (Reproduced from PwC, 2018)

Measurement Category	Benefit Area
Costs	• Fewer changes made to the design • Increased collaboration and clash detection reduces cost • Reduction in the number of litigation claims • Improved interface management reduces costs
Time	• common data environment provides quicker information exchange • time reduction by 64% for cost and quantity estimation • Improved definition of information requirements • Faster streamlined procurement process • Time savings in design due to faster retrieval and review of information
Material	• Reduction in wasted material due to design accuracy • Improved accuracy of materials procurement • Reduced need for rework
Quality	• Improved quality control • Improved working environment • Reduced Failure rates
Safety	• Safety risks reduced in controlled shop environment

	• Reduced exposure to hazardous conditions • Improved work environment
Risk	• Reduction in material waste • Reduction in noise, air and water pollution • Reduced energy usage
Asset Utilisation	• Reduced rigging and working at heights • Reduced permitting process due to parallel work

In South Africa, the benefits of implementing BIM in construction projects was well documented. Kaber (2010) claims that in the early design and planning stages of projects, planners and designers are afforded the opportunity to use BIM tools such as ArchiCAD and Revit in conjunction to aid their objectives of producing the best possible design which is in line with the relevant statutes of its intended location. Kaber (2010) identifies the main benefits of BIM in construction industry in South Africa, namely: increased visualization, increased productivity as a result of accessibility of data and increased coordination of documents. Other benefits of BIM according to Kaber (2010) include the ability of embedding and linking of vital data such as specified materials, location of details, and all the quantities required for tendering and estimating purposes.

2.9.1.4 Challenges of BIM

In any project implementation there are challenges that accompany benefits. In South Africa, a study conducted by Kekana, Aigbavboa and Thwala (2015) reveals that although the benefits of BIM in construction industry, there are certain constraints which affect its implementation, namely: lack of skills, education, and knowledge on BIM. The

challenges must be understood and mitigated. Other challenges identified are listed in Table 0-6.

Table 0-6: Challenges for Building Information Modelling (Reproduced from PwC, 2018)

Measurement Category	Challenge Area
Costs	• Implementations costs for training and software • Benefits realised does not accrue to those that pay for the implementation costs • BIM perceived as net cost as difficult to quantify less tangible and other complex benefits • No clear methodology for construction clients to undertake benefits measurement and evaluation thus impacting adoption of the technology

2.9.2 Augmented Reality and Visualisation

Virtual Reality (VR) allows the user to be immersed in a computer generated world. Augmented Reality (AR) is a sub-category of virtual reality where computer generated imagery is superimposed on the real world. Bottani and Vignali (2019) explain that AR technology is becoming increasingly important, due to the ease of application development and the widespread use of hardware devices able to support its adoption. Currently, there is a growing number of applications based on AR solutions are being developed for industrial purposes. Van Krevelen and Poelman (2010) describe AR as a

set of technologies that enables the view of real world environment to be 'augmented' by computer-generated elements or objects. In other words, it is a mediated reality, where the visual perception of the physical real-world environment is enhanced by means of computing devices.

VR on the other hand is a set of technologies that enables the user to interact with a computer in a simulated environment (Khan et al., 2011). VR allows the user to be immersed in a computer-generated world. According to Dini and Dalle Mura (2015), AR has the capability to provide the user of the needed information about a process or a procedure directly on the work environment. A study reveals that VR can be used to supplement reality by blending the physical and the virtual in the actual physical environment (Johnsen & Mark, 2010).

2.9.3 Big Data and Predictive Analytics

Big data refers to large amounts of data gathered from a range of diverse sources in near real-time. Analytics is the use of data to produce useful information and insights. Big data is used in the generation, sharing and storing of data. The application BIM generates large volumes of data including planning and procurement.

2.9.3.1 Artificial Intelligence

Artificial Intelligence (AI) is the simulation of human intelligence processes such as learning, reasoning and self-correction by machines, especially computer systems.

2.9.4 Wireless Monitoring and Connected equipment

The ability to embed physical object with electronics, software, sensors and connectivity allows them to collect and exchange data creating the Internet of things (IoT), a network of internet-connect objects as described by (Zihao et al., 2018). Wireless monitoring has further been defined as hardware and software of the system designed to monitor

the well site environment (Chen, Zhang, Deng, Ge & Hu, 2017). Wireless monitoring has the advantage of working in a wide space for data collection to host centre which allows for decision to made based on the change of environmental factors (Ghini, Bettiol & Hamada, 2011; Xufeng, Xiong, Hu, Xie & Zhou, 2013).

2.9.5 Cloud and Real-time Collaboration

Cloud computing is the practice of using a network of remote servers hosted on the internet to store, manage and process data, rather than using local servers or personal computers. AlCattan (2014) posits that cloud computing technology is an emerging new computing paradigm for delivering computing services. Cloud computing is a service-oriented architecture which minimises information technology overhead for the end-user. It also has the benefits such as great flexibility, reduction in total ownership cost (AlCattan, 2014).

Collaboration considered as the process whereby individuals work together in groups towards to the shared goal collective. Real-time collaboration is a software or technology that allow several users to work together on a project in real time, or simultaneously. Shukor et al., (2011) contend that collaboration in a project requires project team members and other stakeholders to communicate and be aware of each other's activities. Lang et al., (2002) advocate that collaboration requires successful and efficient sharing of knowledge, negotiation, coordination and management of activities. Could collaboration increase participation levels, improves access to large files and facilitates brainstorming among team members. It is also an effective method which provides more insights into the process of integration and, most significantly, to improve the productivity, efficiency and effectiveness of the construction industry (Fathi et al., 2012).

2.9.6 3D Scanning and Photogrammetry

Photogrammetry involves making measurements from photographs. Aerial photographs taken from an aircraft, drone or terrestrial (close-range) method are used to create a map, drawing, a measurement or 3D model of a real-world object or scene.

Evin et al., (2016) argue that 3D digitisation is frequently used in a museum environment for research, conservation or dissemination. There are different methods to attain the 3D digitization of objects which include CT imaging, structured light scanner and photogrammetry. However, photogrammetry is commonly used as it is a low cost and versatile technique to obtain 3D model (Tsiafaki et al., 2015). Photogrammetry involves making measurements from photographs. It is an advanced construction tool that allows 3D reconstruction of surface geometry from photographs of the same object taken from multiple views (Mathys et al., 2014). Aerial photographs taken from an aircraft, drone or terrestrial (close-range) method are used to create a map, drawing, a measurement or 3D model of a real-world object or scene. Photogrammetry will play an important role in the construction of nuclear plants in South Africa. Photogrammetry will assist locate, identify and map the site with grids detailing the areas with densely populated rare plants.

Table 0-7: Benefits and Challenges of 3D Scanning and Photogrammetry

Benefits	**Challenges**
Photogrammetry enables instantaneous data capture	Photogrammetry can be difficult to set up and use
3D scanning produces higher resolution and detail	It is not easily portable

	Rapid changing technology makes purchased solution obsolete quickly

Source: Adopted from Remondino, 2011

Photogrammetry will play an important role in the construction of nuclear plants in South Africa. The sites identified for the new build are along the coast and have many indigenous rare plants growing in it. Photogrammetry will assist locate, identify and map the site with grids detailing the areas with densely populated rare plants. Site clearance activities can then be prioritised to these areas where construction activities are necessary.

2.10 Advance Building Material

With the advent of new techniques for fabrication and manufacturing and also the ability to control and modify atoms at the nanoscale, new nano structured material and devices become reality (CII, 2009).

Table 0-8: Advanced Building and Finishing Materials (Reproduced from WEF, 2016)

Type of Innovation	Examples of Advanced Materials	Benefits
Incremental Innovation - Advances on traditional materials and existing	Neopor offers 20% efficiency in insulation"	• Reduced life-cycle costs • Higher energy efficiency
	ArcelorMittal's organically coated steel achieves 30 year guaranteed durability"	• Reduced life-cycle costs • Higher energy efficiency
	iQ Natural is an advanced vinyl flooring	• Higher recyclability/

characteristics	that is 100% recyclable".	reusability • Improved health / well-being
New material combinations and multi-functional characteristics	Super lightweight ceramic sidings combine fast-hardening cement with organic fibres meeting performance at half the weight"	• Faster construction process • Reduced material costs
	Self-healing concrete, generated through the addition of bacterial spores reduces lifetime costs by up to 50%. (Early development)	• Reduced life-cycle costs
	Concrete admixed with special construction chemicals achieves 50% faster curing times	• Faster construction process
Radical Innovation – Innovative materials with entirely new functionality	Rain-absorbing roof mats, imitating the process of perspiration considerably reduces air-conditioning costs (Early development)	• Reduced life-cycle costs • Higher energy efficiency
	Micronal, a micro-encapsulated phase-change material incorporated into building materials, enables intelligent temperature management	• Reduced life-cycle costs • Higher energy efficiency
	Slippery liquid-infused porous surfaces	• Reduced life-cycle costs

	constitute super-repellent surfaces inspired by the carnivorous nepenthes pitcher plant (Early development)	• Improved health / well-being

As reflected in the Table 2-8, there are diverse innovative advanced building and finishing materials that can be used in construction projects. Each advanced building and finishing material has its unique benefits as for as construction project is concern. For instance, incremental innovation has the following benefits, namely: reduced life-cycle costs; higher energy efficiency; reduced life-cycle costs and higher energy efficiency. New material combinations and multi-functional characteristics produce benefits such as faster construction process, reduced material costs, reduced life-cycle costs and faster construction process (WEF, 2016).

2.11 Additive Manufacturing and 3D printing

Additive Manufacturing is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing technologies. Additive manufacturing and 3D printing is a game changer and this innovative technology will have a disruptive impact on the construction industry. The technology enables the production of purpose-built shapes that cannot be produced by any other method; it promises productivity gains of 80% for some applications, together with an important reduction in waste (WEF, 2016). Key challenges with the technology includes resolution issues as large items printed have issues, speeds are slower for larger items and the costs. The technology has found traction in the construction industry with steel and concrete components now being printed for use.

Additive manufacturing has advantages over conventional manufacturing including reductions in lead time, reductions of scrap materials, lower inventory costs, less manufacturing complexity, reduced floor space and the ability to deliver manufactured pieces with complex shapes and geometries.

2.11.1 Digital Twins

“Digital technologies have had an impact on the way products are manufactured” (IEA, 2017). Manufacturing for nuclear projects need to transform to adapt to digital technologies as it has the ability to add tremendous value to the construction process. Early adopters of digital technologies such as aircraft manufacturer Boeing has developed models to leverage digital technologies as shown in Figure 0-16. By taking the system engineering design “V” model, Boeing has created the diamond model of digital twins. The top half of the model is the virtual representation of the physical system. This allows for the design, engineering, production planning, production and certification to take place in the virtual world. Once all issues and risks are resolved, the manufacturing takes place in the physical world. The bottom half of the diamond represents the physical systems. The centre of the diamond represents the systems and models to support the virtual and physical worlds. The digital twins’ model is a powerful tool. Similar application of this process to building information modelling creates the ability in a project to “build it twice”, once in the virtual world and then the physical construction.

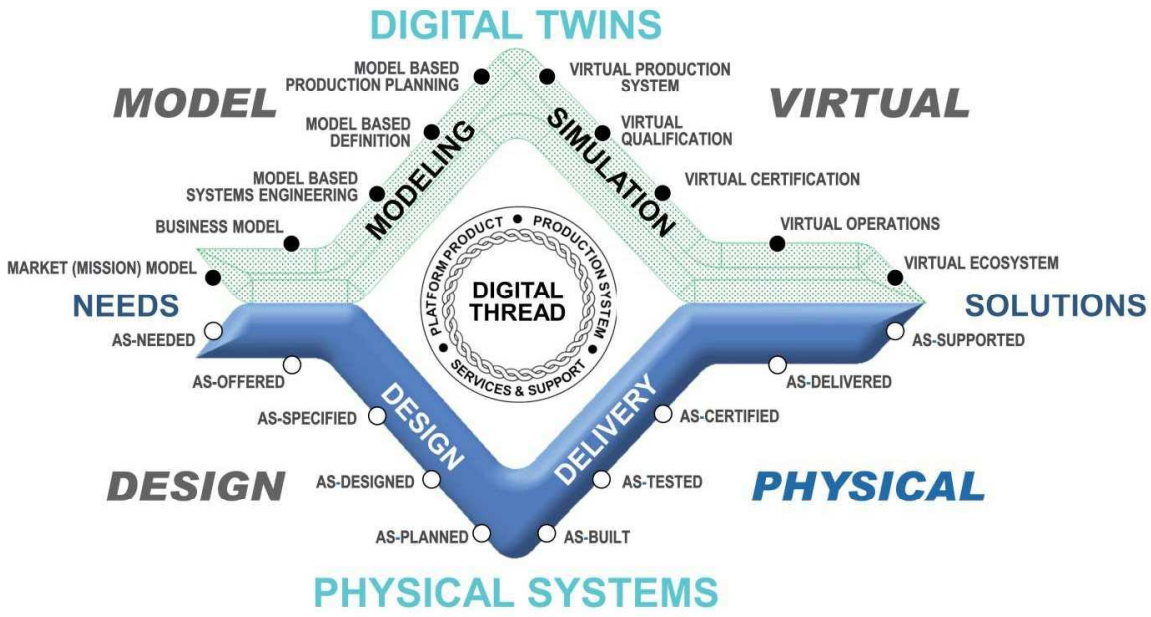


Figure 0-16: Digital Twins Model (Reproduced from Seal, 2018)

2.12 Autonomous Construction

The construction industry generally has low levels of automation. New technologies in the digital space could become significant enablers of innovation in construction equipment. These technologies include robotics and drones (WEF, 2016).

2.12.1 Robotics

Robotics is the science of designing, building and applying robots. In construction, automation and robotics technologies are used in all stages, from the automation of the design process through the use of Computer Aided Design, the production of cost estimates, construction schedules and project management. The benefits include enhancing productivity and work efficiency with reduced costs, solid quality with higher accuracy and occupational safety enhancement (Strukova & Lizka, 2011). Table 0-9 and Table 0-10 summarises the benefits and challenges with these technologies.

Table 0-9: Robotics in Construction (Reproduced from Ruggiero et al, 2016)

Type	Advantage	Challenges
Demolition Robots: Used for tearing down building walls and structures.	• Requires one worker behind the controls • Safer as human away from demolition structures	• Application mainly for small scale demolition • Job loss • Requires significant power source
Brick laying Robots: Performing tedious tasks as brick layering	• Task performed efficiently and quickly	• High Investment cost
Welding Robots: Precise welds joining metal in steel structures	• Safer for workers • High quality of welding	• Stationary device requires worker intervention
Exoskeletons: Mechanical suits enhancing human task ability	• Allows worker to lift heavier objects • Allows disable people to work on site	• Excessive cost
Forklift Robots:	• Low cost of ownership • Ability to lift large loads	• Terrain limitations

2.12.2 Drones

Drones are unmanned that are controlled remotely by human interface and are used to perform tasks (Ruggiero et al, 2016).

Table 0-10: Drones in Construction (Reproduced from Ruggiero et al, 2016)

Type	Advantage	Challenges
Transportation Drones:	• Attain high locations easily	• Affected by wind
Survey Drones:	• Capture images in multiple angles in short space of time	• Poor quality of images

2.12.13 Cyber Security

Digitalisation brings many benefits, but cybersecurity remains a key risk. "Cyber-attacks generally target the computers, software and networks used to control, monitor, manage and protect the IT business systems. The techniques can target personnel, products (both data and physical infrastructure and processes (System Data Flow). It is paramount to protect the integrity and confidentiality of information (IEA, 2017). A summary of cyberattacks over the past years are described in Table 0-11. Furthermore, geomagnetic storms are natural hazards that pose risks to the technology.

Table 0-11: Cyber Attacks affecting Energy Infrastructure (Reproduced from IEA, 2017)

Incident	Description
WannaCry (2017)	Using a weakness in the Microsoft operating system, the "WannaCry" ransomware hit hundreds of thousands of computers in thousands of organisations in 150 countries.

	Power plant infrastructure was not attacked, but several energy companies went offline.
Nuclear Plant Ppear Phising Attack (2017)	Hackers in the United States used email messages containing fake Microsoft word resumes for engineering jobs thus exposing recipients' credentials for the control engineering network.
Industroyer / Crash Overide (Ukraine, December 2016 – reported May 2017)	Malware Industroyer (Crash Override) used in a significant attack on the Ukraine electricity system. The malware enables attackers to view, block, control or destroy grid control equipment such as circuit breakers. This was an example of a cyber breach into the control systems of critical infrastructure.
The Mirai Botnet (2016)	Mirai malware exploited low security in connected smart devices such as cameras to deliver the largest denial of service attack to date. This illustrates the vulnerability of Internet of things.
Western Ukraine power grid (2015)	Cyber Attackers accessed substations' supervisory control and data acquisition (SCADA) and firmware with a combination of malware, personnel credentials obtained by means of email phising and denial of service to prevent customers from obtaining call centre information about the blackout.

Digital security should be built around 3 key concepts:

- **Resilience –** system's ability to withstand shocks and quickly recover or adapt to a desired level of stability while preserving the continuity of critical infrastructure operations.

- **Cyber Hygiene –** creating awareness, secure configuration of equipment and networks, keeping software up to date, avoid users gaining unnecessary system privileges and data access rights and training to establish a security conscious culture organisation wide.

- **Security by design –** incorporation of security objectives and standards as core part of the research and design phase.

2.13 Skills for Advanced construction techniques

It is vital to identify the skills required in South Africa for new nuclear plant construction and develop the necessary infrastructure to commence and be prepared for the construction. Key manufacturing skills will require a detailed plan with training standards to support the program. Nuclear skills require more time and also experience. As part of the localisation effort, training will be critical in ensuring success.

Table 0-12: Skills required in construction in the future (Reproduced from WEF, 2018)

Skills in 2018	**Skills in 2022**
Analytical thinking and Innovation	Analytical thinking and Innovation
Active learning and learning strategies	Active learning and learning strategies
Creativity, originality and initiative	Creativity, originality and initiative

Attention to detail, trustworthiness	**Technology design and programming**
Critical thinking and analysis	Critical thinking and analysis
Complex problem solving	Complex problem solving
Leadership and social influence	Leadership and social influence
Emotional Intelligence	Emotional Intelligence
Reasoning, problem solving and ideation	Reasoning, problem solving and ideation
Coordination and time management	**Systems analysis and evaluation**

As observed from the Table 2-12, the WEF (2018) identifies critical skills that will be required in the construction sector in the future including analytical thinking and innovation, active learning and learning strategies, technology design and programming, critical thinking and analysis, complex problem solving, leadership and social influence, emotional intelligence, reasoning, problem solving and ideation, systems analysis and evaluation, creativity, originality and initiative. However, in South Africa, one of the biggest challenges facing construction sector is skills shortage (Erasmus & Breier, 2009; Makhene & Thwala, 2009). The Constriction Industry Development Board (cidb) (2007) notes with much concern that the challenge of the quality and relevance of the training that students received from training programmes and what is required of them has had an adverse effect on the skilled worker supply pipeline.

Construction is a labour-intensive industry, and it places much emphasis on the skills of its workforce. Thus, the construction industry requires workforce who possess unique skills to assist in managing projects. To this end, for ESKOM to properly execute its

nuclear projects, it will require people with special skills such as technical, analytical thinking and innovation, technology design and programming, critical thinking and analysis, problem solving and ideation, systems analysis and evaluation, creativity, originality and initiative. Nevertheless, these skills need updating continually since most of the trades involved in the construction industry become increasingly specialised. In addition to the need to update the workforce skills, ESKOM should join the competition for talent in order to identify, attract, develop and retain workforce with high potential skills. Universities should also play an important role in addressing the skills shortage in the construction industry by training more students to acquires skills that are relevant to the construction field.

2.14 Requirements for Successful Advanced Construction Technologies Implementation

In order to implement advanced construction technologies, companies require steps that include best practice based on experience achieved globally. This process is shown in **Error! Reference source not found.**. This study will focus on the company level actions require and not focus on the sector level and government level actions. The company level actions are grouped in four sections and will be dealt with in the section below.

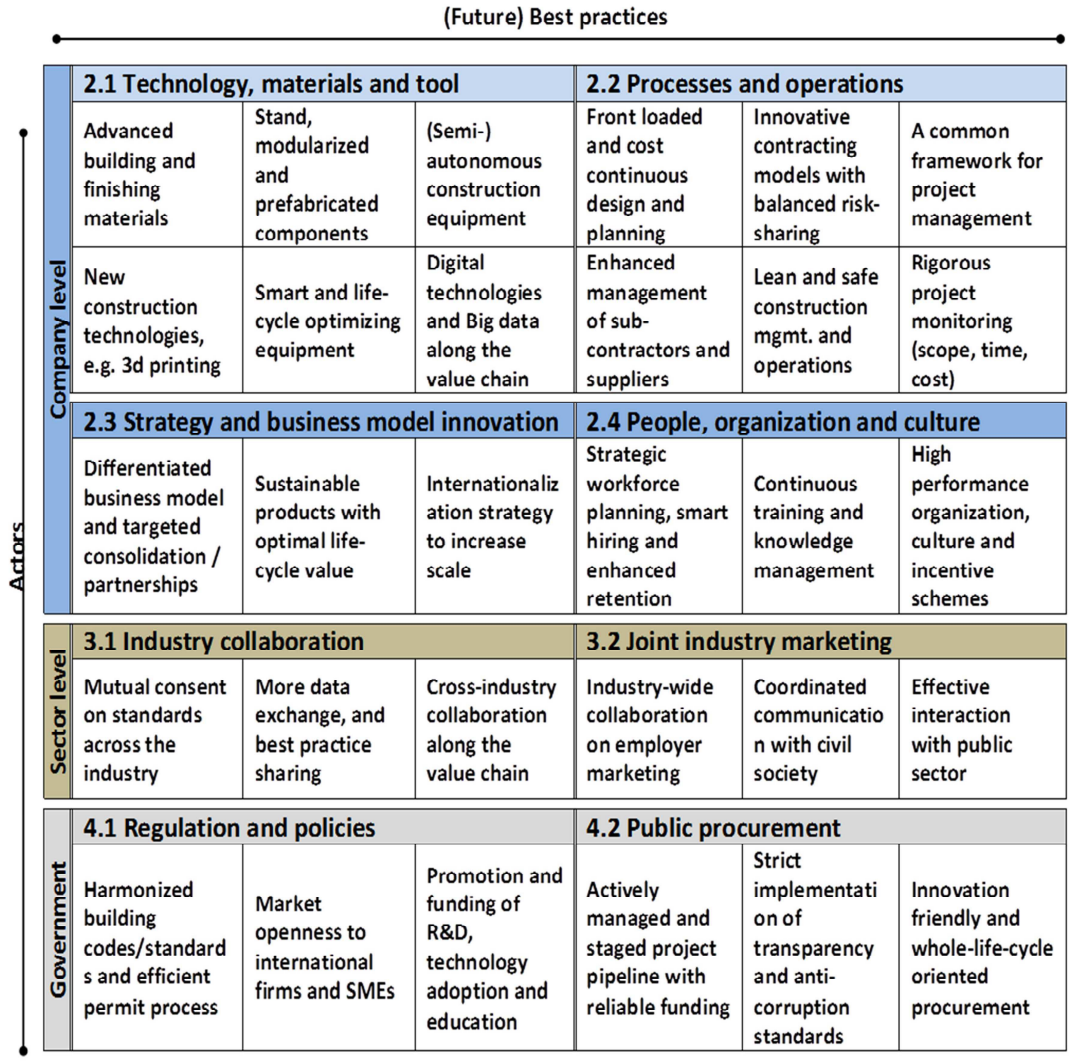


Figure 0-17: Digital transformation best practice (Reproduced from WEF, 2016)

2.14.1 Technology, Materials and Tools

Companies need to adopt advanced construction technologies. These include advanced building and finishing materials, standardised, modularised and prefabricated components, automated construction equipment and digital technologies and big data (WEF, 2016). Advanced construction technology plays a successful role in helping construction firms to improve on their efficiency and effectiveness (Ioannou & Liu, 1993). Evidence shows that the adoption of advanced construction technology can improve construction industry productivity by 30-45%, and improved material

predictability and reliability (Chudley & Greeno, 2005). A study carried out by Zhou, Irizarry and Li (2013) shows that technology adoption is deemed an effective way to increase construction safety management. It has also been found that automation improves most key areas in construction sector including cost, schedule, quality, safety and production (Chudley & Greeno, 2005).

New advanced construction materials provide opportunities to change the way in which firms construct and retrofit buildings (Delgado, Cerný, de Lima & Guimarães, 2015). The advanced construction material also give added value by increasing performance and functionality. It has been argued that reduction of carbon footprint for construction materials can start at the production phase, where energy efficient processes can be developed and waste or recycled materials can be employed. Advanced construction material can also help address the new challenges of durability in a changing climate (Delgado, Černý, Barbosa de Lima & Guimarães, 2018).

2.14.2 Processes and Operations

To achieve substantial improvements in construction productivity and to reduce operating and maintenance costs, companies need to ensure that, during the design and engineering phase, they keep the actual construction process in mind as well as the final operations phase (WEF, 2016). The construction industry is a complex and dynamic industrial sector which involves several role players at various stages. Projects within the construction sector requires processes and operations such as planning, design, construction, and maintenance (Mohd Nawi, Baluch & Bahaudin, 2014.)

2.14.3 Strategy and business model innovation

Companies need to improve collaboration at project level in order to bridge the gap with knowledge and skills. The strategy can also be to partner buy companies that can

provide the knowledge and skills needed for advanced construction technologies (WEF, 2016). For construction industry to compete internationally and achieve growth and competitive advantage, they need to pursue strategies such as existing competitor's strategy and global positioning strategy (Han, Kim, Jang & Choi, 2010).

2.14.4 People, Organisation and Culture

With the increasing sophistication of technologies, new and broader skills sets are required at all levels of the company (WEF, 2016). People need to continuously trained and effective retention strategies in place to keep staff. Companies need to have a high-performance culture in place.

To survive in the nuclear construction industry, firms should be ready to adjust themselves and respond to some of these forces that might occur. These forces may present both opportunities and threats to nuclear construction firms.

2.15 Conclusion

The literature survey performed in this chapter identified by thematic method the key advanced construction techniques. The chapter discusses key items in understanding the technology and provides benefits and challenges. Skills required for these technologies are identified and discussed. A best practice process is identified and discussed for the implementation of nuclear projects.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

The chapter described the research methodology and research methods adopted to empirically investigate the research questions and objectives. Careful selection of a research methodology was necessary to avoid selecting inappropriate research methods for the study. The researcher reviewed literature on research methodology which enabled him to be conscious of the strengths and weaknesses of different research methods. The chapter addressed methodological issues such as the research design, research method, the location of the study, target population of the study, sampling technique and procedures, sample size, data collection instrument, data quality control, data measurement scale, data analysis and ethical consideration.

3.2 Research Objectives

The objective of the research was to develop a framework that stakeholders in the construction of nuclear projects in South Africa can use in the future. This objective was realised by making use of the methodology as shown in Figure 0-18. A literature review has been conducted to gather adequate and relevant information on the experience of the usage of advanced construction techniques globally. The knowledge obtained from the findings, existing models and empirical work was used to develop the conceptual model that which guide the study as shown in Figure 0-19. The data collected from the survey questionnaire was analysed and key findings documented with the necessary recommendations and conclusions.

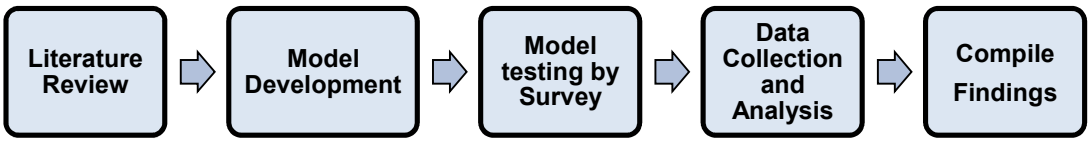


Figure 0-18: Research Methodology

3.3 Research Design

The main purpose of research design is to assist the researcher to plan and complete the study in a systematic manner (Hayes, Bonner & Douglas, 2013). A good research design contains a detailed plan of how an investigation would be carried out (Sekaran & Bougie, 2013). There are different kinds of research designs, namely: descriptive; explanatory; exploratory; action research; survey; experimental; cross-sectional research; and case study research. These research designs can be categorised under experimental and non-experimental research. However, the study was based on non-experimental research method using the thematic method to survey literature that has practical relevance.

In this regard, a descriptive study was conducted with the view to adequately and accurately describe the research phenomenon (Dane, 2011). The scholars such as Thomas (2010) and Royse (2011) argued that a descriptive research is a large-scale numerical study which attempts to provide accurate and detailed picture of the patterns of a particular group and to distinguish them from other phenomena. In this study, the descriptive study helped the research to accurately describe the researcher phenomenon which helped in gaining a true picture of the existence of the phenomenon. The data gathered resulted in a model development as shown in Figure 0-19. For each of the technologies a common set of information was discussed

including benefits and challenges, skills requirements and success factors for implementation. The theory gathered was tested with a sample of respondents using a survey questionnaire as data acquisition method. A qualitative method was used for data analysis. Using this information, the necessary conclusions and recommendations were made.

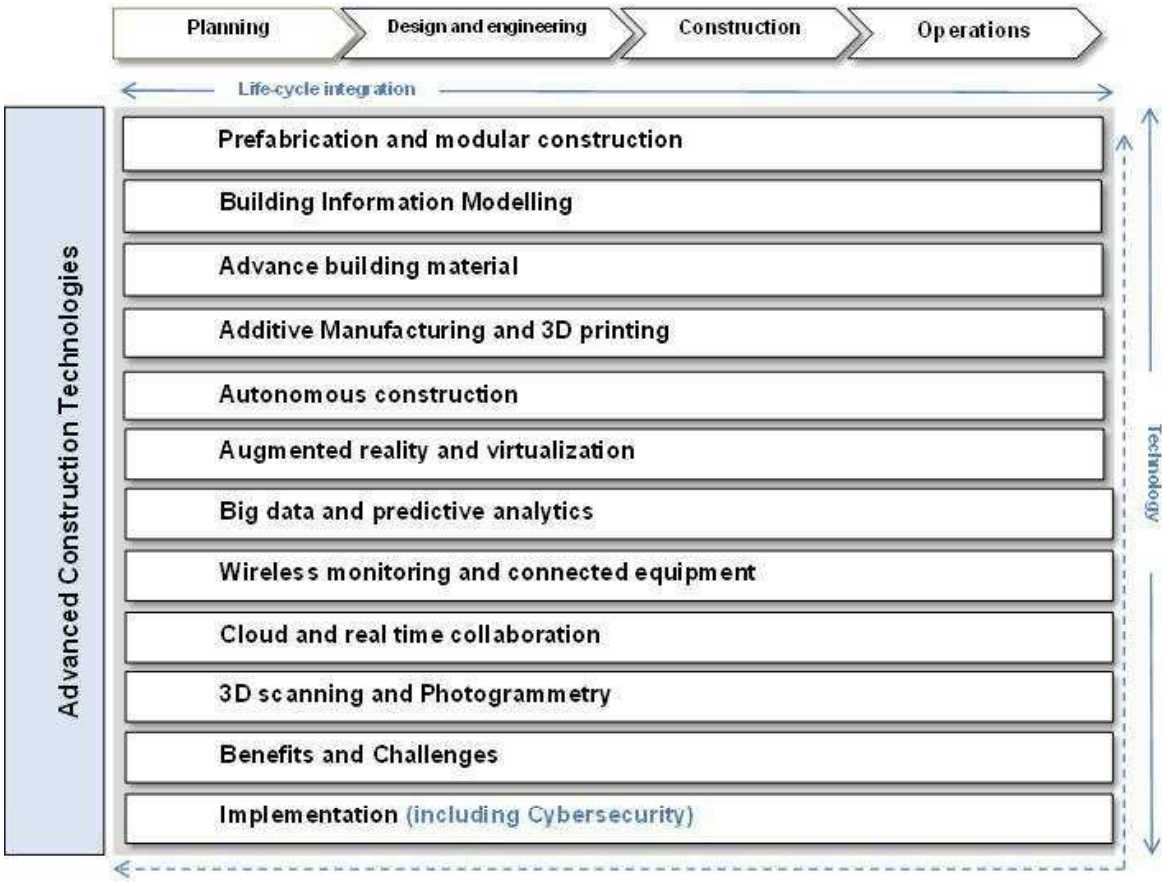


Figure 0-19: Model to be used for this study

3.4 Research Method

There are three methods of research, namely: quantitative, qualitative and mixed methods research. Each method of research is unique in a specific study depending on the nature of the study and the research design. However, for the purpose of this study,

a quantitative research was conducted. Sekaran and Bougie (2016) postulated that a quantitative research is often conducted when the desires to collect numerical data. Quantitative research method is unique in its surveying and experimentation, as it builds upon existing theories (Williams, 2011). A quantitative research maintains the assumption of the positivist paradigm which states that research itself is independent of the researcher. Abiwu (2016), in his study, argues that quantitative research is useful in scientific research because it provides meaningful understanding through objectivity uncovered in the data gathered. According to Abiwu (2016), quantitative research uses several strategies of inquiry such as experimental and surveys and collect data on predetermined instruments that yield statistical information. In this study, a quantitative research was conducted with the view to make meaning of the data through the use of sophisticated statistics. Furthermore, a quantitative research conducted because it is easy to analyse the data.

3.5 Population and Sample

Guzman (2010) describes population as the collective or total of all the items, subjects or things which form part of a large society which the researcher intends to study. The target population of the study was the employees at Nuclear Project Management Environment within the Eskom. The Nuclear Project Management Environment has many disciplines that work together to deliver the project. Advanced construction technologies were used across these disciplines. It is therefore important to ensure that the population provides a representative sample for the study. The sample size of 35 was drawn from Eskom's Koeberg Operating Unit's project management and engineering teams, NECSA project management team, nuclear power plant vendors.

3.6 Sampling Technique

Abiwu (2016) defines sampling technique as the method of selecting some elements, portion, units or fractions of the study population to represent the entire population in a specific study. There are two methods of sampling, namely: probability and non-probability sampling. Probability sampling technique provides a known non-zero chance of selection from each population element, and the simple random sample is considered as a special case in which population has a known and equal chance of selection. Non-probability sampling on the other hand, refers to a sampling technique which is based on a subjective or non-statistical approach to selecting a sample (Sekaran & Bougie, 2016). The nature of the study (quantitative research) required the researcher to used probability sampling technique to select the participants for the study.

Probability sampling has various techniques such as systematic sampling, stratified sampling, cluster sampling and simple random sampling. However, stratified sampling technique was used to select the participants for the study. Etikan and Bala (2017) suggested that stratified sampling technique is used when the researcher perceives that the target population from which sample will be drawn does not have homogeneous group. Odoh (2015) explains stratified sampling as the process of segregating the population into several mutually exclusive subpopulations, or strata. Having divided the target population into different sub-groups, the researcher will then have to decide on which of the sub-groups to select for the study and draws the sample from each sub-groups, using either simple random or systematic sampling, until the required sample size is achieved (Bryman & Bell, 2011; Wilson, 2011).

The target population within the Nuclear Project Management Environment was sub-divided into different groups and simple random sampling was used to select the

participants. Stratified sampling was used to ensure that each of the group was adequately represented in the study.

3.7 Research Instrument

The research instrument used in this research study was a questionnaire survey. Questionnaire is the most popular survey method in quantitative research. A questionnaire contain a list of items designed to solicit specific information from a particular group of people (Sekaran & Bougie, 2016). The survey explored the experience of respondents with advanced construction techniques and provided a better understanding of key areas that the framework needs to address. The literature survey provided all the key information that will form part of the framework. The survey questionnaire was used to verify if the data obtained from the literature survey has any correlation. The questionnaire was divided into two sections, biographical details and section on advanced construction techniques. An introductory page laid out the key reasons for the study and also instruction on completing the questionnaire and details for return of the survey. Nominal and Likert scales were used in the questionnaire for respondents indicate their choices. Once the key data were identified the questionnaire was designed, constructed and sent to some of the subject matter experts to review and updated with the relevant comments. Stratified random sampling was used to identify the list of individuals to send the survey. The survey was delivered by mean of outlook with prior notification.

3.7.1 Procedure for Data Collection

The data collection tool for this research study was a questionnaire that was developed using data from the literature review. After compilation, the questionnaire was rigorously

reviewed by nominated individuals. The distributed questionnaires were collected and, in some cases, reminders were issued.

3.8 Pre-Testing

Prior to the data collection, a pilot study was conducted to test the research protocols and procedures for the investigation. Gumbo (2014) sees a pilot study as mini research which aims to test the feasibility of procedures and to gather information prior to a larger study. The pilot study was conducted among three employees within the organisation. These participants were excluded from the actual study. The questionnaires were further given to experts who have adequate knowledge of the subject matter for their inputs. The validity and reliability of the questionnaires were determined before the commencement of the data collection.

3.9 Data Quality Control

Data quality control was measured through the use of statistical tools such as reliability and validity. Sekaran and Bougie (2016) defined reliability as the consistency of research instrument when adopted. This relates to the fact that the research instrument should produce the same scores or results over repeated measures. To determine the reliability of the instrument, Cronbach's alpha efficient was computed using Statistical Package for Social Science. According to the rule of thumb, the Cronbach's alpha efficient score of 0.70 and beyond was considered as reliable.

Validity on the other hand refers to the extent to which the research instrument measures what it is supposed to measure (Sekaran & Bougie, 2016). The validity of the research instrument (questionnaire) was established using content validity. Content validity refers to the representativeness or sampling adequacy of the content of a measuring instrument. Factor analysis was further employed to test the validity of the

research instrument. Two types of factor analysis were computed in this study, namely: Rotated Component Matrix and Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett's Test. The KMO and Bartlett's Test measures the adequacy of the sample size which ranges from 0 to 1, reaching 1 when each variable is perfectly predicted without any error by other variables". The scores can be interpreted as follows: 0.80 or above (meritorious); 0.70 or above (middling); 0.60 or above (mediocre); 0.50 or above (poor); and below 0.50 (unacceptable).

As part of a validation process, a number of subject matter experts were used to validate the information gathered for this research study as shown in Table 0-13. The data obtained from the literature survey was verified using the survey questionnaire as positive response to the questions.

Table 0-13: Subject Matter Experts

Name of Expert	**Area of Expert**	**Contact information**
Dave Nicholls	Nuclear Power Plant	0838002125
Chrystal Robinson	Nuclear Safety	0824571227
Rod Speedy	Nuclear Project Management and construction techniques	0832605254
Des Muller	BIM	0728080200

3.10 Data Analysis and Interpretation

The data collected from respondents were coded and analysed using using the Statistical Package for Social Sciences (SPSS), version 25.0. The analysis and interpretation of the results were done by employing both the descriptive (i.e. mean, minimum, maximum, standard deviation) and inferential statistics (i.e Cronbach's alpha coefficient, factor analysis, correlations and analysis of variance-Anova and Post Hoc Scheffe's Test)

3.11 Ethical Considerations

Ethical considerations remain key issues in every research which must be addressed by the researcher. Ethical approval for the study was granted by the research office in the University. The ethical considerations addressed in this study were, namely: informed consent, anonymity and privacy.

(i) Informed Consent

An informed consent remains a key issue in every research. The participants were first approached by the researcher to participate voluntarily in the study. A written informed consent form was given to each respondent, which contained the methods and procedures for the investigation, the risks and potential benefits associated with the study. Each participant was asked to read and sign the form to indicate his/her voluntary participation in the study.

(ii) Anonymity

The principle of anonymity was ensured by substituting the participants' names with pseudonyms and limiting their identity information within dissertation, oral presentations, and subsequent publications.

(iii) Privacy and Confidentiality

Data gathered from the respondents were kept secret at secured and safe place within the University. The data will be kept for five years after which it will be destroyed based on the University's policy.

(iv) Bias

The potential bias in the study was eliminated by giving the participants the opportunity to verify and confirm the results of the study. The results were sent back to the research participants for them to verify and confirm their authenticity. Furthermore, the results of the study were discussed with the supervisors to ensure their credibility.

3.12 Limitations of Study

The study was confined to the construction phase of the project lifecycle. The advanced construction techniques field is vast and thus only ten key technologies were discussed in this research study. Due to the limitation of time, this study was not an in depth look at all aspects of advanced construction techniques.

3.13 Conclusion

South Africa's future energy planning has nuclear as one of the technologies that will need to be delivered successfully. This success can be achieved by utilising advanced construction techniques that similar new build constructions projects have adopted globally since the digital age and the arrival of the fourth industrial revolution. A block diagram showing the research methodology was developed. A model for the research was formulated based on the literature review carried out. A survey questionnaire was then developed. The plans for data collection, analysis and verification were discussed.

CHAPTER FOUR: PRESENTATION OF RESULTS

4.1 Introduction

This chapter of the study deals with the presentation and analysis of the data. A total of 35 questionnaires were administered to the respondents. A total of fifteen (15) respondents returned the completed survey questionnaire to the researcher, which indicates a 43 percent response rate. From these responses, a total of eleven (11) were nuclear professionals and four (4) were non-nuclear but part of the advanced construction industry as vendors or professionals. The responses received are deemed statistically acceptable to carry out this research study. The 15 questionnaires were then coded in Excel and later exported to the SPSS, version 26 for analysis. The analysis and interpretation of the results were done by employing both descriptive and inferential statistics such as mean, minimum, maximum, standard deviation, Cronbach's alpha coefficient, factor analysis, correlations and analysis of variance-Anova.

4.2 Response and Non-Response Rate

Figure 4.1 shows the results of the total number of the surveys that were administered and the number of the surveys that were retrieved from the respondents.

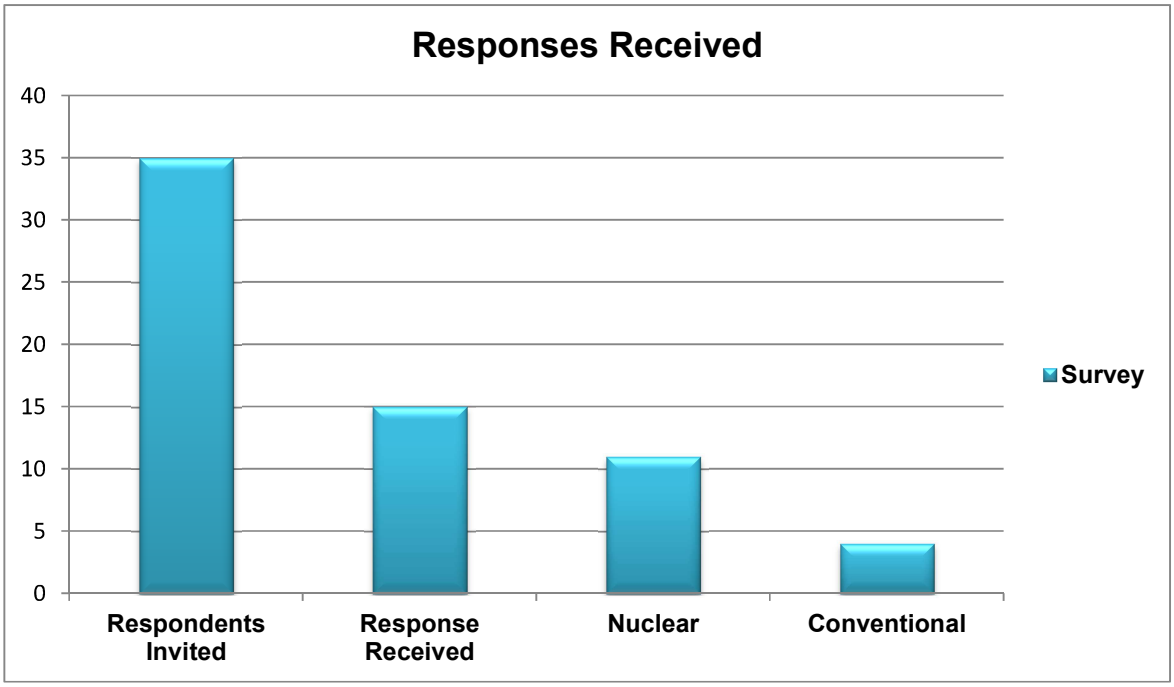


Figure 0-1: Responses Received

As shown in the Figure 4.1, out of the total surveys (35) administered, only 15 were retrieved, which represented 42.86% response rate, while the remaining 20 that could not be retrieved accounted for 57.14% non-response rate. The information from the Figure 4.1 further suggests that the majority (N = 11) of the respondents were from the nuclear unit, whereas only a few (N = 4) were from the conventional unit.

4.3 Reliability: Cronbach's Alpha Coefficient

To determine the reliability of the research instrument, the Cronbach's alpha coefficient was computed. As discussed in the previous chapter, reliability measures consistency of research instrument. According to the rule of thumb, the Cronbach's alpha efficient score of 0.70 and above is considered as reliable, hence the instrument should be accepted. The reliability scores are shown in the Table 4.1.

Table 4.1 4.3 Research Reliability: Cronbach's Alpha Coefficient

Dimension	Number of Items	Cronbach's Alpha Score
All items	67	0.75

From the Table 4.1, the 67 items which measured the advanced construction techniques has the Cronbach's alpha coefficient score of 0.75, exceeding the recommended value. The Cronbach's alpha coefficient score (a = 0.75) suggests that the instrument used to collect the data was reliable, therefore can be adopted by researchers for the same or similar research. The proceeding section presents the findings on the validity of the research instrument.

4.4 Research Validity: Factor Analysis

The validity of the research instrument was assessed using Factor Analysis. In this study, two sets of Factor Analysis were computed, namely: Rotated Component Matrix and Kaiser-Meyer-Olkin measure of sampling adequacy. In extracting the factors, only items with loadings >0.5 were considered significant. With regard to the Rotated Component Matrix, if an item loaded significantly on more than 1 factor, only that with the highest loading was considered. On the other hand, KMO and Bartlett's Test assesses the adequacy of the sample size ranging from 0 to 1, reaching 1 when each variable is perfectly predicted without experiencing any error. The interpretations of the KMO scores are, namely: ≥ 0.80 (meritorious); ≥ 0.70 (middling); ≥ 0.60 (mediocre); ≥ 0.50 (poor); < 0.50 (unacceptable). The results are shown in the Table 4.2 and 4.3 respectively.

Table 4.2 Validity: Factor Analysis, Rotated Component Matrix

Items	Component					
	1	**2**	**3**	**4**	**5**	**6**
MOD1	0.142	0.973	0.008	-0.141	-0.100	-0.043
DIG2	0.749	-0.114	0.322	-0.120	-0.184	0.522
ACTBA	0.924	0.215	0.282	-0.031	-0.014	0.134
ACTBB	0.473	-0.330	0.526	0.304	0.052	-0.538
ACTBC	0.616	0.548	0.058	0.114	0.233	-0.493
ACTBD	-0.198	0.684	0.247	0.178	0.295	-0.559
ACTBE	0.435	0.268	0.085	-0.264	0.698	-0.292
ACTBF	0.363	0.039	0.083	0.637	0.664	-0.079
ACTBG	0.036	0.186	0.314	0.042	0.024	0.094
ACTCA	-0.207	0.672	0.081	-0.451	-0.077	0.164
ACTCB	0.968	-0.085	-0.202	-0.057	-0.041	0.015
ACTCC	0.571	0.569	0.054	0.371	-0.173	0.011
ACTCD	0.078	0.512	0.817	0.037	0.041	0.211
ACTCE	0.198	-0.132	0.361	0.153	-0.598	-0.652
ACTCF	0.163	0.128	-0.034	0.474	-0.749	0.0311
DTA	0.780	0.523	0.042	0.286	-0.154	0.056
DTB	-0.572	0.351	0.632	0.005	0.069	0.154
DTC	0.619	-0.390	0.452	0.460	-0.008	0.213
DTD	0.082	0.660	-0.019	-0.699	-0.251	-0.005
DTE	0.248	-0.328	0.812	-0.396	-0.014	-0.073
DTF	0.709	-0.498	0.298	-0.378	-0.048	-0.125
DTG	-0.704	-0.181	0.516	0.064	0.114	0.144
SRA	0.783	0.263	-0.421	0.282	-0.186	-0.061
SRB	-0.968	0.085	0.202	0.057	0.041	-0.015

SRC	0.704	0.022	-0.201	0.282	0.582	0.201
SRD	0.181	-.0296	0.717	-0.493	0.245	0.205
SRE	-0.271	0.537	-0.573	0.319	0.247	0.384
SRF	-0.713	0.039	0.382	0.576	-0.051	0.082
SRG	-0.067	0.081	0.294	0.459	-0.163	0.060
SRH	-0.968	0.085	0.202	0.057	0.041	-0.015
SRI	-0.263	-0.711	0.239	0.595	0.005	0.113
SRJ	0.546	-0.787	0.201	0.114	0.086	0.141
SFA	0.840	0.113	0.395	0.046	-0.287	-0.193
SFB	0.078	0.512	0.817	0.037	0.041	0.211
SFC	0.968	-0.085	-0.202	-0.057	-0.041	0.015
SFD	0.968	-0.085	-0.202	-0.057	-0.041	0.015
SFE	0.764	0.273	0.072	-0.111	0.308	0.476
Eigenvalue	13.302	13.302	13.302	13.302	13.302	13.302
% of Variance	35.95	19.08	14.83	10.97	7.83	6.84

From the Table 4.2, 15 items loaded perfectly on Factor 1 and account for 35.951% of the total variance. Of the total, 1 item was related to advanced construction technique called digitalisation, 2 items were related to benefits of advance construction techniques, 3 items were related to the challenges of advance construction techniques, 2 items were related to digital technologies, 3 items were related to the skills are required in order to implement advanced construction techniques, and 4 items were related to the key success factors required to implement advanced construction techniques. The findings showed that more items (*N* = 4) were related to key success factors required to implement advanced construction techniques. Therefore, Factor 1 may be called success factors of advanced construction techniques.

The results further indicated that 11 items loaded significantly at Factor 2 and accounted for 19.08% of the total variance. Out of the total items (11), 1 item was related to advance construction technique called modularisation, 2 items were related to benefits of advance construction techniques, 3 items were related to the challenges of advance construction techniques, 2 items were also related to digital technologies, 2 items were related to the skills are required in order to implement advanced construction techniques, and the remaining 1 item was related to the key success factors required to implement advanced construction techniques. According to the rule of thumb, Factor 2 may be called challenges of advance construction techniques since it has the majority (*N* = 3) of the items.

The information from the Table 4.2 suggests that 7 items loaded significantly at Factor 3 and accounted for 14.83% of the total variance. Of the total items, 1 item was related to , to the benefits of advance construction techniques, another 1 item was also related to the challenges of advance construction techniques, 2 items were related to digital technologies, 1 item was related to the skills are required in order to implement advanced construction techniques, and the remaining 1 item was related to the key success factors required to implement advanced construction techniques. Statically, Factor 3 may be termed as to “digital technologies” because more items (N = 2) were related to it.

The results of the study indicated that 3 items loaded perfectly at Factor 4 and accounted for 10.97% of the total variance. Of the total, 1 item as related to the benefits of advance construction techniques, while the remaining 2 items were related to the skills are required in order to implement advanced construction techniques. Statistically, Factor 4 may be named as advanced construction techniques skills.

A total of 3 items further loaded significantly at Factor 5 and accounted for 7.83% of the total variance. Out of the total items, 2 items were related to benefits of advance construction techniques, while the remaining 1 item was related to the skills are required in order to implement advanced construction techniques. Factor 5 can be called benefits of advance construction techniques.

Finally, 1 item loaded significantly at Factor 6 and accounted for 6.84% of the total variance. The 1 item was related to advance construction technique called digitalisation. Therefore, Factor 6 may be termed as digitalisation. The results of the, KMO and Bartlett's Test are shown in the Table 4.3.

Table 4.3 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.731
Bartlett's Test of Sphericity	2851.27
	1463
	0.000

From the Table 4.3, the results of the KMO was of 0.731. Statistically, the instrument used to collect the data was middling (≥ 0.70). The questionnaire is considered valid, hence can be accepted or adopted for similar studies.

4.5 Biographical Details of Respondents

The biographical details of the respondents are shown in the Table 4.4.

Table 4.4 Biographical Details of Respondents

Biographical Variables	Category of Biographical Variable	Frequency	Percentage
Gender	Male Female	14 1	93.3 6.7
Age	30 – 39 years 40 – 49 years 50 – 60 years Above 61 years	4 1 4 6	26.7 6.7 26.7 40.0
Qualification	Matric Diploma B Degree Master's Degree PhD Other (Specify)	1 5 4 4 1 --	6.7 33.3 26.7 26.7 6.7 --
Experience: Nuclear	6-10 years 11-15 years 16-20 years Over 20 years	5 4 3 3	33.3 26.7 20.0 20.0
Experience: Conventional	1-5 years 6-10 years 11-15 years 16-20 years Over 20 years	2 3 2 1 7	13.3 20.0 13.3 6.7 46.7
Job Description: Nuclear	Project Manager Engineer Procurement Information and Communication Technology professional Other (Specify)	6 3 3 3	40.0 20.0 20.0 20.0
Job Description: Conventional	Project Manager Engineer Professional Other (Specify)	5 3 1 6	33.3 26.7 6.7 40

The Table 4.4 shows that males constituted the majority (93.3%) of the respondents. The results suggested that the majority (40%) of the respondents were above 61 years of age and followed by 26.75 (30-39 years) and another 26.7% (50-60 years)

respectively. It was found that 33.3% of the respondents had Diploma, followed Bachelor Degree (26.7%) and Master's Degree (26.7%). The findings of the study showed that 33.3% of the respondents who specialised in nuclear had 6-10 years of experience, followed by 26.7% who had 11-15 years of experience, and 20% who had 16-20 years and over 20 years of experience respectively. When it comes to experience in the field of conventional construction industry, 46.7% of the respondents had over 20 years of experience and 20% (6-10 years of experience). In terms of job description in the nuclear construction industry, 40% of the respondents were Project Managers, 20% of them were Engineers, Procurement Managers and other professionals respectively. Moreover, within the conventional construction industry, the results showed that 40% of the respondents fall within different categories of managers or experts, 33.3% were Project Managers and 26.7% as Engineers.

4.6 Advanced Construction Technologies

Table 4.5 shows the results of the kind of advanced construction technologies that the respondents are exposed to in the nuclear project environment.

Table 4.5 Advanced Construction Technologies

Items	**Category of Responses**	**Frequency**	**%**
Pre-fabrication and Modularisation construction	Yes No	12 3	80.0 20.0
Building information modelling:	Yes	15	100
3D printing and Additive manufacturing:	Yes No	5 10	33.3 66.7
Augmented reality and visualization:	Yes	15	100

Big Data and predictive analytics:	Yes No	5 10	33.3 66.7
Wireless monitoring and connected equipment	Yes No	5 9	33.3 60.0
Cloud and real time collaboration:	Yes No	8 7	53.3 46.7
Autonomous construction:	Yes No	3 11	20.0 73.3
Advanced materials:	Yes No	9 6	60.0 40.0
3D scanning and Photogrammetry:	Yes No	14 1	93.3 6.7

The results of the study revealed that 80% of the respondents were exposed to pre-fabrication and modularisation construction as compared to a few (20%). Moreover, the findings showed that all (100%) the respondents were exposed to building information modelling. Nonetheless, it was found that 66.7% of the respondents were not exposed to 3D printing and additive manufacturing as opposed to 33.3% who indicated that there were exposed to 3D printing and additive manufacturing. Again, all (100%) the respondents were exposed to augmented reality and visualisation. The results showed that 66.7% of the respondents were not exposed to big data and predictive analytics, while just 33.3% of them were exposed to big data and predictive analytics. Furthermore, 60% of the respondents were not exposed to wireless monitoring and connected equipment, while 33.3% of them were exposed to them. In addition, 53.3% of the respondents were exposed to cloud and real time collaboration, whereas 46.7% of the respondents were not. Majority (*73.3%*) of the respondents were not exposed to autonomous construction, whereas 33.3% of them were exposed to it. About 60% of the respondents of the respondents were exposed to advanced materials as compared to

40% of them who were not exposed to advanced materials. Lastly, 93.3% of the respondents were exposed to 3D scanning and Photogrammetry as against a few (6.7%).

4.7 Advanced construction technologies: Nuclear safety culture

Table 4.6 contains the results of the types of advanced construction technologies the respondents were exposed to that are used to improve nuclear safety culture in the project environment.

Table 4.6 Advanced construction technologies: Nuclear safety culture

Items	Category of Responses	Frequency	%
Pre-fabrication and Modularisation construction	Yes No	14 1	93.3 6.7
Building information modelling:	Yes	15	100
3D printing and Additive manufacturing:	Yes No	10 5	66.7 33.3
Augmented reality and visualization:	Yes No	14 1	93.3 6.7
Big Data and predictive analytics:	Yes No	11 4	73.3 26.7
Wireless monitoring and connected equipment	Yes No	7 7	46.7 46.7
Cloud and real time collaboration:	Yes No	11 4	73.7 33.3
Autonomous construction:	Yes No	10 5	66.7 33.3
Advanced materials:	Yes No	11 4	73.3 26.7
3D scanning and Photogrammetry:	Yes No	13 2	86.7 13.3

The results of the study showed that the type of advanced construction technologies that were used to improve nuclear safety culture in the project environment were, namely: pre-fabrication and modularisation construction (93.3%); building information modelling (100%); 3D printing and additive manufacturing (66.7%); augmented reality and visualization (93.3%); Big Data and predictive analytics (73.3%); wireless monitoring and connected equipment (46.7%); cloud and real time collaboration (73.3%); autonomous construction (66.7%); advanced materials (73.3%) and 3D scanning and photogrammetry (86.7%).

4.8 Advanced Construction Technologies: Nuclear Quality

The results of the advanced construction technologies used to improve nuclear quality are shown in the Table 4.7.

Table 4.7 Advanced construction technologies: Nuclear Quality

Items	Category of Responses	Frequency	%
Pre-fabrication and Modularisation construction	Yes	15	100
Building information modelling:	Yes No	14 1	93.3 6.7
3D printing and Additive manufacturing:	Yes No	11 4	73.3 26.7
Augmented reality and visualization:	Yes No	14 1	93.3 6.7
Big Data and predictive analytics:	Yes No	7 8	46.7 53.3
Wireless monitoring and connected equipment	Yes No	6 8	40 53.3

Cloud and real time collaboration:	Yes No	7 8	46.7 53.3
Autonomous construction:	Yes No	7 7	46.7 46.7
Advanced materials:	Yes No	12 3	80 20
3D scanning and Photogrammetry:	Yes No	14 1	93.3 6.7

As reflected in the Table 4.7, the types of advanced construction technologies used by the respondents to improve nuclear quality in the construction project were pre-fabrication and modularisation construction (100%), building information modelling (93.3%), 3D printing and additive manufacturing (93.3%), augmented reality and visualization (93.3%), big data and predictive analytics (53.3%), wireless monitoring and connected equipment (53.3%), advanced materials (80%) and 3D scanning and Photogrammetry (93.3%)

4.9 Descriptive Statistics

The respondents perception on advanced construction techniques, advanced construction technologies, advantages of advanced construction techniques, challenges of advanced construction techniques, digital technologies, advanced construction techniques skills and key success factors required to implement advanced construction techniques were assessed by asking the respondents to respond of the various aspects of the items using the 1 to 5 point-Likert scale. The interpretations of the scale are: Strongly Disagree (SD) = 1; Disagree (D) =2; Neutral (N) = 3; Strongly Agree (SA) = 4; and Agree (A) = 5. The results are presented as follows.

4.9.1 Advanced Construction Techniques

Table 4.8 shows the results of the advanced construction techniques that the respondents were exposed to in the project environment.

Table 4.8 Advanced Construction Techniques

Dimension	Mean	95 % Confidence Interval		Std. Dev.	Min.	Max.
		Lower Bound	Upper Bound			
Modularisation	3.93	3.57	4.28	0.616	1.00	5.00
Digitalisation	4.07	3.65	4.49	0.730	1.00	5.00

As reflected in the Table 4.8, digitalisation had the highest mean score value (Mean = 4.07), closely followed by modularisation (Mean = 3.93). Statistically, the mean scores suggested that modularisation and digitalisation were the most common advanced construction used in the nuclear construction project environment. To determine the scoring patterns, the results are further presented using frequency and percentage. The results showed that 80% of the respondents agreed that they were exposed to modularisation in the project environment as compared to 20% who indicated that they were not exposed to modularisation. On the other hand, 73.3% of the respondents agreed that they were exposed to digitalisation, while 26.7% of them indicated that they neither agreed nor disagreed that there exposed to digitalisation in the project environment. The comparing of the scoring patterns suggest that more respondents were exposed to modularisation as compared to digitalisation. The differences in the results could be based on a number of assumptions, namely: costs, level of technology

within the organisation, user friendly; efficiency and effectiveness and organisational policy.

4.9.2 Benefits of Advanced Construction Technologies

Table 4.9 shows the results of the benefits of advanced construction technologies in nuclear construction project.

Table 4.9 Benefits of Advanced Construction Technologies

Dimension	Mean	95 % Confidence Interval		Std. Dev.	Min.	Max.
		Lower Bound	Upper Bound			
Safety	4.27	4.01	4.52	0.458	1.00	5.00
Costs	4.60	4.25	4.95	0.632	1.00	5.00
Schedule	4.53	4.25	4.82	0.516	1.00	5.00
Productivity	4.33	4.06	4.60	0.488	1.00	5.00
Performance	3.67	3.27	4.07	0.724	1.00	5.00
Waste	3.80	3.57	4.03	0.414	1.00	5.00
Permits	3.13	2.67	3.60	0.835	1.00	5.00
ACT Benefits	4.05	3.84	4.26	0.831	1.00	5.00

As shown in the Table 4.9, the results suggested that all the items that measured the benefits of advanced construction techniques in nuclear construction had mean scores exceeding the recommended value (Mean = 3). The findings showed that costs had the highest mean score value of (Mean = 4.60), closely followed by schedule (Mean = 4.53), productivity (Mean = 4.33), safety (Mean = 4.27), waste (Mean = 3.80), performance (Mean = 3.67) and permits (Mean = 3.13). The overall items which measured the benefits of advanced construction benefits also had a mean score value

(Mean = 4.05) exceeding the recommended value. To further determine where the difference in the various scores lie, the results were further presented using frequency and percentage.

The findings showed that the benefits of advanced construction techniques were, namely: increased safety (100%); reduced the overall costs (93.3%) improved schedule (100%); increased productivity (100%); better environmental performance (53.3%); reduced waste (80%). On the contrary, 53.3% said that they neither agreed nor disagreed that advanced construction technologies reduced site-based permits. Based on the findings, it can be argued that the major benefits of advanced construction techniques in the nuclear project environment were increased safety, reduced the overall costs, improved schedule, increased productivity and reduced waste. It can therefore be conducted that advanced construction techniques offer several benefits to nuclear construction firms including Eskom.

4.9.3 Challenges of Advanced Construction Technologies

Table 4.10 shows the results of the challenges of advanced construction technologies in the nuclear construction.

Table 4.10 Challenges of Advanced Construction Technologies

Dimension	Mean	95 % Confidence Interval		Std. Dev.	Min.	Max.
		Lower Bound	Upper Bound			
Increased Costs	2.87	1.98	3.75	1.598	1.00	5.00
Increased Co-ordination	4.20	3.97	4.43	0.414	1.00	5.00
Engineering Design	4.27	4.01	4.52	0.458	1.00	5.00
Early Procurement	4.07	3.92	4.21	0.258	1.00	5.00
Logistic	3.93	3.79	4.08	0.258	1.00	5.00
Owner and Contractor	3.73	3.34	4.12	0.704	1.00	5.00

Capability						
ACT Challenges	3.84	3.66	4.03	0.342	1.00	5.00

As reflected in the Table 4.10, engineering design has the highest mean score value (Mean = 4.27), a followed by increase co-ordination (Mean = 4.20), early procurement (Mean = 4.07), logistic (Mean = 3.93), owner and contractor capability (Mean = 3.73) and increased costs (Mean = 2.87). The overall mean score value for advanced construction techniques challenges (Mean = 3.84) exceeded the recommended value. The overall findings suggested that all the factors had negative significant impact on nuclear construction project with the exception of increased costs (Mean = 2.87). To determine were the difference in the scores lie, the results were further presented in percentages.

The majority of the results agreed that the challenges associated with the adoption of advanced construction techniques in the nuclear construction industry were, namely: increased in costs (53.4%); increased in co-ordination (100%); engineering design (100%) early procurement (100%); logistic (93.3%); and owner and contractor capability (73.3%). The results suggested that a high number of participants agreed that the challenges of advanced construction techniques were increased in co-ordination, engineering design, early procurement and logistic, as compared to owner and contractor capability.

4.9.4 Digital Technologies Used in the Project Environment

Table 4.11 displays the results of digital technologies that the respondents are currently exposed to and used in the project environment.

Table 4.11 Digital Technologies Used in the Project Environment

Dimension	Mean	95 % Confidence Interval		Std. Dev.	Min.	Max.
		Lower Bound	Upper Bound			
Planning tools	4.33	4.06	4.60	0.488	1.00	5.00
Enterprise Resource Planning (ERP) tool	3.93	3.68	4.19	0.458	1.00	5.00
SmartPlant tool	4.47	4.18	4.75	0.516	1.00	5.00
Positioning systems tools	2.87	2.28	3.45	1.060	1.00	5.00
Imaging Technology tools	3.87	3.51	4.22	0.640	1.00	5.00
Mobile technology tools	4.00	3.58	4.42	0.756	1.00	5.00
Cyber security tools	3.80	3.10	4.50	1.265	1.00	5.00
Advanced construction digital technologies	3.90	3.71	4.07	0.3170	1.00	5.00

From the Table 4.7, smartPlant tool had the highest mean score value (Mean = 4.47), followed by planning tools (Mean = 4.33), mobile technology tools (Mean = 4.00), Enterprise Resource Planning (ERP) tool (Mean = 3.93), imaging technology tools (Mean = 3.87), cyber security tools (Mean = 3.80) and positioning systems tools (Mean = 2.87). The findings indicated that positioning systems tools (Mean = 2.87) was not statistically significant as compared to other advanced construction digital technologies. The overall mean score for all the advanced construction digital technologies (Mean = 3.90) exceeded the recommended mean score (Mean = 3.00).

To determine were the difference in the scores lie, the results were further presented in percentages. The scoring patterns revealed that the types of digital technologies that respondents were exposed to and used in the project environment were, namely: planning tools (100%); Enterprise Resource Planning (86.7%); SmartPlant tool for 3D design, documentation, contract management (100%); Imaging Technology tools

(86.7%); Mobile technology tools (86.7%) and Cyber security tools (80%). On the contrary, the respondents were not exposed to Positioning systems tools (53.3%).

4.9.5 Skills Required to Implement Advanced Construction Techniques

Table 4.12 shows the skills required in order to implement advanced construction techniques in the construction of nuclear projects.

Table 4.12 Skills Required to Implement Advanced Construction Techniques

Dimension	Mean	95 % Confidence Interval		Std. Dev.	Min.	Max.
		Lower Bound	Upper Bound			
Analytical thinking and Innovation	4.27	4.01	4.52	0.458	1.00	5.00
Active learning and learning strategies	3.80	3.57	4.03	0.414	1.00	5.00
Creativity, originality and initiative	4.07	3.68	4.46	0.704	1.00	5.00
Technology design and programming	3.93	3.60	4.26	0.594	1.00	5.00
Critical thinking and analysis	4.13	3.94	4.33	0.352	1.00	5.00
Complex problem solving	4.13	3.72	4.54	0.743	1.00	5.00
Leadership and social influence	4.13	3.94	4.33	0.352	1.00	5.00
Emotional Intelligence	3.40	2.71	4.09	1.543	1.00	5.00
Reasoning, problem solving and ideation	4.20	3.97	4.43	0.414	1.00	5.00
Systems analysis and evaluation	4.33	3.99	4.68	0.617	1.00	5.00
Advanced construction skills	4.04	3.93	4.15	0.196	1.00	5.00

As reflected in the Table 4.12, systems analysis and evaluation had the highest mean score (Mean = 4.33), followed by analytical thinking and innovation (Mean = 4.27), reasoning, problem solving and ideation (Mean = 4.20), critical thinking and analysis

(Mean = 4.13), leadership and social influence (Mean = 4.13), complex problem solving (Mean = 4.13), technology design and programming (Mean = 3.93), active learning and learning strategies (Mean = 3.80) and emotional Intelligence (Mean = 3.40). The overall findings suggested that the advanced construction skills (Mean =4.04) required in order to implement advanced construction techniques in the construction of nuclear projects was very significant. This implies that the above skills were critical to the successful completion of nuclear projects in the construction industry.

To further determine were the differences in the scores lie, the results were further presented in percentages to identify the proportion of the respondents who agreed to the various items as against those that have disagreed. The results of the study showed that the majority of the respondents agreed that the type of skills required to implement advanced construction techniques in the construction of nuclear projects were, namely: analytical thinking and innovation (100%); active learning and learning strategies (80%); creativity, originality and initiative (80%); technology design and programming (93.3%); critical thinking and analysis (100%); complex problem solving (80%); leadership and social influence (100%); emotional intelligence (80%); reasoning, problem solving and ideation (100%) and systems analysis and evaluation (93.3%). Based on the various responses, it can be suggested that Eskom as well as construction firms should identify and recruit contractors who have the aforementioned skills to assist in the construction of nuclear projects.

4.9.6 Key Success Factors to Implement Advanced Construction Techniques

Table 4.13 shows the key success factors to implement advanced construction techniques in the construction of nuclear projects.

Table 4.13 Key Success Factors to Implement Advanced Construction T Techniques

Dimension	Mean	95 % Confidence Interval		Std. Dev.	Min.	Max.
		Lower Bound	Upper Bound			
Policies and regulations	4.20	3.89	4.51	0.561	1.00	5.00
Collaboration	4.07	3.92	4.02	0.258	1.00	5.00
Technology, materials and tools	4.20	3.97	4.43	0.414	1.00	5.00
Processes and operations	4.20	3.97	4.43	0.414	1.00	5.00
People, organisations and culture	4.33	4.06	4.60	0.488	1.00	5.00
Key success factors	4.20	4.08	4.39	0.346	**1.00**	**5.00**

As shown in the Table 4.13, people, organisations and culture had the highest mean score value (Mean = 4.33), followed by technology, materials and tools (Mean = 4.20), processes and operations (Mean = 4.20), policies and regulations (Mean = 4.20), respectively and collaboration (Mean = 4.07). The overall mean score for all the key success factors was also computed. The findings (Mean = 4.20) showed that the key success factors required to implement advanced construction techniques in the construction of nuclear projects was very significant.

To determine the scoring patterns, the results were further presented in percentage. The majority of the respondents agreed that the key success factors required to implement advanced construction techniques in the construction of nuclear projects were, namely: policies and regulations (93.3%); collaboration between industry and owners (100%); technology, materials and tools (100%); processes and operations (100%) and people, organisations and culture (100%). The analysis suggest that there were no significant difference in the results regarding collaboration between industry

and owners technology, materials and tools, processes and operations and people, organisations and culture, with the exception of policies and regulations.

4.10 Inferential Statistics

Inferential statistics were further computed on the dimensions (advanced construction techniques, benefits of advanced construction techniques, challenges of advanced construction techniques, digital technologies, skills required for nuclear construction and key success factors) to enable the researcher to draw valid conclusions. The results are shown in the proceeding sections.

4.10.1 Spearman's Correlations

Spearman's correlations was computed to test the relationship between the various dimensions. The results are shown in the Table 4.14.

Table 4.14 Spearman's Correlations

Dimension	r/ p	ACT Techniques	ACT Benefits	ACT Challenges	Digital Technologies	ACT Skills	Success Factors
ACT Techniques	***R***	1.00	--	--	--	--	--
ACT Benefits	***R*** ***P***	0.128 0.649	100	--	--	--	--
ACT Challenges	***R*** ***P***	0.827 0.000*	-0.50 0.859	100	--	--	--
Digital Technologies	***R*** ***P***	0.182 0.516	-0.032 0.910	0.369 0.175	1000	--	--
ACT Skills	***R*** ***P***	-0.500 0.058	-0.067 0.814	-0.387 0.115	-0.075 0.791	100	--
Success Factors	***R*** ***P***	0.790 0.000*	0.505 0.055	0.444 0.097	0.086 0.760	-0.552 0.046	100

The information from the Table 4.14 shows that significant relationships existed amongst the dimensions such as advanced construction techniques, advanced

construction techniques challenges and key success factors. However, there was no significant relationship between the rest of the dimensions. The section below presents the results using Anova.

4.10.2 Analysis of variance -Anova

The influence of the biographical variables such as age, educational qualification, experience and job description/position on all the key dimensions were computed using Anova. The results are shown as follows

4.10.2.1 Advanced Construction Techniques and Biographic

The influence of the biographic variables on advanced construction techniques are shown in the Table 4.15.

Table 4.15 Advanced Construction Techniques and Biographical Variables

Biographical Variables	**F**	**P**
Age	0.923	0.462
Level of education	4.032	0.034*
Experience: Nuclear	2.414	0.145
Experience: Conventional	3.708	0.063*
Job/Position: Nuclear	22.050	0.000***
Job/Position: Conventional	19.222	0.002**

As reflected in the Table 4.15, there existed a significant difference in the perceptions of respondents varying in level of education, experience (nuclear and conventional) and job description regarding advanced constructions technique, respectively at 1% level of significance. However, there was no significance difference in the perceptions of the respondents varying in age regarding advanced constructions technique respectively at

1% level of significance. To determine exactly where the difference lies, the Post Hoc Scheffe's test was conducted and the results shown in the Table 4.16.

Table 4.16 Post Hoc Scheffe's Test

Dimension	**Level of education**	**N**	**Mean**
Modularisation	Matric	1	5.00
	Diploma	5	4.00
	B Degree	4	3.25
	Master's Degree	4	4.00
	PhD	1	5.00
Digitalisation	**Level of education**	**N**	**Mean**
	Matric	1	5.00
	Diploma	5	4.40
	B Degree	4	4.25
	Master's Degree	4	3.25
	PhD	1	3.00
Conventional: Modularisation	**Experience**		
	1-5 years	2	3.00
	6-10 years	3	4.00
	11-15 years	2	4.50
	16-20 years	1	4.00
	Over 20 years	7	4.25
Conventional: Digitalisation	**Experience**		
	1-5 years	2	4.00
	6-10 years	3	3.00
	11-15 years	2	4.00
	16-20 years	1	5.00
	Over 20 years	7	4.25
Nuclear	**Job Position**		

	Project Manager	6	4.17
	Engineer	3	3.00
	Procurement	3	4.00
	Other	3	3.00
Conventional	**Job Position**		
	Project Manager	5	4.00
	Engineer	3	3.00
	BIM Professional	1	4.00
	ICT Professional	6	5.00

As reflected in the Table 4.16, in terms of the adoption of modularisation, the respondents who had the educational qualification such matric and PhD were more satisfied that they were able to use modularisation as compared to those who had the qualification such as diploma, bachelor's degree and master's degree. On the other hand, in terms of the adoption of digitalisation in the nuclear project, the respondents who had qualification such as matric and diploma were more satisfied that they were able to use it as opposed to those that had bachelor's degree, master's degree and PhD.

The results of the Post Hoc Scheffe's Test showed that when it comes to experience, conventional experts who had 11-15 years of experience were more satisfied with the use of modularisation as compared to those who had 1-5 years, 6-10 years, 16-20 years and over 20 years of experience respectively. On the contrary, when it comes to digitalisation, conventional experts who had 16-20 years of experience were more satisfied in using digitalisation as compared to others.

In terms of job description, conventional project and procurement managers were more satisfied that there were exposed to advanced construction techniques as against the other managers. However, with respect to nuclear project, ICT Professionals were more satisfied that they were exposed to advanced construction techniques as compared to other.

4.10.2.2 Benefits of Advanced Construction Technologies and biographic

The Table 4.17 shows the influence of biographic variables on the benefits associated with the exposure to advanced construction technologies.

Table 4.12 Benefits pf Advanced Construction Benefits and biographic

Biographical Variable	**F**	**P**
Age	6.942	0.007**
Level of education	1.179	0.377
Experience: Nuclear	7.776	0.011*
Experience: Conventional	1.319	0.351
Job/Position: Nuclear	5.743	0.25*
Job/Position: Conventional	1.5852	0.236

The results of the study revealed that there existed a significant difference in the perceptions of respondents varying in level of age, experience (conventional) and job description (nuclear) regarding the benefits of advanced construction technologies, respectively at 1% level of significance. However, there was no significance difference in the perceptions of the respondents varying in level of education, experience (conventional) and experience (conventional) regarding the benefits of advanced construction technique respectively at 1% level of significance.

In order to determine where the difference lies, the Post Hoc Scheffe's test was conducted and the results shown in the Table 4.18.

Table 4.18 Post Hoc Scheffe's Test

Dimension	Age	N	Mean
Benefits of ACT	30 – 39 years	4	3.82
	40 – 49 years	1	4.00
	50 – 60 years	4	3.75
	Above 61 years	6	4.41
Nuclear	**Experience**		
	6-10 years	5	3.91
	11-15 years	4	3.68
	16-20 years	3	4.42
	Over 20 years	3	3.00
Nuclear	**Position**		
	Project Manager	6	3.79
	Engineer	3	3.86
	Procurement	3	4.43
	Other	3	3.78

In terms of the benefits of advanced construction techniques, the respondents who were between the ages of 30 – 39 years and above 61 years were more satisfied that advanced constructions techniques benefited construction firms as compared to others. Furthermore, the respondents who had 16-20 year work experience in nuclear project were satisfied that the organisation derived much benefits from the adoption advanced construction techniques as opposed to others. When it comes to position, the nuclear

procurement managers were more satisfied that the organisation derived maximum benefits from advanced construction techniques as opposed to other managers.

4.10.2.3 Advanced Construction Technologies Challenges and Biographic

The influence of biographic variables on the challenges of advanced construction technologies the respondents are exposed to are shown in the Table 4.19.

Table 4.19 Advanced Construction Technologies Challenges and biographic

Biographical Variable	**F**	**P**
Age	3.893	0.04**
Level of education	4.533	0.024*
Experience: Nuclear	3.963	0.058*
Experience: Conventional	4.846	0.034*
Job/Position: Nuclear	11.344	0.003**
Job/Position: Conventional	74.222	0.000***

As shown in the Table 4.19, there existed a significance difference in the perceptions of the respondents varying in age, level of education, experience (nuclear and conventional) and job description/position (nuclear and conventional) regarding the challenges of advanced construction technique respectively at 1% level of significance.

4.10.2.4 Digital Technologies and Biographic

Table 4.20 shows the influence of biographical variables on the kind of digital technologies the respondents were exposed to in the nuclear construction industry.

Table 4.20 Digital Technologies Challenges and biographic

Biographical Variable	F	P
Age	2.448	0.119
Level of education	9.344	0.002**
Experience: Nuclear	0.064	0.938
Experience: Conventional	2.484	0.139
Job/Position: Nuclear	0.000	1.000
Job/Position: Conventional	19.222	0.002**

The results of the study indicated that there existed a significance difference in the perceptions of the respondents varying in level of education and job description/position (conventional) regarding the kind of digital technologies the respondents were exposed to and used in the project environment respectively at 1% level of significance. However, there was no significance difference in the perceptions of the respondents varying age, experience (nuclear and conventional) and job description/position (nuclear) regarding the kind of digital technologies the respondents were exposed to and used in the project environment respectively at 1% level of significance.

4.10.2.5 Advanced Construction Skills and Biographic

Table 4.21 shows the results of the influence of biographical variables on advanced construction skills required in order to implement advanced construction techniques in the construction of nuclear projects.

Table 4.21 Advanced Construction Skills and biographic

Biographical Variable	F	P
Age	7.053	**0.007****
Level of education	3.339	**00.56***

Experience: Nuclear	2.708	0.120
Experience: Conventional	2.30	0.158
Job/Position: Nuclear	9.364	0.006**
Job/Position: Conventional	107.556	0.000**

The findings showed that there existed a significance difference in the perceptions of the respondents varying in age, level of education experience (nuclear and conventional) regarding the skills required in order to implement advanced construction techniques in the construction of nuclear projects respectively at 1% level of significance. However, there was no significance difference in the perceptions of the respondents varying in experience (nuclear and conventional) regarding the kind of skills required in order to implement advanced construction techniques in the construction of nuclear projects at 1% level of significance.

4.10.2.6 Key Success Factors of Advanced Construction Techniques and Biographic

Table 4.22 shows the results of the influence of biographical variables on the key success factors to implement advanced construction techniques in the construction of nuclear projects.

Table 4.22 Key Success Factors of Advanced Construction Techniques and Biographic

Biographical Variable	**F**	**P**
Age	1.024	0.419
Level of education	0.865	0.517

Experience: Nuclear	0.656	0.542
Experience: Conventional	1.918	0.212
Job/Position: Nuclear	0.450	0.651
Job/Position: Conventional	1.306	0.338

The results of the study revealed that there was no significance difference in the perceptions of the respondents varying in age, level of education, experience and job description respectively regarding key success factors to implement advanced construction techniques in the construction of nuclear projects at 1% level of significance.

4.11 Conclusion

The chapter presented and analysed the research findings as per each objective. The findings from the study indicated that the respondents were exposed to advanced construction techniques such as modularisation (Mean = 3.93) and digitalization (Mean = 4.07) in the project environment. The findings further showed that the respondents were exposed to advanced construction technologies. It was also found that they were exposed to nuclear safety and nuclear quality advanced construction technologies. Moreover, findings (Mean =4.05) showed that there were significant benefits associated with advanced construction techniques in the nuclear construction industry or project environment. Nevertheless, the results showed that there were several challenges countered by the respondents in an attempt to use the advanced construction techniques in the nuclear industry or project environment. Furthermore, the results indicated that the majority of the respondents were exposed to advanced construction digital technologies (Mean = 3.90) in the project environment. Also, the

results showed that the skills required in order to implement advanced construction techniques in the construction of nuclear projects (Mean = 4.04) had a significant effect on the nuclear construction project.

CHAPTER FIVE: DISCUSSION OF THE RESULTS

5.1 Introduction

This chapter of the study discusses the findings that were presented in the chapter four. The chapter integrates existing literature into the discussion of the findings. The purpose of the discussion is to determine whether the findings which emerged from this study conform with or deviate from the existing findings. The discussion of the results are aligned to the research objectives, namely: to identify the advanced construction techniques used in construction globally; to determine the benefits and challenges the technologies provide from experience and good practice from global projects; to provide a best practice process for implementation; and to verify the framework by testing the developed model in the nuclear construction environment. All these specific research objectives were achieved and the findings presented in the chapter four. The discussion of the results are presented as follows.

5.2 Advanced Construction Techniques

The study investigated the advanced construction techniques that the respondents were exposed to in the project environment. The findings from the study showed that digitalisation and modularisation were the main advanced construction techniques used in the nuclear project engineering and management personnel at Eskom's Koeberg Operating Unit and NECSA project management personnel. The WEF (2016) argues that digitalisation concerns the development and deployment of digital technologies and processes in the transformation of industries. It is the adoption of information technology (IT) tools and systems and combining them on a single platform to assist in delivering a project on time and on budget. Digitalisation has three basic elements, namely: data, analytics and connectivity. Markovitch and Willmot (2014) discovered that

digitalisation reduced costs by up to 90 percent and turnaround times improved by several orders of magnitude. Moreover, it was found that the real-time reports and dashboards on digital-process performance allow managers to solve problems before they become critical (Markovitch & Willmot, 2014). A study conducted by Sabbag et al. (2012) reveals that digitalisation allows managers and other stakeholders to operate with greater transparency and efficiency. Experience from the UK, USA, France suggests that digitalization has potential to simultaneously solve several of the current challenges of nuclear power thereby increasing operational efficiency. The use of digitalisation can help build capacity in efficient management of nuclear information and resources and improve skills and competences of nuclear facility personnel.

By contrast, Henriette et al. (2015) argued that although the benefits of digitalisation, many firms are yet to understand its potential impact and benefits. It is suggested that digitalisation of project involves implementing digital capabilities to support business model transformations impacting on the whole organisation, particularly operational processes, resources, internal and external users.

Modularisation involve the large-scale transfer of stick build construction effort from the job site to one or more local or distant fabrication shops/yards, to exploit any strategic advantage (CII, 2013). Just like digitalisation, there are three levels of modularisation including pre-fabrication, pre-assembly and module. According to CII (2013), modularisation as a construction technology has many benefits in the successful delivery of a project, namely: lower capital costs, improved schedule performance, increased productivity, higher overall quality, increased safety performance, reduced waste, better environmental performance and reduced site-based permits. Wrigley et al. (2018) contend that although modularisation has been utilised in nuclear to reduce costs, however, more work needs to be done to create effective modules. Choi (2014)

points out that the utilisation of modularisation is associated with several barriers, namely: costs; coordination, engineering design, procurement, logistics expertise and culture.

5.3 Advanced Construction Technologies

The study further investigated the type of advanced construction technologies nuclear and conventional expertise were exposed to in the project environment. The study revealed that the kind of advanced construction technologies that the respondents were exposed to in the project environment were, namely: pre-fabrication and Modularisation construction; building information modelling; augmented reality and visualisation; cloud and real time collaboration; advanced materials and 3D scanning and photogrammetry. On the contrary, the respondents indicated that there were not exposed to advanced construction technologies such as 3D printing and additive manufacturing, Big Data and predictive analytics, wireless monitoring and connected equipment and Autonomous construction.

Pre-fabrication and modularisation are construction technologies that existed for several years ago. Pre-fabrication and modular building processes are not new activities. According to Fenner, Razkenari, Hakim and Kibert (2017), pre-fabricated construction is well known for employing construction techniques that minimise construction time and project costs. Pre-fabrication is a factory-produced pre-engineered building unit that is delivered to the project site and assembled as a building component. Pre-fabrication as an advanced construction technology is recognized as having superior environmental and social benefits. Pre-fabrication and modularization emerged in times of climate change and intensified natural disasters, as alternative methods of construction and an example of resilient design. It has been found that pre-fabricated construction allows the

rebuilding of homes affordably, efficiently and quickly (Fenner et al., 2017). It has been argued that pre-fabrication reduces disruptions due to weather. It also reduces on-site vandalism. In a nutshell, it has been found that the prefabrication process could potentially reduce the environmental impacts caused by conventional construction (Zhong, Peng, Xue, Fang, Zou, Luo & Huang, 2017).

Eynon (2016) argues that BIM is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from the earliest conception to demolition. BIM became commercially available to the construction industry in the 1990s with the availability of computers with sufficient processing capability for #D CAD models. Eynon (2016) claims that a University of Maryland study revealed that BIM reduced the design phase of a project by 30% and its cost by 8%. In addition, BIM cut 10% from a project's construction phase and 3% from the construction costs. PwC (2018) indicates that BIM has several benefits, namely: increased collaboration and clash detection reduces cost; reduced the number of litigation claims; improved interface management reduces costs; reduced time by 64% for cost and quantity estimation; faster streamlined procurement process; reduced wasted material due to design accuracy; Improved accuracy of materials procurement; improved quality control; improved working environment; reduced exposure to hazardous conditions; improved work environment; reduction in material waste; reduction in noise, air and water pollution; reduced rigging and working at heights and reduced permitting process due to parallel work.

Bottani and Vignali (2019) explain that AR technology is becoming increasingly important, due to the ease of application development and the widespread use of hardware devices able to support its adoption. Currently, there is a growing number of

applications based on AR solutions are being developed for industrial purposes. Van Krevelen and Poelman (2010) describe AR as a set of technologies that enables the view of real world environment to be 'augmented' by computer-generated elements or objects. In other words, it is a mediated reality, where the visual perception of the physical real-world environment is enhanced by means of computing devices. VR on the other hand is a set of technologies that enables the user to interact with a computer in a simulated environment (Khan et al., 2011). VR allows the user to be immersed in a computer-generated world. According to Dini and Dalle Mura (2015), AR has the capability to provide the user of the needed information about a process or a procedure directly on the work environment. A study reveals that VR can be used to supplement reality by blending the physical and the virtual in the actual physical environment (Johnsen & Mark, 2010).

Cloud computing is the practice of using a network of remote servers hosted on the internet to store, manage and process data, rather than using local servers or personal computers. AlCattan (2014) posits that cloud computing technology is an emerging new computing paradigm for delivering computing services. Cloud computing is a service-oriented architecture which minimises information technology overhead for the end-user. It also has the benefits such as great flexibility, reduction in total ownership cost (AlCattan, 2014). Collaboration considered as the process whereby individuals work together in groups towards to the shared goal collective. Real-time collaboration is a software or technology that allow several users to work together on a project in real time, or simultaneously. Shukor et al., (2011) contend that collaboration in a project requires project team members and other stakeholders to communicate and be aware of each other's activities. Lang et al., (2002) advocate that collaboration requires successful and efficient sharing of knowledge, negotiation, coordination and

management of activities. Could collaboration increase participation levels, improves access to large files and facilitates brainstorming among team members. It is also an effective method which provides more insights into the process of integration and, most significantly, to improve the productivity, efficiency and effectiveness of the construction industry (Fathi et al., 2012).

CII (2009) notes that due to the advent of new techniques for fabrication and manufacturing and also the ability to control and modify atoms at the nanoscale, new nano structured material and devices become reality. Due to the rapidly changing technology, construction firms have adopted several measures to rebuild or recompose the materials such that it can be more efficient and durable with respect to the previous materials. It has been found that generation of large amounts of industrial inorganic by-products and waste resulting from renewable resources is becoming a more reason which increases the utilisation in cement and concrete materials (Stevulova et al., 2018). According to Špak et al. (2016), high-performance concrete and ultra-high-performance concrete are ranked among advanced concrete technologies. The use of these construction technologies have the to improve the construction efficiency from several points of view. For example, these advanced construction technologies may offer the following benefits, namely: reduce construction time and construction material; improve construction quality; minimise environmental impact and increase the durability and lifetime of structures (Špak et al., 2016). In a study conducted by Niu, Lu, Chen, Huang and Anumba (2016), different advanced construction building materials were identified to enhance efficiency in the construction industry including high performance concrete, aerated concrete, light transmitting concrete, floating concrete, foamed aluminium, aerogel, woven stainless steel, creative weave metal mesh, laminated thermo plastic panels, super black, banner works, geoweb, corrugated Glass etc.

Evin et al. (2016) argue that 3D digitization is frequently used in a museum environment for research, conservation or dissemination. There are different methods to attain the 3D digitization of objects which include CT imaging, structured light scanner and photogrammetry. However, photogrammetry is commonly used as it is a low cost and versatile technique to obtain 3D model (Tsiafaki et al., 2015). Photogrammetry involves making measurements from photographs. It is an advanced construction tool that allows 3D reconstruction of surface geometry from photographs of the same object taken from multiple views (Mathys et al., 2014). Aerial photographs taken from an aircraft, drone or terrestrial (close-range) method are used to create a map, drawing, a measurement or 3D model of a real-world object or scene. Photogrammetry will play an important role in the construction of nuclear plants in South Africa. Photogrammetry will assist locate, identify and map the site with grids detailing the areas with densely populated rare plants.

Additive manufacturing, commonly refers to 3D printing, represents a major change in industrial production (Jordan, 2019). Additive manufacturing and 3D printing is a game changer and this innovative technology will have a disruptive impact on the construction industry. This technology enables the production of purpose-built shapes that cannot be produced by any other method; it promises productivity gains of 80% for some applications, together with an important reduction in waste (WEF, 2016). The technology has found traction in the construction industry with steel and concrete components now being printed for use. Additive manufacturing has advantages over conventional manufacturing including reductions in lead time, reductions of scrap materials, lower inventory costs, less manufacturing complexity, reduced floor space and the ability to deliver manufactured pieces with complex shapes and geometries (WEF, 2016).

Big data refers to large amounts of data gathered from a range of diverse sources in near real-time. In other words, Big data is a term which describes exponential growth along with the structured and unstructured availability of data (Poornima & Pushpalatha, 2018). Big data is used in the generation, sharing and storing of data. Analytics is the use of data to produce useful information and insights. Big Data Analytics has its origin in the earlier data analysis methodologies using statistical techniques like regression, factor analysis. It includes data mining from high speed data streams and sensor data to get real time analytics (Chen et al., 2014). Predictive Analytics on the other hand, is the art discovering meaningful patterns of data using pattern recognition techniques, statistics, machine learning, artificial intelligence and data mining (Abbott, 2014). Predictive Analytics is designed to find the optimum regression coefficients of relationship to minimize the errors in the model.

Zihao et al. (2018) describe wireless monitoring has the ability to embed physical object with electronics, software, sensors and connectivity allows them to collect and exchange data creating the Internet of things (IoT), a network of internet-connect objects. Wireless monitoring has further been defined as hardware and software of the system designed to monitor the well site environment (Chen et al., 2017). Wireless monitoring has the advantage of working in a wide space for data collection to host centre which allows for decision to made based on the change of environmental factors (Xufeng et al., 2013; Ghini et al., 2011).

The construction industry is a major economic sector; however, it is plagued with inefficiencies and low productivity (Delgado et al, 2019). Nevertheless, robotics and automated systems have the potential to mitigate these challenges in the construction industry. In construction, automation and robotics technologies are used in all stages, from the automation of the design process through the use of Computer Aided Design,

the production of cost estimates, construction schedules and project management. The benefits include enhancing productivity and work efficiency with reduced costs, solid quality with higher accuracy and occupational safety enhancement (Strukova et al., 2011).

5.4 Nuclear Safety Culture

The study also explored the advanced construction technologies the respondents were exposed to that are being used to improve nuclear safety culture in the project environment. The results of the study showed that the type of advanced construction technologies that the respondents were exposed to and used to improve nuclear safety culture in the project environment include pre-fabrication and modularisation construction, BIM, 3D printing and additive manufacturing, augmented reality and visualization, Big Data and predictive analytics, cloud and real time collaboration and autonomous construction, advanced materials and 3D scanning and photogrammetry.

Safety and security of nuclear plants and equipment is a vital element of project management. It has been acknowledged in the industry that the safe operation of a nuclear site requires not only the proper design and operation of the safety systems but a safety-conscious attitude of the workforce (Devgun, 2013). The fundamental safety objective is to protect people and the environment from the harmful effects of ionising radiation (IAEA, 2015). Cooper (2000) explains safety culture as a sub-facet of organisational culture, which is thought to affect member's attitudes and behaviour in relation to an organisation's ongoing health and safety performance. According to Misnan et al., (2008), the nature of accidents and injuries at construction recurrent and serious shows that the construction industry is unique. It is suggested that an efficient

safety management system should be based on the safety awareness that should become a culture in the construction industry involving all the stakeholders. Also, promoting safety culture in the construction industry should focus on providing key skills and knowledge and training that can be used to encourage and modify behaviour and attitudes of workers (Misnan et al., 2008). According to Jamal et al. (2005), one important measure that can be adopted to create a good or better image of construction industry is to provide safe working environment. Misnan and Mohammed (2007) suggest that efforts to improve occupational safety and health at work will only be effective if occupational safety and health culture is improved. Misnan and Mohammed (2007) recommend that the promotion of safety culture within the construction industry should include, namely: leadership support, employee participation and involvement, employee training, communication, motivation, setting up health and safety committee, work environment and policy and safety planning.

5.5 Nuclear Quality

The type advanced construction technologies the respondents were exposed to and used to improve nuclear quality in the project environment were also investigated. The results of the study showed that the advanced construction technologies used to improve nuclear quality in the project environment were, namely: pre-fabrication and Modularisation construction; BIM; 3D printing and additive manufacturing; augmented reality and visualization; advanced materials and 3D scanning and photogrammetry. On the contrary, the findings revealed that the advanced construction technologies were not used to improve nuclear quality in the project environment were Big Data and predictive analytics; Wireless monitoring and connected equipment and Cloud and real time collaboration. Nuclear quality control and assurance is intended to provide

adequate confidence that a structure, system or component will perform satisfactorily in service. In South Africa, the requirements for nuclear quality is regulated by the National Nuclear Regulator (NNR) and found in the document titled Quality and Safety Management for Nuclear Installations in South Africa, commonly referred to by its document reference number RD0034. In the construction of nuclear installations, traceability of items provides an important tool through the lifecycle from the initial design through construction and then to commissioning and later during operation and maintenance. Traceability is achieved by the collection and storage of records that the owner and the regulatory body NNR needs (Chen et al., 2014).

5.6 Benefits of Advanced Construction Technologies

The benefits of advanced construction technologies in nuclear construction were explored in this study. The results of the study indicated that the benefits of advanced construction technologies in nuclear construction include increased safety, lowered overall costs, improved schedule, increased productivity, better environmental performance and reduced waste.

PwC (2018) confirms that using advanced construction technologies such as BIM offers benefits such as reduced costs (i.e. fewer changes made to the design, increased collaboration and clash detection reduces cost, reduction in the number of litigation claims and improved interface management reduces costs); improved time efficiency (i.e. common data environment provides quicker information exchange, time reduction by 64% for cost and quantity estimation, improved definition of information requirements and faster streamlined procurement process); reduced material wastage (i.e. reduction in wasted material due to design accuracy, improved accuracy of materials procurement and reduced need for rework); improved quality (i.e. improved quality control, improved

working environment and reduced failure rates); improved safety (i.e. safety risks reduced in controlled shop environment, reduced exposure to hazardous conditions and improved work environment) and reduced risks (i.e. reduction in material waste, reduction in noise, air and water pollution and reduced energy usage).

5.6 Challenges of Advanced Construction Technologies

The challenges associated with the use of advanced construction techniques in the nuclear project environment was investigated. The findings showed that the challenges which hampered the adoption and utilisation of advanced construction technologies were, namely: increased in costs; increased in co-ordination; engineering design; early procurement; logistic and owner and contractor capability.

According to PwC (2018), advanced construction technologies like BIM increased cost such as training and software costs and implementation costs. Also, it was found that the advanced construction technologies like 3D scanning and photogrammetry are difficult to set up and use. In addition, 3D scanning and photogrammetry are not easily portable (PcW, 2018). Moreover, advanced construction technologies such as robotics have the challenges such as job loss, requires significant power source, high costs and terrain limitations (Ruggiero et al., 2016). Furthermore, advanced construction technologies like drones are affected by wind and has poor quality of images. Delgado et al. (2019), in their study, identified four factors affecting the use of robotics and automated systems in construction industry, namely: contractor-side economic factors; client-side economic factors; technical and work-culture factors; and weak business case factors.

5.8 Digital Technologies used in Project Environment

The types of digital technologies used in project environment were explored in this study. It was found that the category of digital technologies the respondents were currently exposed to and used in the project environment include planning tools, enterprise resource planning (ERP) tools, smartplant tool, imaging technology tools, mobile technology tools and cyber security tools.

Nimbal and Jamadar (2017) explain that project planning is the key to bring the expected projects into reality or in existence. Planning tools like Oracle's Primavera P6 is the commonly accessible and fastest, powerful, user friendly, easy to use robust and software application which is used to manage projects, programmes and portfolio (Nimbal & Jamadar, 2017). Primavera is very useful in planning and scheduling projects quickly and conveniently. It also creates principal programme schedule by integrating the schedules from owners, engineers, architects, planners and subcontractors. Moreover, it controls budgets, estimates even after changes at finishing point to relic successful delivery of the project (Nimbal & Jamadar, 2017).

The ERP is considered as an expensive investment for architectural and construction companies. ERP is an integral software that is spanning to cover all organisation functions with one shared database that increase information sharing and integrity of business processes (Hadidi et al., 2017). According to Méxas and Quelhas (2012), although, ERP implementation was originated in manufacturing environment, its adoption and utilisation in construction environment will help the construction industry increase efficiency in handling contracts and designs. Hewavitharana, Nanayakkara, Perera, and Perera (2019) found that 90% of construction firm who implemented ERP have achieved significant success with their construction activities.

5.9 Skills Required to Implement Advanced Construction Techniques

Based on the findings, a numbers of skills required to implement advanced construction techniques in the construction of nuclear projects, namely: analytical thinking and Innovation; active learning and learning strategies; creativity, originality and initiative; technology design and programming; critical thinking and analysis; complex problem solving; leadership and social influence; emotional intelligence; reasoning, problem solving and ideation; and systems analysis and evaluation.

WEF (2018) suggests that it is important to identify the skills required in South Africa for new nuclear plant construction and develop the necessary infrastructure to commence and be prepared for the construction. Key manufacturing skills will require a detailed plan with training standards to support the program, while nuclear skills require more time and also experience. The WEF (2018) identifies some key skills requires in the nuclear project environment, namely: analytical thinking and Innovation; active learning and learning strategies; creativity, originality and initiative; Critical thinking and analysis; complex problem solving; leadership and social influence; emotional Intelligence; reasoning, problem solving and ideation and coordination and time management.

5.10 Key Success Factors Required to Implement Advanced Construction Techniques

The last objective of the study explored the key success factors required in order to implement advanced construction techniques in the construction of nuclear projects. The findings from the study showed that the key success factors required for the implementation of advanced construction techniques in the construction of nuclear projects were, namely: organisations and culture, technology, materials and tools, processes and operations, policies and regulations and collaboration.

In order to implement advanced construction technologies successfully, there are certain critical success factors that must be present. The findings from the study reaffirms the findings contained in the WEF (2016) report. According to the WEF (2016) report, with the increasing sophistication of technologies, new and broader skills sets are required at all levels of the company (WEF, 2016). It is also suggested that people need to continuously trained and effective retention strategies in place to keep staff. Companies need to have a high-performance culture in place (WEF, 2016). Apart from the people, organisation and culture, technology, materials and tools are critical to the successful implementation of advanced construction techniques. Construction companies need to adopt advanced construction technologies including advanced building and finishing materials, standardised, modularised and prefabricated components, automated construction equipment and digital technologies and big data (WEF, 2016). In addition to the above critical factors, it is also important for the construction firms to formulate policies and regulations for the purpose of promoting advanced construction techniques as strategy. Moreover, WEF (2016) suggests that construction firms need to improve collaboration at project level in order to bridge the gap with knowledge and skills. This strategy can also be to partner buy companies that can provide the knowledge and skills needed for advanced construction technologies. To achieve substantial improvements in construction productivity and to reduce operating and maintenance costs, companies need to ensure that, during the design and engineering phase, they keep the actual construction process in mind as well as the final operations phase (WEF, 2016).

5.11 Conclusion

The chapter discussed results which emerged from the study. The study concluded that digitalisation and modularisation were the main advanced construction techniques used

in the nuclear project engineering and management personnel at Eskom's Koeberg Operating Unit and NECSA project management personnel. The study also showed that the personnel in the focal organisation were exposed to advanced construction technologies such as pre-fabrication and modularisation construction, building information modelling, augmented reality and visualization, cloud and real time collaboration, advanced materials and 3D scanning and Photogrammetry.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The previous chapter discussed the results of the study. This chapter proceeds to present the conclusion and recommendations of the study based on research findings as per each objective, namely: to identify the advanced construction techniques used in construction globally; to determine the benefits and challenges the technologies provide from experience and good practice from global projects; to provide a best practice process for implementation; and to verify the framework by testing the developed model in the nuclear construction environment.

6.2 Conclusion of the Study

The following conclusion are drawn based on the findings of the study.

6.2.1 Advanced construction techniques

Based on the findings, it was discovered that the advanced construction techniques used in the nuclear project engineering and management personnel at Eskom's Koeberg Operating Unit and NECSA project management personnel were digitalisation and modularisation. These advanced construction techniques are commonly used in nuclear project environment in many advanced countries, particularly in UK, USA and France. The techniques when applied in the project environment in South Africa will help to simultaneously solve several challenges associated with nuclear power thereby increasing operational efficiency.

6.2.2 Advanced construction technologies

Apart from the advanced construction techniques, the study also investigated the type of advanced construction technologies nuclear and conventional expertise were

exposed to in the project environment. Based on the findings, it can be concluded that the type of advanced construction techniques that the nuclear and conventional experts were exposed to in the project environment included, namely: pre-fabrication and Modularisation construction; building information modelling; augmented reality and visualization; cloud and real time collaboration; advanced materials and 3D scanning and Photogrammetry. On the contrary, the type of advanced construction technologies that the respondents were not exposed to included 3D printing and Additive manufacturing, Big Data and predictive analytics, wireless monitoring and connected equipment and autonomous construction.

6.2.3 Nuclear safety culture

Moreover, the study also examined the advanced construction technologies that were used to improve nuclear safety culture in the project environment. From the findings, it can be concluded that the types of advanced construction technologies used to improve nuclear safety culture in the project environment included pre-fabrication and modularisation construction, building information modelling, 3D printing and additive manufacturing, augmented reality and visualization, Big Data and predictive analytics, cloud and real time collaboration, autonomous construction, advanced materials and 3D scanning and photogrammetry. These advanced construction techniques when applied in the nuclear project environment will help to improve on safety measures. Efforts to improve occupational safety and health in nuclear project environment can will only be effective if sophisticated advanced construction techniques are adopted.

6.2.4 Nuclear quality

Additionally, the study explored the types of advanced construction technologies the respondents were exposed to and used to improve nuclear quality in the project environment. Based on the results, it can be concluded that the advanced construction

technologies used to improve nuclear quality in the project environment were, namely: pre-fabrication and modularisation construction; building information modelling; 3D printing and additive manufacturing; augmented reality and visualization; advanced materials and 3D scanning and photogrammetry. On the contrary, the findings revealed that the advanced construction technologies that cannot be used to improve nuclear quality in the project environment were Big Data and predictive analytics wireless monitoring and connected equipment and Cloud and real time collaboration.

6.2.5 Benefits of advanced construction technologies

The benefits of advanced construction technologies in nuclear construction were explored in this study. From the findings, it can be concluded that the benefits of advanced construction technologies in nuclear construction included increased safety, lowered overall costs, improved schedule, increased productivity, better environmental performance and reduced waste. The findings and conclusions of this study underscore the findings of other existing studies. Advanced construction technologies offer benefits such as reduced costs, improved time efficiency, reduced material wastage and reduced risks.

6.2.6 Challenges of advanced construction technologies

The study further investigated the challenges associated with the use of advanced construction technologies in the nuclear project environment. From the study, conclusion can be drawn to the fact that the challenges which hampered the adoption and utilisation of advanced construction technologies were, namely: increased in costs, increased in co-ordination; engineering design; early procurement; logistic and owner and contractor capability. These challenges if not properly addressed will affect effectiveness and efficiencies of nuclear projects.

6.2.6 Digital technologies used in project environment

The types of digital technologies used in project environment were explored in this study. It was found that the category of digital technologies used in the nuclear project environment included planning tools, enterprise resource planning tool, smartplant tool, imaging technology tools, mobile technology tools and cyber security tools.

6.2.7 Skills required to implement advanced construction techniques

The study also explored the skills required to implement advanced construction techniques. Based on the findings, the of skills required to implement advanced construction techniques in the construction of nuclear projects were analytical thinking and innovation, active learning and learning strategies, creativity, originality and initiative, technology design and programming, critical thinking and analysis, complex problem solving, leadership and social influence, emotional intelligence, reasoning, problem solving and ideation and systems analysis and evaluation.

6.2.8 Key success factors

The last objective of the study explored the key success factors required in order to implement advanced construction techniques in the construction of nuclear projects. Based on the findings, it can be concluded that the key success factors required for the implementation of advanced construction techniques in the construction of nuclear projects were organisations and culture, technology, materials and tools, processes and operations, policies and regulations and collaboration.

6.3 Recommendations of the Study

The following recommendations are made based on the findings of the study.

6.3.1 Adoption of 3D printing and additive manufacturing

Nuclear experts within the ESKOM should consider the adoption of 3D printing and additive manufacturing in their project environment. 3D printing and additive manufacturing are common advanced technologies used in a museum environment for research, conservation or dissemination. These technologies are game changers and these innovative technologies will cause significant changes in the construction industry when properly adopted. These advanced construction technologies are noted for producing purpose-built shapes that cannot be produced by any other method. The additive manufacturing, in particular has the following advantages over conventional manufacturing including reductions in lead time, reductions of scrap materials, lower inventory costs, less manufacturing complexity, reduced floor space and the ability to deliver manufactured pieces with complex shapes and geometries.

6.3.2 Adoption of Big Data and predictive analytics

In addition to 3D printing and additive manufacturing, the nuclear and conventional project experts should consider using Big Data and predictive analytics in their project environment. The Big Data will enable the nuclear experts to generate, share and store data in the most efficient manner. The predictive analytics on the other hand will allow the project experts to minimise the possibility of errors occurring within the project environment thereby ensuring the efficient use of resources.

6.3.3 Adoption of wireless monitoring and connected equipment

Apart from the 3D printing, additive manufacturing, Big Data and predictive analytics, the nuclear and conventional project expert should consider using wireless monitoring and connected equipment in their project environment. Wireless monitoring has the ability to embed physical object with electronics, software, sensors and connectivity

allows them to collect and exchange data creating the IoT. Wireless monitoring has the advantage of working in a wide space for data collection to host centre which allows for decision to made based on the change of environmental factors.

6.3.4 Co-ordination among project team members

As shown in the study, lack of co-ordination was one of the challenges that was identified in the nuclear project environment. Co-ordination refers to the harmonious adjustment or interaction of different people or things to achieve a goal or effect. In a typical project environment, it is suggested that small teams are more effective in co-ordination as compared to large teams. As task interdependence increases, the need for co-ordination becomes greater. Therefore, it is important for project team members to co-ordinate and work as a team or group. Coordination will help to ensure that a team functions as a unitary whole and is identified as a key process to understanding work team effectiveness.

6.3.5 Availability of logistic and other resources

Lack of logistics was identified as one of the challenges of using advanced construction techniques. To this end, the study recommends for the availability of logistics and other resources to ensure timely execution of nuclear projects. Nowadays, the use of logistics as a complementary approach to construction management is fast gaining popularity. Logistics is now considered as a key feature of pre-construction planning; not just on large complex schemes, but also in the planning and delivery of mainstream construction projects. To avoid disruptions in the nuclear project environment, the organisation or project managers should ensure that the necessary logistics required are made available to the project team member. In addition, the logistics available should meet the quality standard.

6.3.6 Efficient procurement process and system

One of the biggest constraints affecting the execution of projects is procurement issues. The common procurement related issues that often affect timely execution of projects include supplier-related concerns, strategy selection issues, cost effectiveness and savings achievement factors, data accuracy issues and stakeholder management concerns. Other procurement issues may include lack of training of the project team, corruption, favouritism, fraud, delays from suppliers, policy compliance and consistency in compliancy of procurement laws. To ensure that projects are executed within the minimum duration, the organisation and project managers should ensure that all procurement issues are addressed as early as possible.

6.3.7 Formulation and implementation of organisational policy

The use of advanced construction technologies in nuclear project can be possible only if the organisation has a policy in place. Therefore, the organisation should formulate a policy on advanced construction technologies usage.

6.4 Conceptual Model

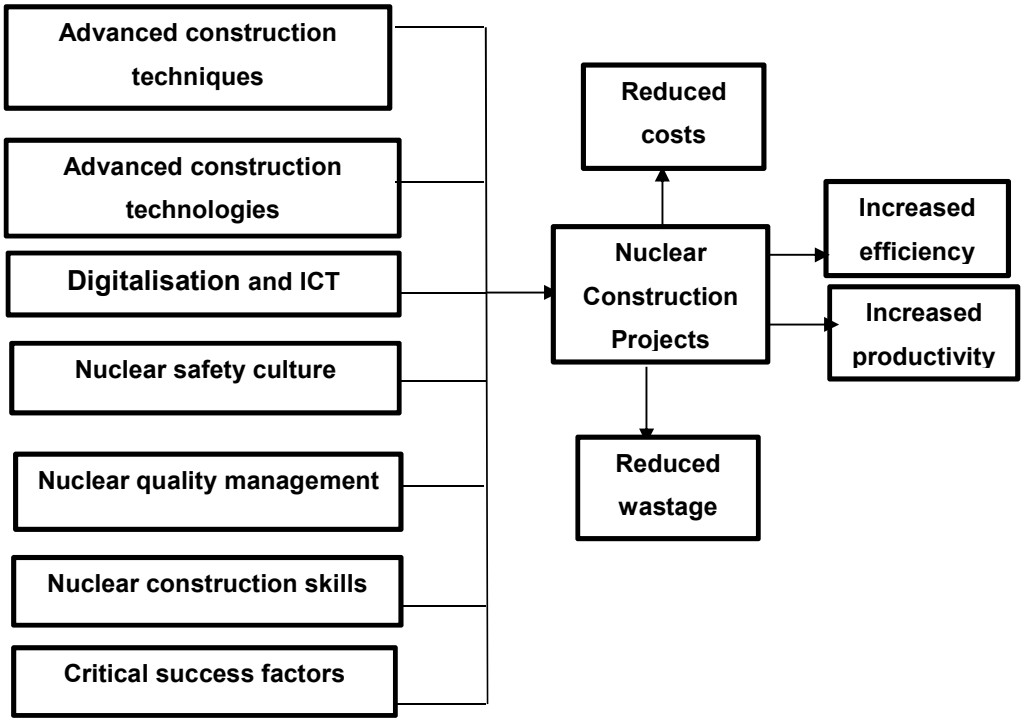


Figure 6-1 Conceptual model for nuclear construction projects

The construction industry is one of the great strategic importance on the local, national and international levels. Globally, this industry is one of the largest industrial sectors, which contributes 13% of global GDP. In recent times, it is estimated that the construction industry is worth circa $10 trillion annually and that it will increase to $14 trillion by 2025, with an expected growth of 3.6% per annum (Pistorius, 2019). However, certain global forces are pressuring for change which calls for reinvention of construction. This sector is indeed ripe not just for change, but for a much more serious disruption. Nowadays, a range of new technologies such as digitalisation and automation of the industry as well as new materials have emerged with ultimate goal of enhancing construction works. These new technologies will have a transformative effect on the construction industry and will contribute towards address the challenges confronted by the sector. The disruption will also bring huge opportunities for only those

who seize them. The Figure 6-1 is the conceptual model which is developed from the findings and existing nuclear construction models to assist nuclear construction industry to cope with new changes. Nuclear project is a very unique and complex activity which requires careful thinking and strategic decisions during the planning, design, scheduling, implementation, execution, monitoring and evaluation phase. For nuclear industry to compete in the global market, they will need to ride the next wave. Thus, they need to digitize and adopt innovative business practices, new techniques and emerging technologies. The need to consider adopt advanced construction techniques such as modularisation and digitalisation.

Apart from these advanced construction techniques, construction firm need to adopt and utilise emerging technologies such as pre-fabrication and modularisation construction, BIM, 3D printing and additive manufacturing, AR and visualization, Big Data and predictive analytics, wireless monitoring and connected equipment, cloud and real time collaboration, autonomous construction, advanced materials, 3D scanning and photogrammetry, VHL crane, lasers and GPS equipment, automatic rebar assembly machine, laser alignment equipment, Gas metal arc welding, uranium-235 and gas turbine modular helium reactor. Nuclear construction firms need to embrace innovation in its broadest sense. An innovation and culture mindset should be developed and the quest for innovation and the innovation premium should be fundamental objectives.

Technological innovation is critical for construction industry, but it should be blended with other important strategic issues like safety culture. Safety constitutes an important priority for workers, especially those working in the engineering and construction industries. Promoting safety culture is become a key priority in construction business given the number of accidents and industrial injuries which always occur in construction sites. Fostering safety culture will be an effective way of reducing accidents and injuries

in the nuclear construction industry. To improve safety performance, nuclear construction companies need to implement innovative safety management programmes which should focus on shaping workers' beliefs, attitudes, and commitment to achieve safe behaviour on construction sites. Nuclear construction firms must take advantage of new technologies in fostering safety culture, especially on construction sites.

The success of a project can be assessed by the extent to which it meets customers' expectations, specification and requirements. Achieving quality in nuclear projects requires not only the availability of resources, but also the successful interaction amongst project stakeholders. The concept of total quality management (TQM) has arisen to ensure that all stakeholders, particularly customers' demands, and level of quality and conformance are achieved. TQM in nuclear industry can be achieved through an integrated effort among workers and management at all levels to increase customer satisfaction. Nuclear quality can be achieved through process improvement, participation and involvement of customers and suppliers, teamwork, training and education and adoption of advanced construction technologies. For nuclear construction companies to foster quality management, they need to adopt advanced construction technologies like pre-fabrication and modularisation construction, BIM, 3D printing and additive manufacturing, AR and AV, Big Data and predictive analytics, wireless monitoring and connected equipment, cloud and real time collaboration, autonomous construction advanced materials and 3D scanning and photogrammetry.

In addition to the advanced construction techniques, technologies, safety culture and quality management, nuclear projects require people with critical and scarce skills like analytical thinking and innovation, active learning and learning strategies, creativity, originality and initiative, technology design and programming, critical thinking and analysis, complex problem solving, leadership and social influence, emotional

intelligence, reasoning, problem solving and ideation, and systems analysis and evaluation skills. The study recommends that for nuclear project to be executed successfully, certain critical factors are required, namely: policies and regulations promoting advanced construction techniques as strategy; collaboration between industry and owners; technology, materials and tools are in place; processes and operations to aid advanced construction techniques; and people, organisations and culture to support advanced construction techniques. This model when adopted by nuclear construction industry will help them to achieve the following benefits but not limited to reduced costs, reduced wastage, increased efficiency and increased productivity.

6.5 Directions for Future Research

The advent of the fourth industrial revolution has created an explosion of new technologies with capabilities that allow for things to be done that was not possible only a few years ago in construction. This study only focused on ten technologies that the World Economic Forum identified will impact the future of construction. Some of these technologies are mature on the technology life cycle. However, a great number of the technologies can be classified as emerging and are still in their infancy. There are also technologies that fall outside the ten identified and these must form part of future research studies (i.e. heavy lift (VHL) crane, lasers and GPS equipment, computerised concrete batching plants, automatic rebar assembly machine, laser alignment equipment, Gas metal arc welding, uranium-235 and gas turbine modular helium reactor). With further development over the short to medium term on the ten identified technologies, it will be possible to perform individual studies on each. Therefore, future research should focus on the use on new advanced construction technologies in nuclear project.

6.6 Conclusion

The chapter presented the conclusion and recommendations of the study in accordance with the findings. It was found that digitalisation and modularisation were the main advanced construction techniques used in th nuclear project environment. The study also identified the key advanced technologies that were used in the nuclear project environment, namely: pre-fabrication and modularisation construction; building information modelling; augmented reality and visualization; cloud and real time collaboration; advanced materials and 3D scanning and photogrammetry. The study also identified the benefits of advanced construction techniques such as increased safety, lowered overall costs, improved schedule, increased productivity, better environmental performance and reduced waste. Moreover, the study identified the challenges associated with the use of advanced construction techniques such as increased in costs, increased in co-ordination, engineering design, early procurement, logistics and owner and contractor capability. The skilled required to implement advanced construction techniques were also identified in the study which included analytical thinking and innovation, active learning and learning strategies, creativity, originality and initiative, technology design and programming, critical thinking and analysis, complex problem solving, leadership and social influence, emotional intelligence, reasoning, problem solving and ideation and systems analysis and evaluation. Lastly, the key critical success factors required to implement advanced construction techniques in the nuclear project were identified including organisations and culture, technology, materials and tools, processes and operations, policies and regulations and collaboration.

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APPENDIX A

SURVEY QUESTIONNAIRE

Dear Participant,

Nuclear Construction projects globally are increasingly adopting advanced construction techniques as part of the process to deliver the project within time, cost and quality. The speed and scope of technological change as a result of the onset of the fourth industrial revolution creates tremendous opportunities for the use of advanced construction techniques in the construction industry.

The nuclear construction industry can benefit from improved productivity and efficiency thanks to digitalisation, innovative techniques and new construction technologies. This research study is an investigation into advanced construction techniques opportunities for usage in nuclear construction in South Africa and to produce a framework document to be used by all stakeholders.

This research survey is undertaken as part of the fulfilment of a mini-dissertation "**A framework for advanced construction techniques used in the construction of nuclear projects in South Africa**" for the degree Masters of Science in nuclear engineering at the North-West University. The Research Supervisor is Professor JH Wichers, North-West University

The questionnaire should take approximately 20 minutes to complete. **Your personal information and your responses will be treated as confidential.**

The questionnaire uses a five-point Likert scale for most questions. For each statement only tick or make a cross ("X") in the box which corresponds to your choice. There are no right or wrong answers. When you have completed the questionnaire please check that all questions have been responded to prior to returning the completed questionnaire.

Kindly send your electronic responses to sewsanp@eskom.co.za.

It will be appreciated if you can return the completed survey on or before 04 November 2019.

Thank you in advance for your contribution.

PART 1: Biographical details of respondents

Question 1

What is your Gender?	
Male	
Female	

Question 2

Which age category do you belong?	
20 – 29 years	
30 – 39 years	
40 – 49 years	
50 – 60 years	
Above 61 years	

Question 3

What is your highest level of education?	
No formal education	
Matric	
Diploma	
B Degree	
Hons Degree	
Master's Degree	
PhD	

Other (Specify)	

Question 4

How many years of work experience do you have in the construction Industry and in which sector?		
	Nuclear	**Conventional**
0-11 months		
1-5 years		
6-10 years		
11-15 years		
16-20 years		
Over 20 years		
Other (Specify):		

Question 5

Which of the following best describes the job you perform?		
	Nuclear	**Conventional**
Project Manager		
Construction Manager		
Supervisor		
Safety		
Quality		

Engineer		
Procurement		
Owner		
Nuclear Regulator		
Building Information Modelling professional		
Information and Communication Technology professional		
Other (Specify):		

PART 2: Advanced Construction Techniques

Question 6 (Advanced Construction Techniques)

Please indicate your level of agreement or disagreement with the statements below.

What advanced construction techniques are you exposed to in the project environment?

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Modularisation					
Digitalisation					

Question 7 (Advanced Construction Technologies)

Please indicate your level of agreement or disagreement with the statements below.

What advanced construction technologies are you exposed to in the project environment?

		Yes	No
a	Pre-fabrication and Modularisation construction		
b	Building information modelling		
c	3D printing and Additive manufacturing		
d	Augmented reality and visualization		
e	Big Data and predictive analytics		
f	Wireless monitoring and connected equipment		
g	Cloud and real time collaboration		
h	Autonomous construction		
i	Advanced materials		
j	3D scanning and Photogrammetry		

Question 8(Nuclear Safety)

Please indicate your level of agreement or disagreement with the statements below. **What advanced construction technologies are you exposed to that is used to improve nuclear safety culture in the project environment?**			
		Yes	**No**
a	Pre-fabrication and Modularisation construction		
b	Building information modelling		
c	3D printing and Additive manufacturing		
d	Augmented reality and visualization		
e	Big Data and predictive analytics		
f	Wireless monitoring and connected equipment		

g	Cloud and real time collaboration		
h	Autonomous construction		
i	Advanced materials		
j	3D scanning and Photogrammetry		

Question 9 (Nuclear Quality)

Please indicate your level of agreement or disagreement with the statements below. **What advanced construction technologies are you exposed to that is used to improve nuclear quality in the project environment?**			
		Yes	**No**
a	Pre-fabrication and Modularisation construction		
b	Building information modelling		
c	3D printing and Additive manufacturing		
d	Augmented reality and visualization		
e	Big Data and predictive analytics		
f	Wireless monitoring and connected equipment		
g	Cloud and real time collaboration		
h	Autonomous construction		
i	Advanced materials		
j	3D scanning and Photogrammetry		

Question 10 (ACT Benefits)

Please indicate your level of agreement or disagreement with the statements below.

What are the benefits of advanced construction technologies in nuclear construction?						
		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
a	Increased safety					
b	Overall lower costs					
c	Improved Schedule					
d	Increased productivity					
e	Better environmental performance					
f	Reduced waste					
g	Reduced site based permits					

Question 11 (ACT Challenges)

Please indicate your level of agreement or disagreement with the statements below. **What are the Challenges of advanced construction technologies in nuclear construction?**						
		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
a	Increased Costs					
b	Increased Co-ordination					
c	Engineering Design					
d	Early Procurement					
e	Logistic					
f	Owner and Contractor Capability					

Question 12

Please indicate your level of agreement or disagreement with the statements below. **What digital technologies are you are currently exposed to and used in the project environment?**						
		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
a	Planning tools, e.g. primavera					
b	Enterprise Resource Planning (ERP) tool e.g. SAP for finance,					
c	SmartPlant tool for 3D design, documentation, contract management,					
d	Positioning systems tools e.g. Global positioning Systems (GPS), Radio Frequency (RF) technology					
e	Imaging Technology tools e.g. photogrammetry, laser scanning, augmented reality, Geographic Information System (GIS)					
f	Mobile technology tools e.g. mobile phones, tablets					
g	Cyber security tools e.g. firewalls, virus protection, malware protection					

Question 13

Please indicate your level of agreement or disagreement with the statements below. **What skills are required in order to implement advanced construction techniques in the construction of nuclear projects?**						
		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
a	Analytical thinking and Innovation					

b	Active learning and learning strategies					
c	Creativity, originality and initiative					
d	Technology design and programming					
e	Critical thinking and analysis					
f	Complex problem solving					
g	Leadership and social influence					
h	Emotional Intelligence					
i	Reasoning, problem solving and ideation					
j	Systems analysis and evaluation					

Question 14

Please indicate your level of agreement or disagreement with the statements below.

What are the key success factors to implement advanced construction techniques in the construction of nuclear projects?

		Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
a	Policies and regulations promoting advanced construction techniques as strategy					
b	Collaboration between industry and owners					
c	Technology, materials and tools are in place					
d	Processes and operations to aid advanced construction techniques					
e	People, organisations and culture to support advanced construction techniques					

APPENDIX B

Sample a Framework

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Sample a Framework

Eskom	Report	Group Capital Division

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1. INTRODUCTION

This report is an investigation into advanced construction techniques opportunities for usage in nuclear construction in South Africa, and to produce a framework to be used by all stakeholders. This report will concentrate on the construction phase of the construction project management lifecycle. The investigation identifies advance construction methods used in nuclear projects globally, the best practice for advanced construction management, and the key requirements. These construction technologies include modularisation, building information modelling (BIM), additive manufacturing (3D printing), robotics, augmented reality, Blockchain, artificial intelligence, autonomous equipment, advanced materials, and Internet of Things. The framework will provide a guideline to assist in transforming practitioners performing nuclear projects to successfully plan and deliver a nuclear new build project in South Africa.

2. SUPPORTING CLAUSES

2.1 Scope

This report identifies and investigates the experience of advanced construction technologies application in global projects and provides a framework to aid in implementation within the South African nuclear new build project. The following key items will be discussed:

- Nuclear Safety Culture
- Nuclear Quality
- Pre-fabrication and Modularisation construction
- Open top method
- Building information modelling
- 3D printing and additive manufacturing
- Augmented reality and visualisation
- Big Data and predictive analytics
- Wireless monitoring and connected equipment
- Cloud and real-time collaboration
- Artificial intelligence
- Autonomous construction, including robotics
- Advanced materials
- 3D scanning and photogrammetry

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2.1.1 Purpose

The purpose of this document is to provide a framework for advanced construction techniques used in the construction of nuclear projects in South Africa. The framework will identify key technologies currently used, provide the benefits and disadvantages and provide a process that can be used to ensure successful implementation.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

2.1.3 Effective date

This document will be effective from the date of authorisation of this document until it is reviewed or withdrawn.

2.2 Normative/Informative References

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems

[2] The Electricity Regulation Act 4 of 2006

[3] European Utility Requirements For LWR Nuclear Power Plants Revision D, October 2012;

[4] Employers Requirements Specification for the Fleet of Standardised Design NPP, Reference 233-158, 30 June 2014;

[5] The National Nuclear Regulator Act 1999 (Act No. 47 of 1999);

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2.3 Definitions

Definition	Explanation
3D printing	3D (three-dimensional) printing, or additive manufacturing, is a computer-controlled technology that builds objects by depositing consecutive layers of material.
Artificial intelligence (AI)	The simulation of human intelligence processes by machines, especially computer systems. These processes include learning, reasoning and self-correction. One subfield or application of AI is machine learning.
Autonomous vehicle	Often referred to as “driverless” or “self-driving”, an autonomous vehicle is capable of sensing its environment and navigating safely and effectively with no or minimal human intervention.
Blockchain	Also called distributed ledger technology. A decentralised data structure in which a digital record of events (such as a transaction) is collected and linked by cryptography into a time-stamped “block” together with other events.
Cybersecurity	The ability to protect or defend the use of cyberspace from cyber-attacks and cyber incidents, preserving the availability and integrity of networks and infrastructure and the confidentiality of the information these contain. Commonly also refers to the safeguards and actions available to do this.

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Definition	Explanation
Digitalisation	Digitalisation describes the increasing application of digital technologies (i.e. ICT) across the economy, including energy, to achieve desired outcomes such as improved safety, efficiency and productivity. The trend toward greater digitalisation is enabled by advances in data, analytics and connectivity: increasing volumes of data thanks to the declining costs of sensors and data storage, rapid progress in advanced analytics and computing capabilities, and greater connectivity with faster and cheaper data transmission.
Drone	Also known as an unmanned aerial vehicle (UAV), a drone can either be piloted remotely by a human or else can be a fully autonomous vehicle.
Internet of Things (IoT)	Where everyday objects are connected to networks to provide a range of services or applications in areas such as cars, home automation and smart grids. The IoT encompasses both machine-to-machine (M2M) connection, where devices interact and share data without the direct involvement of people, and things connected to networks to enable people to control processes or manage their devices remotely.

2.4 Abbreviations

Abbreviation	Explanation
ALARA	As low as reasonably achievable
APMI	American Project Management Institute
CGNPC	China Guangdong Nuclear Power Corporation
CII	Construction Industry Institute
DOE	Department of Energy
FFD	Fitness for duty
IAEA	International Atomic Energy Agency
IRP	Integrated Resource Plan
KEPCO	Korea Electric Power Corporation
PPE	Personal Protective Equipment
SCWE	Safety Conscious Work Environment
WEF	World Economic Forum

2.5 Roles and Responsibilities

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3. ADVANCED CONSTRUCTION TECHNIQUES FRAMEWORK

3.1 Introduction

Nuclear construction projects globally are increasingly adopting advanced construction techniques as part of the process to deliver the project within time, cost and quality. The speed and scope of technological change as a result of the onset of the fourth industrial revolution creates tremendous opportunities for the use of advanced construction techniques in the construction industry. The nuclear construction industry has not fully embraced the latest technological opportunities that have radically transformed many other industries. The nuclear construction industry can benefit from improved productivity and efficiency thanks to digitalisation, innovative technologies and new construction technologies. The fourth industrial revolution has ensured that technology and tools developed during the digital revolution have now gained maturity and will play a major role in the future of the construction industry. Innovation has also created many emerging technologies that will affect nuclear construction projects immensely.

This report is an investigation into advanced construction techniques opportunities for usage in nuclear construction in South Africa and to produce a framework document to be used by all stakeholders. This report will concentrate on the construction phase of the construction project management lifecycle. The investigation will identify advance construction methods used in nuclear projects globally. The nuclear industry also has a best practice for advanced construction management and the key requirements will be identified. These construction technologies include modularisation, building information modelling (BIM), additive manufacturing (3D printing), robotics, augmented reality, Blockchain, artificial intelligence, autonomous equipment, advanced materials and internet of things. The output from this research will be a framework for advanced construction technologies that will be used for nuclear construction projects in South Africa. The aim is to provide a guideline with information to assist transform practitioners in nuclear projects to successfully plan and deliver a nuclear new build project in South Africa.

The requirements for the nuclear new build to have some localisation effort must be taken into consideration during the entire lifecycle. The construction phase and the preparation and planning required to adopt advanced construction will ensure a successful project saving time and money.

3.2 Construction Management Frameworks

Many construction and project management organisations have models, best practises, and knowledge repositories to aid the successful delivery of a project.

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3.2.1 American Construction Project Management Institute

The American Construction Project Management Institute developed a model that describes the processes required for the successful completion of an industrial project is shown in Figure 3-1. The model shows the construction lifecycle and highlights the key items that must be considered for implementation. This model will be used as the basis to develop a framework of advanced construction techniques that can have positive impacts on the outcome of a project.

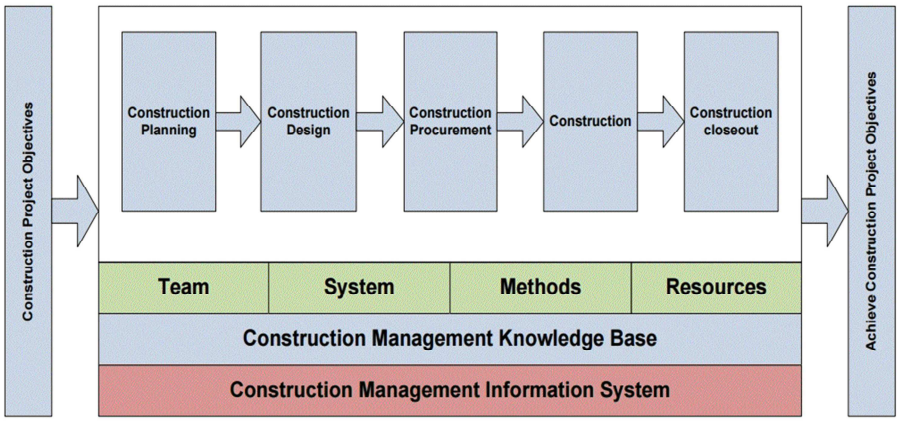


Figure 3-1: Framework for American Project Management Institute

3.2.2 Construction Industry Institute

The Construction Industry Institute (CII) project management model is described in Figure 3-2. The key difference to other models is the emphasis on front end planning. The focus on the feasibility, concept and detail scopes adds confidence to the ability to deliver a successful project. Furthermore, through research, the organisation has produced many best practise guidelines that is in use industry-wide. The organisation has performed research on advanced construction technologies, in particular, modularisation. This information will be incorporated into the framework for advanced construction technologies.

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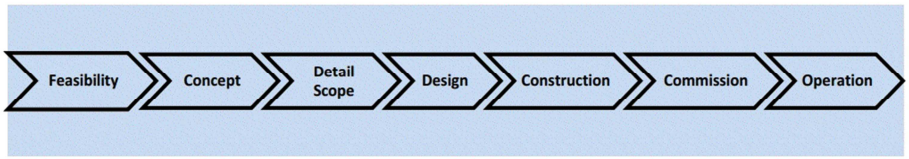


Figure 3-2: Construction Industry Institute Project Management Model

3.2.3 Nuclear Project Management

Nuclear projects are unique because of the presence of radioactivity and radioactive materials. Devgun further explains that nuclear projects have three key areas that make nuclear projects different from other types of projects. These areas are:

- Radiation protection
- Nuclear Safety Culture
- Nuclear quality

3.3 Nuclear Safety Culture

It is well recognised in the industry that safe operation of a nuclear site requires not only the proper design and operation of the safety systems but a safety-conscious attitude of the workforce. The fundamental safety objective is to protect the people and the environment from the harmful effects of ionising radiation. The key attributes of a nuclear safety culture site are:

- Site management cultivates and promotes a safety-conscious work environment (SCWE).
- Each worker is personally responsible for safety.
- Encourage a questioning attitude at all levels of the workforce and provide adequate training.
- Encourage safety culture in every task to be performed
- Organisation demonstrates a strong commitment to safety.
- Workers can raise safety concerns without fear of reprisal.
- Safety is the highest priority in decision making.
- Safety training is provided and continually updated.
- Apply lessons learned from industry experience.
- Nuclear sites contain radiation hazards; thus, nuclear sites have unique training requirements.

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- In addition to the safety of workers, the safety of the public near the site is given proper consideration.
- Open (and free of reprisal fear) flow of information on safety-related issues.
- A formal process is established for differing professional opinions (DPO).

The key elements of a safe nuclear work site are shown in Figure 3-3. To achieve this, advanced technologies can play an important role.

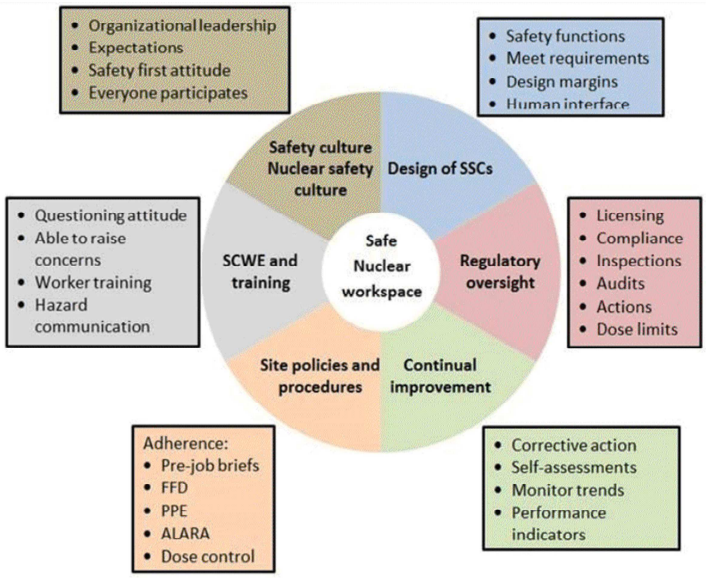


Figure 3-3: Key elements of a safe nuclear workplace

3.4 Nuclear Quality

Nuclear quality control and quality assurance are intended to provide adequate confidence that a structure, system or component will perform satisfactorily in service. In South Africa, the requirements for nuclear quality is regulated by the National Nuclear Regulator (NNR) and found in the document titled Quality and Safety Management for Nuclear Installations in South Africa, commonly referred to by its document reference number RD-0034. BIM can play an important role in the quality process in nuclear construction, as shown in Figure 3-4.

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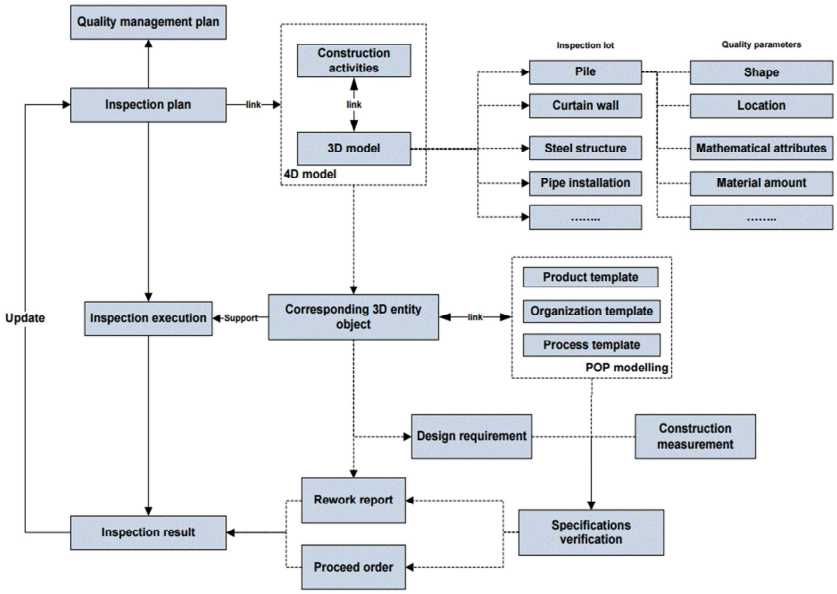


Figure 3-4: Construction quality management plan using BIM quality model

In the construction of nuclear installations, traceability of items provides an important tool through the lifecycle from the initial design through construction and then to commissioning and later during operation and maintenance. Traceability is achieved by the collection and storage of records that the owner and the regulatory body NNR needs. These records include:

- As-built drawings
- Manufacturing and assembly details
- Inspection reports
- On-site traceability records including marking and tagging
- Construction and test records (to be used as baseline data)
- Design calculations
- Documentation of design changes and non-conformance
- Details of equipment qualification

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Advanced construction technologies can support these requirements for traceability by providing a central repository to store and retrieve all information instantaneously.

3.5 Advanced Construction Techniques

A study by Bechtel Power Corporation in 2004 highlighted that standardised plants and advances in construction techniques promise to reduce construction costs and schedule in nuclear power plant construction. A summary of these technologies is listed in Table 3-1. Many of these technologies can be found in the mature phase in the technology lifecycle today. Many new technologies are added daily as the digital age progresses.

Table 3-1: Advanced Reactor Construction Technologies – 2004

#	Description	Recommended for Advanced Reactor Implementation
Sufficiently mature with proven economic benefits		
1	Concrete composition technologies	Yes
2	High deposition rate welding	Yes
3	Robotic welding	Yes
4	3D modelling	Yes
5	GPS application in construction	Yes
6	Open top installation	Yes
7	Pipe bends versus welded elbows	Yes
8	Precision blasting / Rock removal	Yes
Show promise but further technical development needed		
9	Pre-fabrication, preassembly, modularisation	Yes
10	Cable pulling, termination and splicing	Yes
11	Steel plate reinforced concrete structures	Yes
12	Advanced information management and control	Yes
Not Recommended		
12	Fibre-reinforced polymer rebar structures	No

Advanced construction technologies adoption in nuclear construction is gaining momentum as the best practice to improve plant design, ensure the quality of construction and reduce the taken to construct the plant.

Advanced construction technologies are designed around the equipment found in a nuclear power plant, and innovative ideas have created better ways of delivering the construction. The equipment types are summarised in Table 3-2.

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Table 3-2: Equipment comprising a pressurised water reactor in nuclear power plant (Worley Parsons, 2011)

Mechanical Equipment	Electrical Equipment	C&I Equipment	Civil Works
Pressure vessels	Generators	Distributed Control System (DCS)	Civil concrete
Tanks	Transformers	Transmitters	Forms
Valves	Motors	Gauges/indicators	Rebar
Pumps	Switchgear	Sensors/elements	Tendons
Compressors	Motor control centres (MCC)	Transmitters	Structural and reinforcing steel
Fans (HVAC)	Electrical panels		Containment assemblies (electrical pen, piping pen, hatch assemblies)
HVAC (chillers, heating coils)	Cables		
Heat exchangers			
Filters			
Ion exchangers			
Turbines			
Pipes			
HVAC ductwork			
Cranes			

3.6 Modularisation

Modularisation entails the large-scale transfer of stick build construction effort from the job site to one or more local or distant fabrication shops/yards, to exploit any strategic advantage. There are three levels of modularisation, defined as follows:

- Pre-fabrication – joined materials to form a component part of a final installation;
- Pre-assembly – joined component parts to form a sub-unit;
- Module – joined sub-units to create an installation unit or assembly.

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Figure 3-5: Sanmen CA20 module installation

3.6.1 Benefits of Modularisation

Modularisation as a construction technology has many benefits in the successful delivery of a project. These benefits include lower capital costs, improved schedule performance, increased productivity, higher overall quality, increased safety performance, reduced waste, better environmental performance, and reduced site-based permits. The summarised benefits and details are shown in Table 3-3.

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Table 3-3: Benefits of Modularisation

Measurement Category	Benefit Area
Lower capital costs	• Off-site labour costs reduced • On-site accommodation costs reduced • Material delivery cost reduced • On-site crane usage minimised
Improved schedule performance	• Workshop fabrications prevent delays due to the weather • Parallel fabrication and construction reduce schedule time
Increased productivity	• Reduced on-site labour numbers • Increased labour productivity • Highly skilled labour workforce
Higher overall quality	• Improved quality control • Improved working environment • Reduced failure rate
Increased safety performance	• Safety risks reduced in a controlled shop environment • Reduced exposure to hazardous conditions • Improved work environment
Reduced water and better environmental performance	• Reduction in material waste • Reduction in noise, air and water pollution • Reduced energy usage
Reduced site based permits	• Reduced rigging and working at heights • Reduced permit process due to parallel work

3.6.2 Challenges to Modularisation

The research conducted by the Construction Industry Institute identified barriers to modularisation. These include cost barriers, co-ordination barriers, engineering design barriers, procurement barriers, logistics barriers, and expertise/culture barriers.

Table 3-4: Challenges to modularisation

Measurement Category	Challenge Area
Cost	• Increased transportation costs due to bigger cranes and larger ships • Complete engineering required earlier • Investment required earlier
Co-ordination	• Increased engineering is a challenge to resources
Engineering design	• Project scope must be well designed and finalised early
Procurement	• Modules manufactured in parallel will require large equipment to be procured early

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Measurement Category	Challenge Area
Logistic	• Insufficient supply of heavy and mega lifts resulting in the construction of smaller modules • Minimal storage space on site for modules • Module size constrained by transport restriction
Owner and contractor capability	• Methods and benefits of modularisation are unknown to owners

3.6.3 Design and Engineering

A multi-disciplinary effort is required early in the process to ensure success with modularisation. The use of 3D models and virtual design tools to design and also simulate the equipment in the field has great benefits. This equipment is then captured in the materials programme and managed on a single platform to see the effects of late delivery or to determine when the equipment is required.

The plan for manufacturing is critical to ensure that when equipment is required according to the plan, they are manufactured and available. Modularisation allows manufacturing to take place in off-site workshops. The logistics to then transport these items to the site is also important.

Through increased computer speed, storage capacity and processing capabilities digital engineering has empowered a paradigm shift from the traditional design-build-test methodology to a model-analyse-build methodology.

3.7 Advanced Construction Methods

3.7.1 Open-Top Construction

Open-top construction takes place in the reactor building and containment area. In the open-top installation sequence, part of the reactor and containment wall is built. Heavy equipment such as the reactor pressure vessel, containment vessel, steam generators, emergency diesel generators, heat exchangers, overhead cranes, condensers, and feedwater heaters are lifted using very heavy lift cranes into place, and then the rest of the construction continues.

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Figure 3-6: Sanmen unit 1 CA01 Module: 1030-ton module lifted over CV ring and set in the reactor building

3.7.2 Parallel Construction

Modularisation allows the application of parallel construction techniques whereby civil, mechanical and electrical can proceed for the most part in parallel. A qualitative schedule is shown in Figure 3-7 of the conventional method of construction compared to modularisation. To get maximum gain on the schedule, a different strategy needs to be adopted for procurement, scheduling, and module installation. The key factors are:

- Early procurement of equipment for module fabrication;
- Advanced accessibility and transportation plans;
- Extra ground surfaces allocated for heavy lifts and long lift radii;
- Extra laydown space for module handling;
- An integral module/construction management approach.

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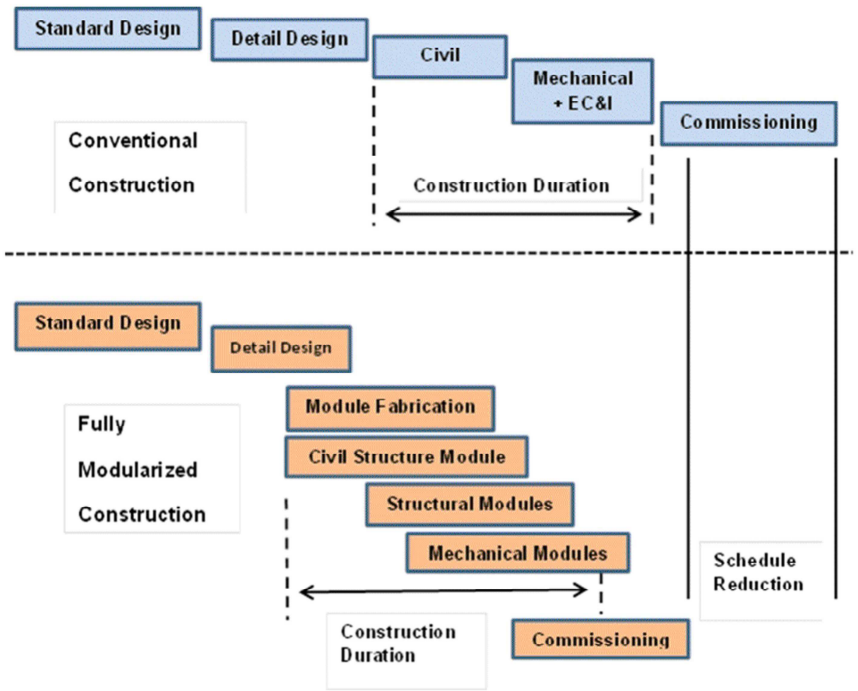


Figure 3-7: Gain in time for parallel construction

Parallel construction involves the concurrent execution of two or more activities that would otherwise follow one after the other. This reduces the time required to deliver the area under construction. This technique is combined with modularisation to be effective. While the construction is progressing, the mechanical manufacturing of the module occurs concurrently.

3.7.3 Civil

The civil works is the longest activity on the critical path in the construction phase of the schedule. One of the time-consuming activities for the civil construction is the rebar installation. This is usually done in situ, but for advance construction technique, prefabricated rebar modules are used. These modules are manufactured off-site and then lifted into position before the concrete is poured. Rebar is required in the basemat, containment wall and containment dome, and the structural walls of the reactor and turbine buildings.

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3.7.4 Mechanical

Mechanical modules usually contain several process components, a selection of equipment combinations of pumps, compressors, motors and control centres, heat exchangers, fans, air ducts valves, interconnecting piping, instruments, cables, cable trays, and wiring. These modules can be fabricated and assembled in a factory environment off-site and then transported and installed into its correct position. Welding is a key activity in a nuclear project and the advanced techniques used include minimising on-site welding by moving the welding off-site which allows for automated welding.

3.7.5 Electrical

Cable tray supports have been improved by removing the support on one side. This reduces the amount of temporary scaffolding required and thus prevents congestion and providing better access to the multi-disciplinary work areas. The use of electronic cable and racking routing will improve the cable routing system.

3.7.6 Control and Instrumentation

The use of multi-core cable, fibre optic cables, and bus systems have created benefits by reducing the number of cables and racking required and thereby reducing the cost of cabling. The further use of 3D systems allows for advance detection of cable clashing and better planning for access to the work area. The control system has now progressed to distributed control systems, which has the flexibility to be available early in the construction process to assist in functional testing of the plant and the control logics.

3.7.7 Digitalisation

Digitalisation is the development and deployment of digital technologies and processes in the transformation of industries. It is described as the increased interaction and convergence of the digital and physical worlds. The digital process has three fundamental elements:

- Data – digital information;
- Analytics – the use of data to produce useful information and insights; and
- Connectivity – exchange of data between humans, devices, and machines (including machine to machine), through digital communication network.

Digitalisation is the adoption of information technology tools and systems and combining them on a single platform to assist in delivering a project on time and budget. These tools and system are used through the entire lifecycle of the project, as shown in Figure 3-8.

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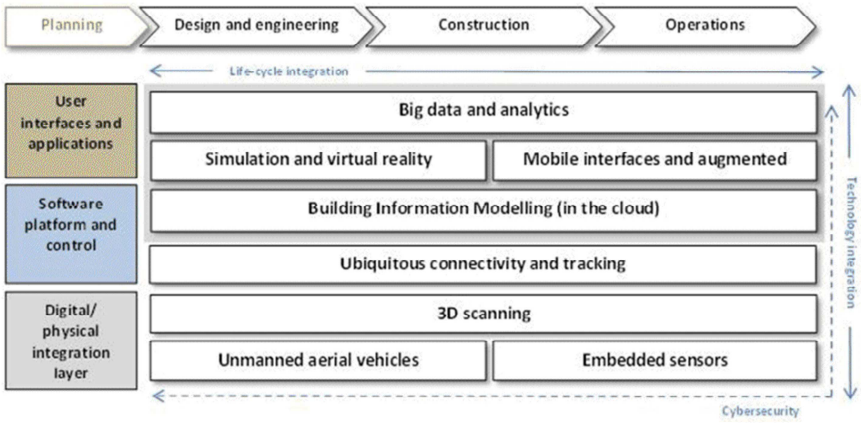


Figure 3-8: Digital tools and systems in the project lifecycle

The South Korean nuclear vendors have used 4D, which is the combination of 3D technology and linking it to the planning software. The Russians have used 7D or Multi-D to deliver nuclear new build projects successfully. The system includes the 3D model, planning, costing, and material and resource management.

The fourth industrial revolution is characterised by the fusion of technologies that is blurring the lines between the physical and digital. The timeline of the industrial revolutions is shown in Figure 3-9, indicating the future that we must understand and prepare for.

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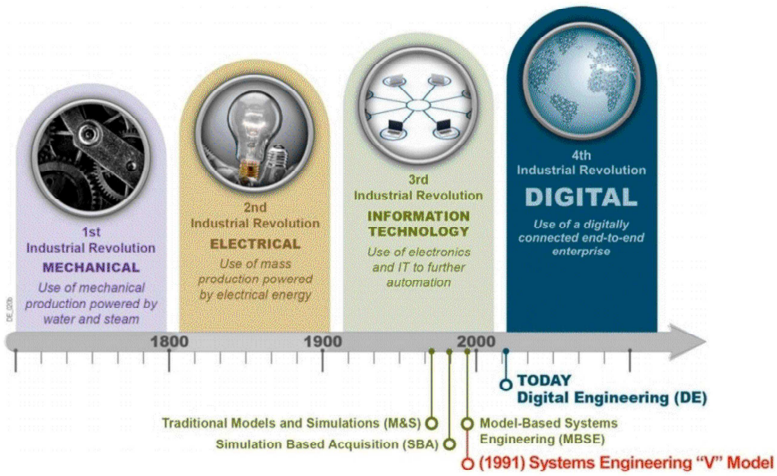


Figure 3-9: Timeline of industrial revolutions

One of the key systems in digitalisation is building information modelling. It is an integrated platform where individual technologies provide data, and when combined with other digital technologies, add significant benefits to the project. These individual technologies are shown in Figure 3-10.

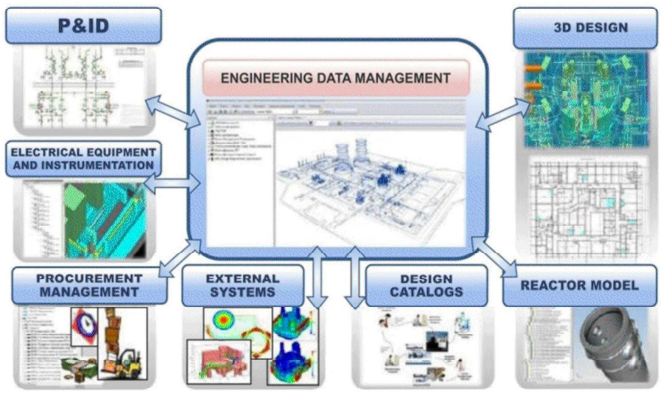


Figure 3-10: Building information modelling

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3.7.8 Building Information Modelling

Building information modelling is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its lifecycle, from the earliest conception to demolition.

BIM is based on object-based parametric Technologies Corporation in the 1980s as described by Hardin et al. It became commercially available to the construction industry in the 1990s with the availability of computers with sufficient processing capability for 3D CAD models. Autodesk's acquisition of Navisworks in 2007 served as a catalyst for BIM adoption among contractors due to its ability to integrate multiple BIM file types. This largely took place during the third industrial revolution. From 2007 to 2012, BIM has moved to the late majority phase of the technology adoption lifecycle.

BIM stores and provides 3D object data, shared information on scheduling (4D), cost (5D), sustainability (6D), and operations and maintenance (O&M) (7D).

A study by the University of Maryland showed that BIM could reduce the design phase of a project by 30% and its cost by 8%. It can also cut 10% from a project's construction phase and 3% from the construction costs.

Russian nuclear vendor Rosatom developed the Multi D system for BIM. It has 3D object data, shared scheduling (4D), cost (5D), sustainability (6D), and operations and maintenance (7D).

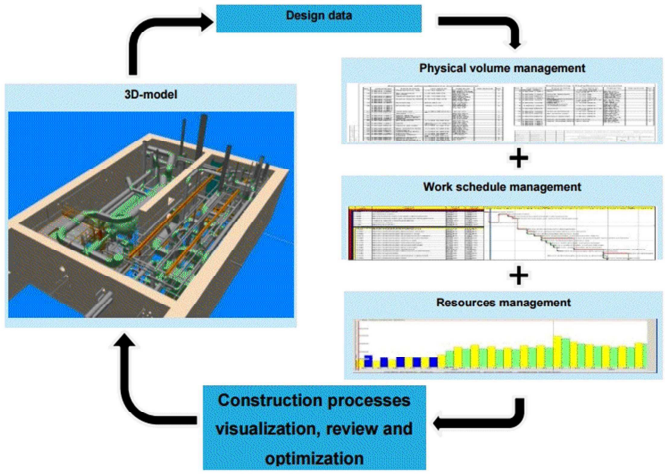


Figure 3-11: Multi-D technology used by Rosatom

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3.7.8.1 Application BIM

- **Co-ordination of construction** – Documentation and installation co-ordination are traditional methods used in construction to ensure quality structures are delivered. Without this, poor quality is the result of issues during construction and operation. The tools used in construction for sequencing, safety, logistics, material storage, deliveries, quality control, equipment management, and reporting still operate in silos. By using BIM, these two co-ordination processes can be aligned, thus resolving clash detection on the elements or systems. BIM's integrated tools are interconnected and consolidated, allowing for better-informed decisions and for responding to information more effectively.
- **Constructability –** Before construction commencement, constructability is used as a technique to identify roadblocks, constraints, and potential issues. BIM's use as the best practice in spatial co-ordination is the key reason for its rapid adoption in construction for conflict resolution between systems. BIM's real-time clash detection prevents failures in the design process.
- **Controlling scheduling** – Model elements and systems are linked to the schedule to animate the sequence of work considering the logistics of construction for efficiencies, safety, and during the construction phase, to justify contractor payments for work completed. Main scheduling platforms such as Asta and Primavera are used. Field BIM on tablets are used on-site to record progress and later synchronised with BIM to have an up-to-date view of progress.
- **Controlling costs** – The costs are linked to the schedule and animation of the sequence of work such that owners have a clear understanding of the cost forecast as work progresses. The model is also used to extract quantities of materials and associated costs to estimate and measure work completed for payment purposes.
- **Facilities management** – Eighty per cent of the lifecycle costs of a structure or building are operating and maintenance. Model-based facilities management focuses on leveraging the model information to reduce the owner's costs. Elements details in the model have information such as serial numbers, manufacturer, warranty information, specifications, purchasing instructions, and training videos that are all available at a click of a button.
- **Analysing data in BIM** – BIM can store a large amount of data and information as construction projects are complex. New analytical tools are available to mine through all the large amounts of data and provide information such as safety reports, material inventory, sub-contractor performance, schedule updates, accounting, and quality that is useful in managing the project. Analysis tools provide meaningful metrics assisting construction management teams to become more productive, safer, and connected.

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- **Close-out –** Project close-out is the final inspection and submission of a project that includes the facility itself, supporting documents, and concluding payment per contract documents. BIM can digitally transfer linked and more meaningful close-out information much earlier than is traditionally done in projects.

The application of building information management through the entire project lifecycle is shown in Figure 3-12. Benefits are realised throughout the lifecycle. The ability to have one system from the front-end planning until handover and through operations creates a seamless process with a huge impact.

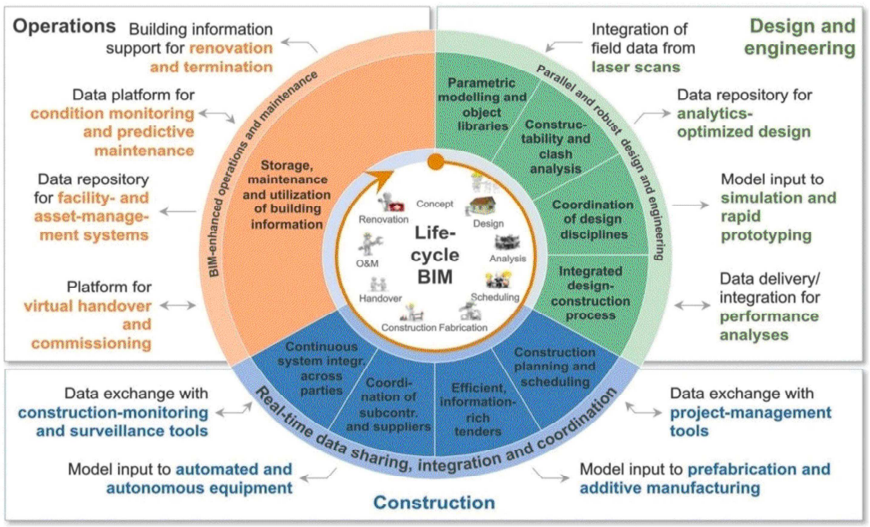


Figure 3-12: Application of BIM along the engineering and construction value chain

3.7.8.2 Integration of individual systems

Organisations globally are using digital technologies that have added value to organisations and made many activities easier and faster. These technologies are used to perform individual tasks currently on projects. The individual systems are shown in Figure 3-13. By using a common integration platform, all the technologies are integrated and linked, creating a powerful tool for nuclear construction practitioners.

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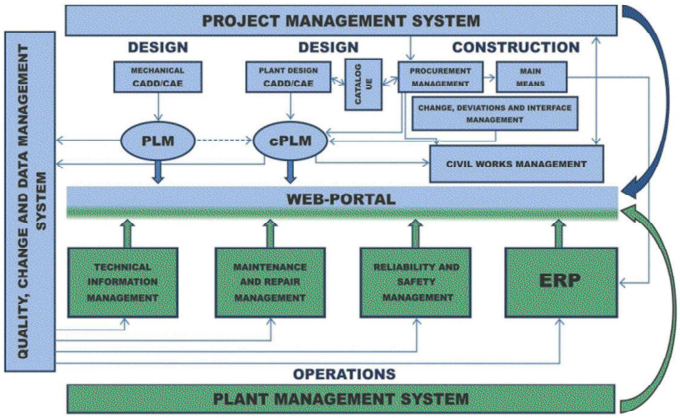


Figure 3-13: Systems integration in BIM

3.7.8.3 Benefits of BIM

The implementation of any technology in an organisation must provide benefits realisation that makes the investment justifiable. The benefits of BIM by category and the area of benefit are shown in Table 3-5.

Table 3-5: Benefits of BIM

Measurement Category	Benefit Area
Costs	• Fewer changes made to the design • Increased collaboration and clash detection reduces cost • Reduction in the number of litigation claims • Improved interface management reduces costs
Time	• Common data environment provides quicker information exchange • Time reduction by 64% for cost and quantity estimation • Improved definition of information requirements • Faster, streamlined procurement process • Time savings in design due to faster retrieval and review of information
Material	• Reduction in wasted material due to design accuracy • Improved accuracy of materials procurement • Reduced need for rework
Quality	• Improved quality control • Improved working environment • Reduced failure rates

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Measurement Category	Benefit Area
Safety	• Safety risks reduced in a controlled shop environment • Reduced exposure to hazardous conditions • Improved work environment
Risk	• Reduction in material waste • Reduction in noise, air, and water pollution • Reduced energy usage
Asset Utilisation	• Reduced rigging and working at heights • Reduced permit process due to parallel work

3.7.8.4 Challenges to BIM

In any project implementation, benefits are often accompanied by challenges. These challenges must be understood and mitigated. The identified challenges are listed in Table 3-6.

Table 3-6: Challenges for BIM

Measurement Category	Challenge Area
Costs	• Implementations costs for training and software • Benefits realised does not accrue to those that pay for the implementation costs • BIM perceived as net cost as difficult to quantify less tangible and other complex benefits • No clear methodology for construction clients to undertake benefits measurement and evaluation thus impacting adoption of the technology

3.7.9 Augmented Reality and Visualisation

Virtual reality (VR) allows the user to be immersed in a computer-generated world. Augmented reality (AR) is a sub-category of virtual reality where computer-generated imagery is superimposed on the real world.

3.7.10 Big Data and Predictive Analytics

Big data refers to large amounts of data gathered from a range of diverse sources in near real-time. Analytics is the use of data to produce useful information and insights. Big data is used in the generation, sharing, and storing of data. The application BIM generates large volumes of data, including planning and procurement.

3.7.11 Artificial Intelligence

Artificial intelligence (AI) is the simulation of human intelligence processes such as learning, reasoning, and self-correction by machines, especially computer systems.

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3.7.12 Wireless Monitoring and Connected Equipment

The ability to embed physical objects with electronics, software, sensors, and connectivity allows them to collect and exchange data creating the Internet of Things (IoT), a network of internet-connect objects.

3.7.13 Cloud and Real-Time Collaboration

Cloud computing is the practice of using a network of remote servers hosted on the internet to store, manage, and process data, rather than using local servers or personal computers.

3.7.14 3D Scanning and Photogrammetry

Photogrammetry involves making measurements from photographs. Aerial photographs taken from an aircraft, drone, or terrestrial (close-range) method are used to create a map, drawing, a measurement, or 3D model of a real-world object or scene.

Table 3-7: Benefits and challenges to photogrammetry

Benefits	Challenges
• Photogrammetry enables instantaneous data capture	• Photogrammetry can be difficult to set up and use
• 3D scanning produces higher resolution and detail	• It is not easily portable
	• Rapid changing technology makes purchased solution obsolete quickly

Photogrammetry will play an important role in the construction of nuclear plants in South Africa. The sites identified for the new build are along the coast and is home to many indigenous and rare plants. Photogrammetry will assist to locate, identify, and map the site with grids detailing the areas with rare plants. Site clearance activities can then be prioritised to these areas where construction activities are necessary.

3.8 Advanced Building Material

With the advent of new techniques for fabrication and manufacturing and the ability to control and modify atoms at the nanoscale, new nano-structured material and devices become a reality.

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Table 3-8: Examples of advanced building and finishing materials

Type of Innovation	Examples of Advanced Materials	Benefits
Incremental Innovation - advances in traditional materials and existing characteristics	Neopor offers 20% efficiency in insulation	• Reduced lifecycle costs • Higher energy efficiency
	Arcelor Mittal's organically coated steel achieves 30-year guaranteed durability	• Reduced lifecycle costs • Higher energy efficiency
	iQ Natural is an advanced vinyl flooring that is 100% recyclable	• Higher recyclability/ reusability • Improved health/well-being
New material combinations and multi-functional characteristics	Super lightweight ceramic sidings combine fast-hardening cement with organic fibres meeting performance at half the weight	• Faster construction process • Reduced material costs
	Self-healing concrete, generated through the addition of bacterial spores reduces lifetime costs by up to 50% (early development)	• Reduced lifecycle costs
	Concrete admixed with special construction chemicals achieves 50% faster curing times	• Faster construction process
Radical innovation – innovative materials with entirely new functionality	Rain-absorbing roof mats, imitating the process of perspiration reduces air-conditioning costs considerably (early development)	• Reduced lifecycle costs • Higher energy efficiency
	Micronal, a micro-encapsulated phase-change material incorporated into building materials, enables intelligent temperature management	• Reduced lifecycle costs • Higher energy efficiency
	Slippery liquid-infused porous surfaces constitute super-repellent surfaces inspired by the carnivorous nepenthes pitcher plant (early development)	• Reduced lifecycle costs • Improved health/well-being

3.9 Additive Manufacturing and 3D Printing

Additive manufacturing is defined as "*the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing technologies. Additive manufacturing and 3D printing is a game-changer, and this innovative technology will have a disruptive impact on the construction industry. The technology enables the production of purpose-built shapes that cannot be produced by any other method; it promises productivity gains of 80% for some applications, together with an important reduction in waste*" (WEF, 2016). Key challenges with this technology include resolution issues such as slower printing speeds for larger items and higher costs. The technology has found traction in the construction industry with steel and concrete components now being printed for use.

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Additive manufacturing has advantages over conventional manufacturing including reductions in lead time, reductions of scrap materials, lower inventory costs, less manufacturing complexity, reduced floor space, and the ability to deliver manufactured pieces with complex shapes and geometries.

3.9.1 Digital Twins

Digital technologies have had an impact on the way products are manufactured. Manufacturing for nuclear projects need to adopt digital technologies as it can add tremendous value to the construction process. Early adopters of digital technologies such as aircraft manufacturer Boeing have developed models to leverage digital technologies as shown in Figure 3-14. By taking the system engineering design "V" model, Boeing has created the diamond model of digital twins. The top half of the model is the virtual representation of the physical system. This allows for the design, engineering, production planning, production, and certification to take place in the virtual world. Once all issues and risks are resolved, the manufacturing takes place in the physical world. The bottom half of the diamond represents the physical systems. The centre of the diamond represents the systems and models to support the virtual and physical worlds. The digital twins model is a powerful tool. Similar application of this process to building information modelling creates the ability in a project to "build it twice"; once in the virtual world and then the physical construction.

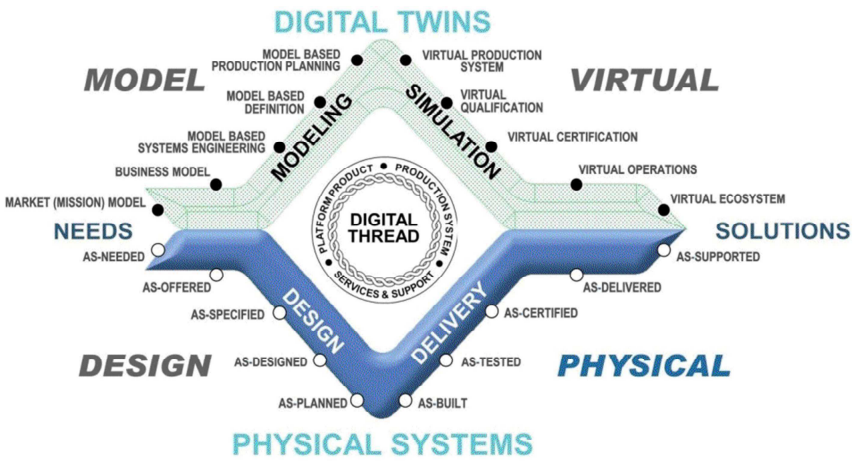


Figure 3-14: Digital twins model

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3.10 Autonomous Construction

The construction industry generally has low levels of automation. New technologies in the digital space could become significant enablers of innovation in construction equipment. These technologies include robotics and drones.

3.10.1 Robotics

Robotics is the science of designing, building, and applying robots. In construction, automation and robotics technologies are used in all stages, from the automation of the design process through to the use of computer-aided design, the production of cost estimates, construction schedules, and project management. The benefits include enhancing productivity and work efficiency with reduced costs, solid quality with higher accuracy, and occupational safety enhancement. Table 3-9 and Table 3-10 summarise the benefits and challenges associated with these technologies.

Table 3-9: Robotics in construction

Type	Advantage	Challenges
Demolition robots: Used for tearing down building walls and structures	• Requires one worker at the controls • Safer as humans are not present at the structures being demolished	• Application mainly for small-scale demolition • Job loss • Requires significant power source
Bricklaying robots: Performing tedious tasks as brick laying	• Task performed efficiently and quickly	• High investment cost
Welding robots: Precise welds joining metal in steel structures	• Safer for workers • High quality of welding	• Stationary device requires worker intervention
Exoskeletons: Mechanical suits enhancing human task ability	• Allows worker to lift heavier objects • Allows disabled people to work on site	• High cost
Forklift robots	• Low cost of ownership • Ability to lift large loads	• Terrain limitations

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3.10.2 Drones

Drones are unmanned aerial vehicles that are controlled remotely by human interface and are used to perform tasks.

Table 3-10: Drones in construction

Type	Advantage	Challenges
Transportation drones	• Attain high locations easily	• Affected by wind
Survey drones	• Capture images in multiple angles in a short time	• Poor quality of images

3.11 Cyber Security

Digitalisation brings many benefits, but cybersecurity remains a key risk. Cyber-attacks generally target the computers, software, and networks used to control, monitor, manage, and protect the IT business systems. The techniques can target personnel, products (both data and physical), infrastructure, and processes (system data flow). It is paramount to protect the integrity and confidentiality of information. A summary of cyberattacks over the past years are described in Table 3-11. Furthermore, geomagnetic storms are natural hazards that pose risks to the technology.

Table 3-11: Cyber-attacks affecting energy infrastructure

Incident	Description
WannaCry (2017)	Using a weakness in the Microsoft operating system, the "WannaCry" ransomware hit hundreds of thousands of computers in thousands of organisations in 150 countries. Power plant infrastructure was not attacked, but several energy companies went offline.
Nuclear Plant Ppear Phishing Attack (2017)	Hackers in the United States used email messages containing fake Microsoft word résumés for engineering jobs thus exposing recipients' credentials for the control engineering network.
Industroyer/Crash Override (Ukraine, December 2016 – reported May 2017)	Malware Industroyer (Crash Override) used in a significant attack on the Ukraine electricity system. The malware enables attackers to view, block, control, or destroy grid control equipment such as circuit breakers. This was an example of a cyber-breach into the control systems of critical infrastructure.
The Mirai Botnet (2016)	Mirai malware exploited low security in connected smart devices such as cameras to deliver the largest denial of service attack to date. This illustrates the vulnerability of the Internet of Things.
Western Ukraine power grid (2015)	Cyber attackers accessed substations' supervisory control and data acquisition (SCADA) and firmware with a combination of malware, personnel credentials obtained by means of email phishing, and denial of service to prevent customers from obtaining call centre information about the blackout.

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Digital security should be built around three key concepts:

- **Resilience –** "system's ability to withstand shocks and quickly recover or adapt to a desired level of stability while preserving the continuity of critical infrastructure operations".
- **Cyber Hygiene –** "creating awareness, secure configuration of equipment and networks, keeping software up to date, avoid users gaining unnecessary system privileges and data access rights and training to establish a security-conscious culture organisation-wide".
- **Security by design –** "incorporation of security objectives and standards as core part of the research and design phase".

3.12 Skills for Advanced Construction Techniques

It is vital to identify the skills required in South Africa for new nuclear plant construction and develop the necessary infrastructure to commence and be prepared for the construction. Key manufacturing skills will require a detailed plan with training standards to support the programme. Nuclear skills require more time and also experience. As part of the localisation effort, training will be critical in ensuring success.

Table 3-12: Skills for the future

Skills in 2018	Skills in 2022
Analytical thinking and innovation	Analytical thinking and innovation
Active learning and learning strategies	Active learning and learning strategies
Creativity, originality, and initiative	Creativity, originality, and initiative
Attention to detail, trustworthiness	Technology design, and programming
Critical thinking and analysis	Critical thinking and analysis
Complex problem solving	Complex problem solving
Leadership and social influence	Leadership and social influence
Emotional intelligence	Emotional intelligence
Reasoning, problem solving and ideation	Reasoning, problem solving, and ideation
Co-ordination and time management	Systems analysis and evaluation

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3.13 Requirements for Successful Advanced Construction Techniques Implementation

To implement advanced construction technologies, companies require steps that include best practice based on experience achieved globally. This process is shown in Figure 3-15. This study will focus on the company-level actions required and not focus on the sector-level and government-level actions. The company-level actions are grouped in four sections, and is dealt with in the section below.

3.13.1 Technology, Materials, and Tools

Companies need to adopt advanced construction technologies. These include advanced building and finishing materials, standardised, modularised and prefabricated components, automated construction equipment, and digital technologies and big data.

3.13.2 Processes and Operations

To achieve substantial improvements in construction productivity and to reduce operating and maintenance costs, companies need to ensure that, during the design and engineering phase, they keep the actual construction process in mind as well as the final operations phase.

3.13.3 Strategy and Business Model Innovation

Companies need to improve collaboration at project-level to bridge the gap with knowledge and skills. The strategy can also be used to collaborate with companies that can provide the knowledge and skills needed for advanced construction technologies.

3.13.4 People, Organisation, and Culture

With the increasing sophistication of technologies, new and broader skills sets are required at all levels of the company. People need to be continuously trained, and effective retention strategies need to be in place to retain staff. Companies need to have a high-performance culture in place.

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(Future) Best practices

Actors

Company level	**2.1 Technology, materials and tool**			**2.2 Processes and operations**		
	Advanced building and finishing materials	Stand, modularized and prefabricated components	(Semi-) autonomous construction equipment	Front loaded and cost continuous design and planning	Innovative contracting models with balanced risk-sharing	A common framework for project management
	New construction technologies, e.g. 3d printing	Smart and life-cycle optimizing equipment	Digital technologies and Big data along the value chain	Enhanced management of sub-contractors and suppliers	Lean and safe construction mgmt. and operations	Rigorous project monitoring (scope, time, cost)
	2.3 Strategy and business model innovation			**2.4 People, organization and culture**		
	Differentiated business model and targeted consolidation / partnerships	Sustainable products with optimal life-cycle value	Internationalization strategy to increase scale	Strategic workforce planning, smart hiring and enhanced retention	Continuous training and knowledge management	High performance organization, culture and incentive schemes
Sector level	**3.1 Industry collaboration**			**3.2 Joint industry marketing**		
	Mutual consent on standards across the industry	More data exchange, and best practice sharing	Cross-industry collaboration along the value chain	Industry-wide collaboration on employer marketing	Coordinated communication with civil society	Effective interaction with public sector
Government	**4.1 Regulation and policies**			**4.2 Public procurement**		
	Harmonized building codes/standards and efficient permit process	Market openness to international firms and SMEs	Promotion and funding of R&D, technology adoption and education	Actively managed and staged project pipeline with reliable funding	Strict implementation of transparency and anti-corruption standards	Innovation friendly and whole-life-cycle oriented procurement

Figure 3-15: Construction industry transformation framework

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4. ACCEPTANCE

This document has been seen and accepted by:

Name	Designation
Bongekile Mthembu	Project Delivery Manager

5. REVISIONS

Date	Rev.	Compiler	Remarks
November 2019	1	Pravin Sewsanker	Initial framework

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APPENDIX C: BAR CHARTS

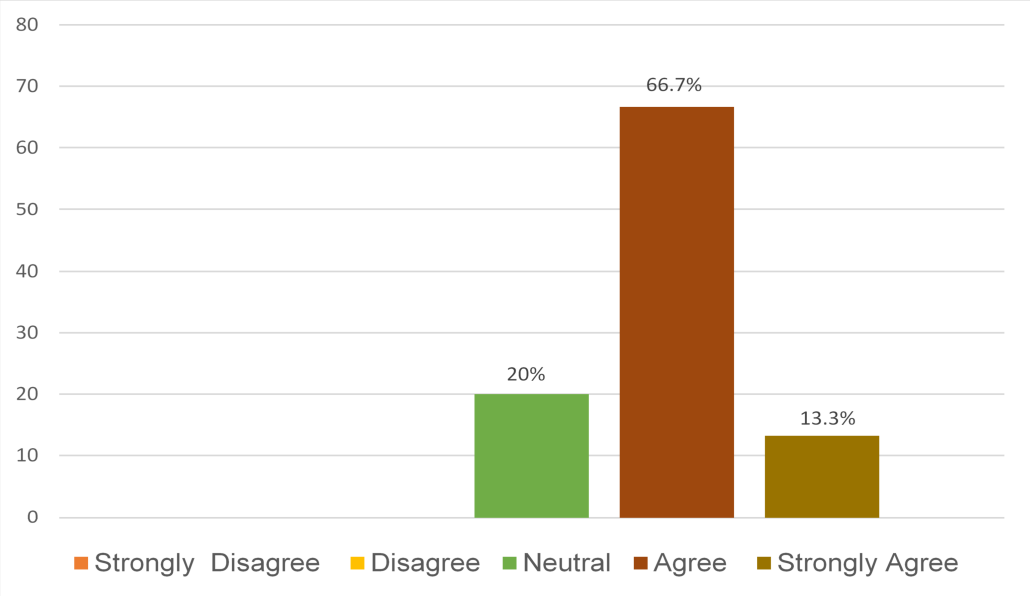


Figure 1 Advanced Construction Techniques: Modularisation

The results showed that 80% of the respondents agreed that they were exposed to modularisation in the project environment as compared to 20% who indicated that they were not exposed to modularisation.

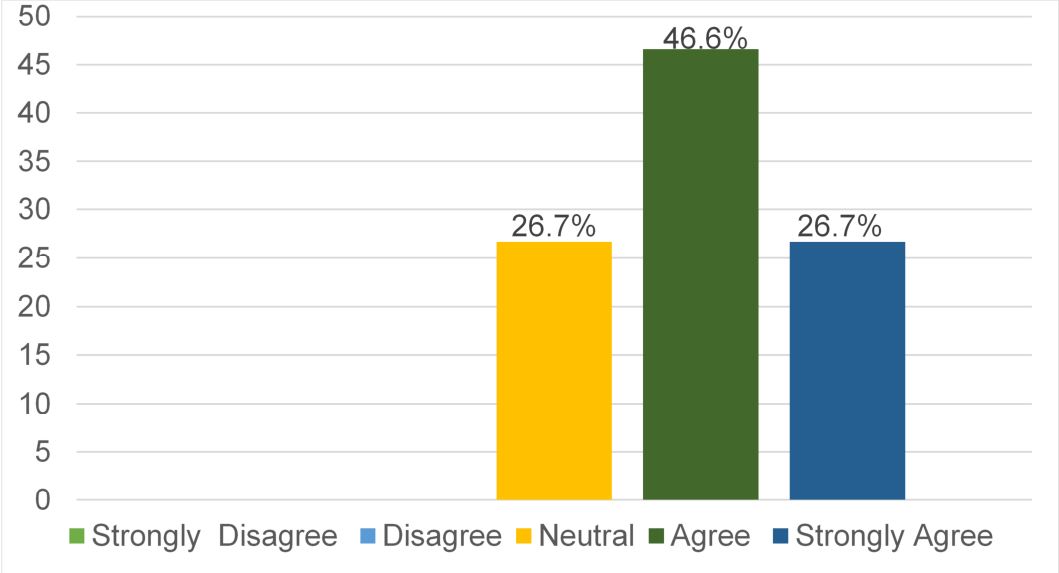


Figure 2 Advanced Construction Techniques: Digitalisation

From the Figure 2, 73.3% of the respondents agreed that they were exposed to digitalisation, while 26.7% of them indicated that they neither agreed nor disagreed that there exposed to digitalisation in the project environment.

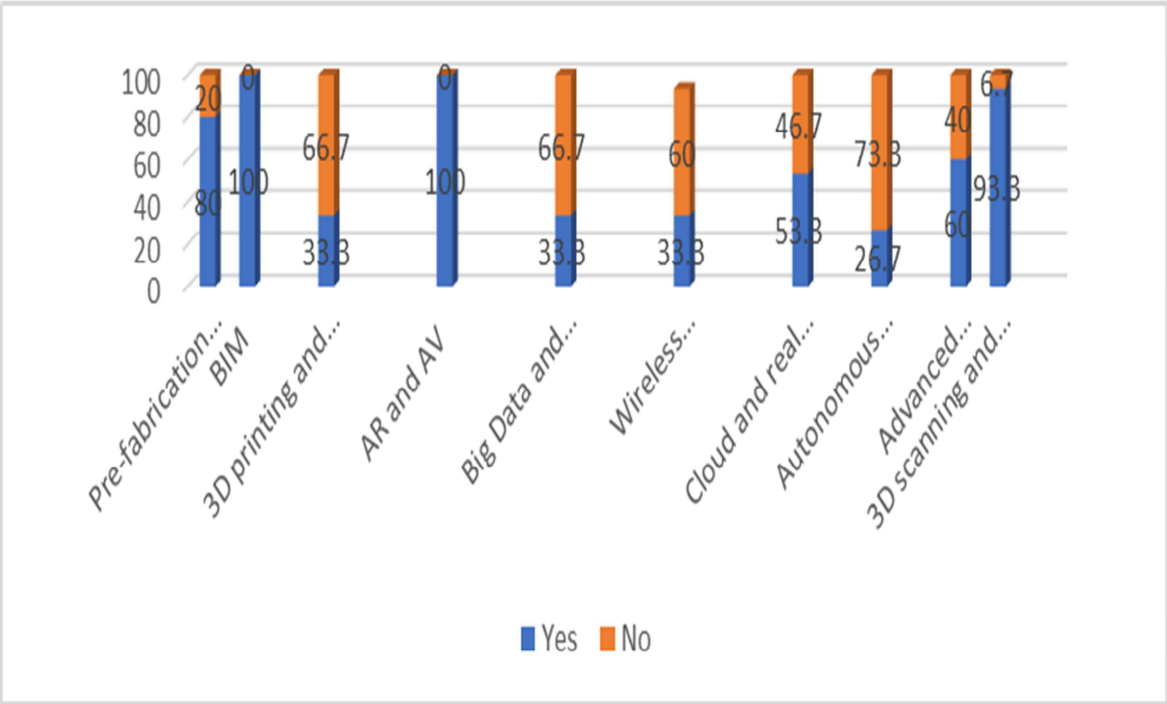


Figure 3 Advanced construction technologies

The results of showed that the advanced construction technologies that the respondents were exposed to included pre-fabrication and modularisation construction (80%), BIM (100%), 3D printing and additive manufacturing (66.7%), augmented reality and visualization (100%), Big data and predictive analytics (66.7%), wireless monitoring and connected equipment (60%), cloud and real time collaboration (53.3%), autonomous construction (73.3%), advanced materials (60%) and 3D scanning and photogrammetry (93.3%).

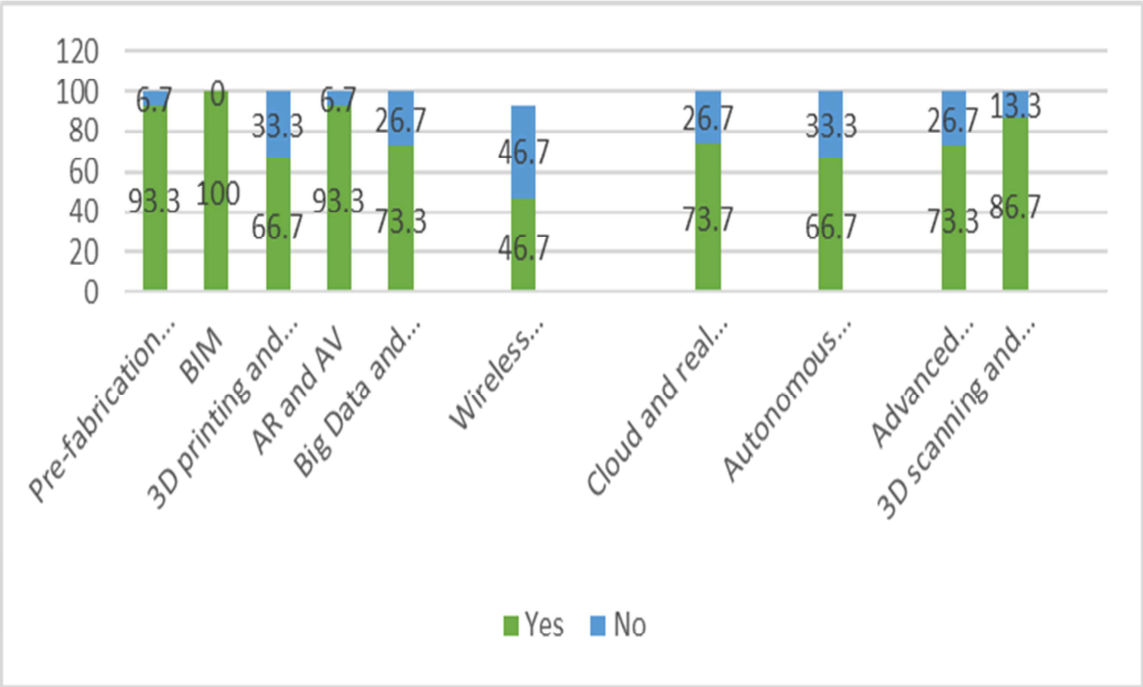


Figure 4 Advanced construction technologies: Nuclear safety culture

The results of the study showed that the type of advanced construction technologies that were used to improve nuclear safety culture in the project environment were, namely: pre-fabrication and modularisation construction (93.3%); building information modelling (100%); 3D printing and additive manufacturing (66.7%); augmented reality and visualization (93.3%); Big Data and predictive analytics (73.3%); wireless monitoring and connected equipment (46.7%); cloud and real time collaboration (73.3%); autonomous construction (66.7%); advanced materials (73.3%) and 3D scanning and photogrammetry (86.7%).

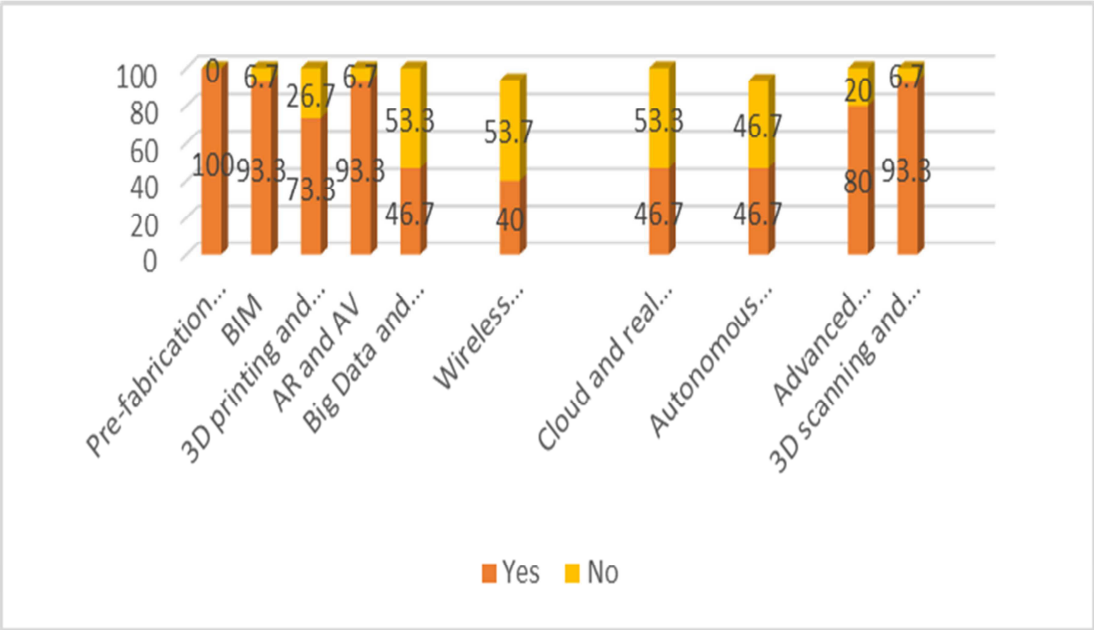


Figure 5 Advanced construction technologies: Nuclear Quality

the types of advanced construction technologies used by the respondents to improve nuclear quality in the construction project were pre-fabrication and modularisation construction (100%), building information modelling (93.3%), 3D printing and additive manufacturing (93.3%), augmented reality and visualization (93.3%), big data and predictive analytics (53.3%), wireless monitoring and connected equipment (53.3%), advanced materials (80%) and 3D scanning and Photogrammetry (93.3%).

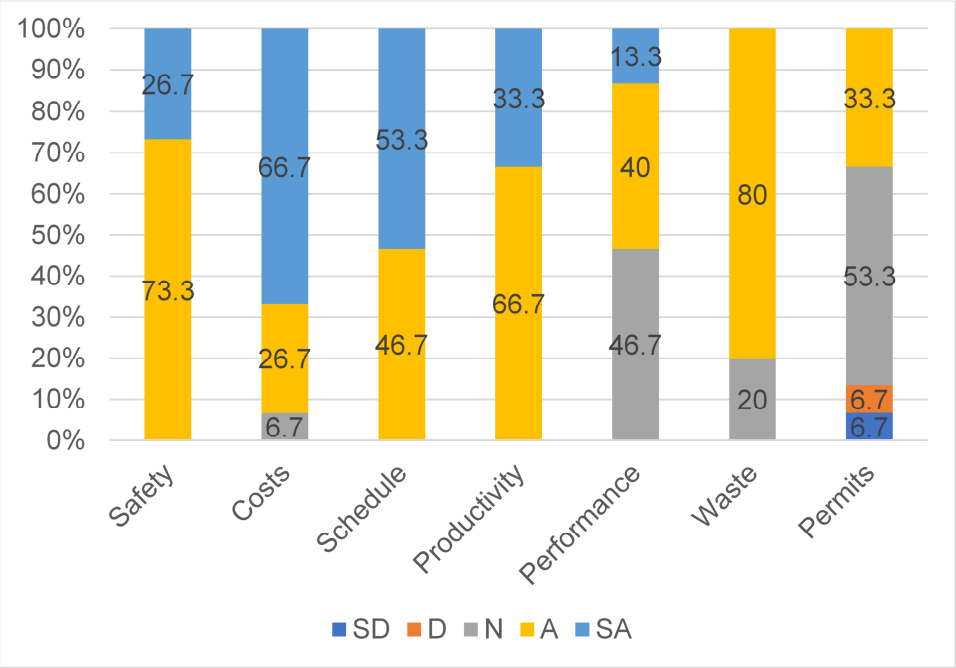


Figure 6 Benefits of Advanced Construction Technologies in Nuclear Construction

The findings showed that the benefits of advanced construction techniques were, namely: increased safety (100%); reduced the overall costs (93.3%) improved schedule (100%); increased productivity (100%); better environmental performance (53.3%); reduced waste (80%). On the contrary, 53.3% said that they neither agreed nor disagreed that advanced construction technologies reduced site-based permits.

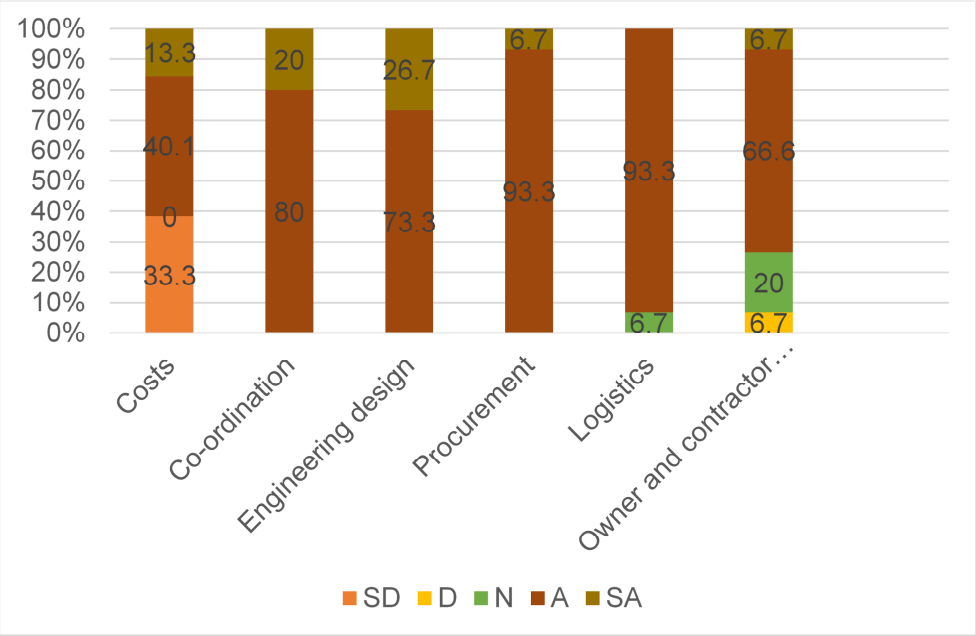


Figure 7 Challenges of Advanced Construction Technologies

As reflected in the Figure 7, the challenge of advanced construction techniques increased in costs (53.4%), increased in co-ordination (100%), engineering design (100%), early procurement (100%), logistic (93.3%) and owner and contractor capability (73.3%) .

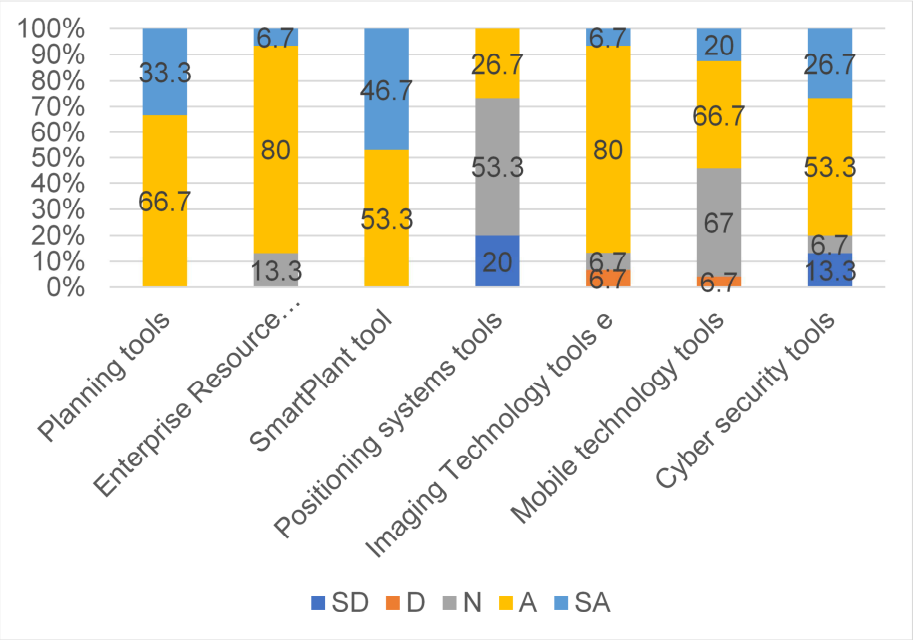


Figure 8 Digital Technologies Used in the Project Environment

The analysis of the data revealed that the kind of digital technologies that the respondents were exposed to and used in the project environment were, namely: planning tools, e.g. primavera (100%); ERP tool e.g. SAP for finance (86.7%); SmartPlant tool for 3D design, documentation, contract management (100%); imaging technology tools e.g. photogrammetry, laser scanning, AR, GIS (86.7%); mobile technology (86.7%) and cyber security tools (80%).

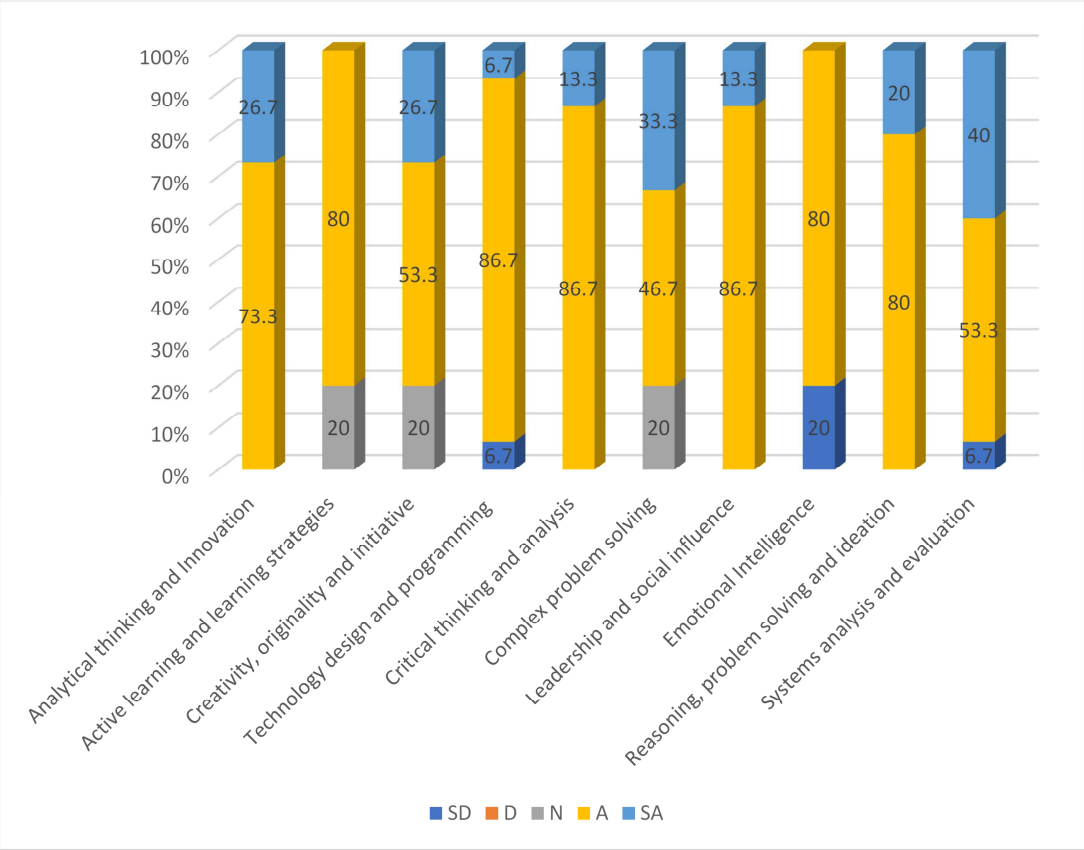


Figure 9 Skills Required to Implement Advanced Construction Techniques

The results of the study showed that the type of skills required to implement advanced construction techniques in the construction of nuclear projects were, namely: analytical thinking and Innovation (100%); active learning and learning strategies (80%); creativity, originality and initiative (80%); technology design and programming (93.3%); critical thinking and analysis (100%); complex problem solving (80%); leadership and social influence (100%); emotional intelligence (80%); reasoning, problem solving and ideation (100%) and systems analysis and evaluation (93.3%).

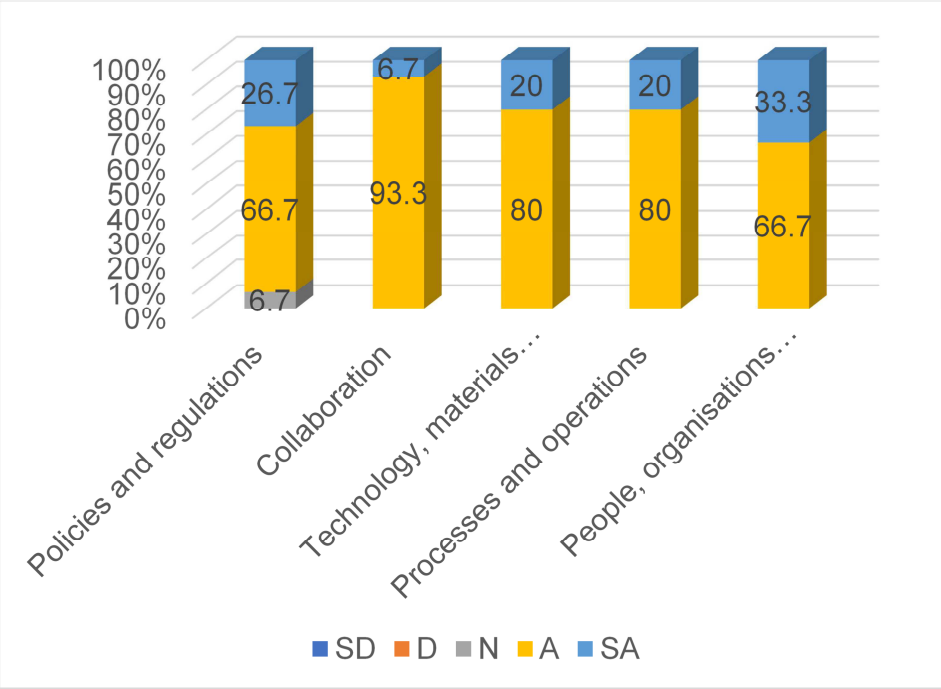


Figure 10 Key Success Factors Required to Implement Advanced Construction Techniques

The results of the study revealed that the key success factors required to implement advanced construction techniques in the construction of nuclear projects were, namely: policies and regulations (93.3%); collaboration between industry and owners (100%); technology, materials and tools (100%); processes and operations (100%) and people, organisations and culture (100%).