BUILDING INFORMATION MODELING FOR SUSTAINABLE CONSTRUCTION

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DECLARATION

I hereby declare that I did this study on my own; it is original work and has never been presented for the award of any academic level in any institution.

Author: **ABDILLAHI ZAHRA ADAN**

Signature...**Date**...15/09/2021...............................

As the supervisor of the above named student and on the behalf of the University of Nairobi, I approve that this study has been submitted in partial fulfilment of the examination requirements.

Supervisor: **Arch. Peter Njeru**

Signature...**Date**...15TH JULY, 2021...............................

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ACRONYMS

AEC	- Architecture, Engineering and Construction
BIM	-Building Information Modelling
BREEAM	-Building Research Establishment’s Environmental Assessment Method
CAD	-Computer Aided Design
CASBEE	- Comprehensive Assessment System for Building Environmental Efficiency
DXF	- Drawing Exchange Format
GBS	- Green Building Studio
GbXML	- Green Building Extensible Markup Language
IFC	- Industry Foundation Classes model; a standard for open BIM data exchange
LCA	-Lifecycle Cost Analysis
LEED	- Leadership in Energy and Environmental Design
IES	-Integrated Environmental Solutions

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ABSTRACT

The study aims at evaluating and investigating the potential of BIM and its capacity in support for sustainable design and construction. This was achieved by: (a) Investigating the current trends in BIM usage within AEC and how it supports sustainable design and construction; (b) Identifying the potentials of Building Information Modelling software relevant to practices for sustainable construction. (d) Determining strategies that can be put in place to increase uptake of BIM amongst built environment professionals. Primary data was collected from Architects, Engineers, Green Building Practitioners, Quantity Surveyors and Construction Project Managers using questionnaires for data collection. Analysis of data was achieved using Statistical Package for Social Sciences and Microsoft Excel.

The study established three major trends in BIM usage i.e., use of Revit, ArchiCAD and Navisworks. MEP (44%), energy analysis (40%) and lighting analysis (38%) on the other hand were the main Computer Aided Analysis being used by the respondents. Majority of the respondents also indicated they have implemented BIM in the design stage. Various environmental performance analysis software for users to analyse building sustainability in the AEC industry however it is not used to its fullest capacity. 42% of the respondents indicated they have not used any of the performance analysis softwares while Platforms such as Graphisoft ecodesigner has been used by only 20% of respondents, Ecotect 18% and IES Virtual Environment 15%.

The study also investigated BIM software packages effectiveness in achieving sustainable construction practices. Three major variables were investigated: Energy efficiency, water efficiency and environmental quality which were further subdivided into 12 subcategories. A hypothesized mean of 3 and above was set as a critical cut-off point in determining BIM software packages effectiveness in achieving sustainability. All the 12 attained a mean of 3 and above hence these findings indicate that BIM software packages are effective in promoting sustainable construction practices.

It is basically asserted that Building Information Modelling has become marketable. This is due to its project visualisation (4.33) project planning and coordination (4.25), clash detection (4.05) and rework reduction (4.02) capabilities. The study also established that sustainable design and Construction is supported by BIM hence the Alternative hypothesis was accepted. The study accordingly recommends education and training focusing on BIM and sustainability to help increase uptake of BIM amongst built environment professionals.

1. CHAPTER ONE - INTRODUCTION

1.1. Background of research

In an era of a steadily growing and complex construction sector, the need to design and construct environmentally sustainable buildings is gaining more platform. With advancement in technology, it is becoming more practicable to incorporate building performance analysis early on from the design stages as opposed to during the construction and operation phase.

Many countries as well as international organizations have introduced rating systems to evaluate and monitor sustainable construction. Examples of these systems include Comprehensive Assessment System for Building Environmental Efficiency-CASBEE developed in Japan, GREEN STAR in Australia, Leadership in Energy and Environmental Design- LEED in the United States, and Building Research Establishment's Environmental Assessment Method- BREEAM in the United Kingdom (Jalaei and Jrade 2014). These sustainable analysis tools have proved useful to professionals by providing means to forecast the performance of a building right from the design stage. These tools have led to significant improvement on cost estimation and quality of the final output.

The construction industry is regarded as the most important natural resources consumer globally. This consumption is estimated at 32% resources, 12% water and 40% energy (IPCC 2012). Moreover, the building sector is the main waste producer generating an estimated one third of global wastes and is responsible for 22% of hazardous waste production. In light of these negative environmental impacts, approaches for estimating sustainability at the end of a project's design stages are continually applied in construction industry.

In vast construction projects sustainable construction has become the new norm globally since it has many benefits. It aims to develop construction and design practices that conforms to efficient usage of natural resources, environmental quality preservation and waste and toxic reduction. The emergence of BIM technology has provided a means of refining and reducing constant errors and inefficiencies of the construction industry by specifically facilitating the design and construction operations. BIM is one of the core tools that has been developed for this purpose. It incorporates variety of expertise and enhances achievement of optimal design during the initial stages and maximises impacts of the entire project's life cycle.

Following these trends, the term Green BIM has come up and is driving forward the sustainability agenda in the construction sector. Green Building Information Modelling deals with preservation of the undertakings within the construction industry in order to reduce negative impacts on the surrounding environment by the use of BIM technology. The principles of the green building information modelling principles evolve around development of construction and design that conforms to efficient use of natural resources such as waste and toxic reduction, operation and maintenance, environmental quality, material selection, water and energy (Krygiel and Nies 2008).

Built environment addresses climate change and environmental degradation: the government recognizes this significant role. To this end as highlighted in the Centre's Strategic Plan of the Government of Kenya (2017/2018- 2021/2022), it is stipulated that it has identified and empowered the Kenya Building Research Centre in championing and coordinating the green building agenda thus impacting on climate change adaptation and mitigation. Some of the Center’s key action areas include: development of green building policy, regulations and guidelines; mainstreaming green building principles in building design and construction; and, conducting research on climate resilient and sustainable building construction materials and technologies. By 2030, the government aims at achieving 75% of both renovated and new private and public large scale buildings as green. These will lead to the achievement of this goal (Green Africa Foundation, 2018).

The building sector must therefore do its part in achieving the goal of reducing GHG emissions and resource depletion. This requires a radical transformation of the methods of designing, constructing, operating and decommissioning buildings. There is a growing global consensus that ‘green building’ or ‘sustainable architecture’ is a useful approach to achieving this transformation (Green Africa Foundation, 2018).

1.2. Problem statement

The construction industry has been growing at a steady rate since the industrial revolution increasingly contributing to negative environmental impacts. The adoption of cutting-edge technological practices has led to the complexity of projects. Today, projects within the construction sector are characterised by many complications. These include; stringent quality requirement, operation on tighter schedule, participation by widely dispersed individuals, embracing of multi-disciplines, and involvement of large capital investment (Alshawi and Ingirige, 2002).

The construction industry is constantly expanding and with it, the energy consumption is increasing as well. The problems proliferating the AEC sectors and the enormous institutional and technological changes has been directly linked to the deteriorating physical environment of our planet. These processes of construction impacts on the environment and they result from emission generation and resource consumption.

As the AEC industry moves from CAD to BIM, the need to incorporate sustainability into the BIM interface is gaining more recognition especially in light of recent global climate change. However, this, much needed building performance analysis is normally implemented following presentation of the construction and design documentations as opposed to the early stages of design. The result therefore is minimal use of design technology and strategies and are energy efficient. The implementation of BIM and building analysis is additionally hindered by fragmentation of the AEC industry, low innovation and slow adoption of ICT.

The use of Building Information Modelling enhances increased project quality and accurate project schedule. Much research has already been done on the potentials BIM's efficient usage of technology and collaborative design. It is opined that there is inadequate information on how to incorporate sustainable performance analysis into BIM process. The study of sustainable construction practices is yet to be prioritized and lacks exposure to innovative practices; there is still a clear gap in the analysis of Building Information Modelling with regard to sustainable construction practices; the study of sustainable construction practices is yet to be prioritized and lacks exposure to innovative practices.

In order to achieve a fully comprehensive built environment, the primary project stakeholders must collaborate and work towards the same. The 2012 Sustainability Survey by the National Bureau of Statistics shows that the role of construction professionals in sustainability is limited to project assessment, energy calculation, advising clients on sustainability, and green product selection. However only a small number of these professionals offered environmental analysis services with only a handful including BIM in their assessment.

Apart from 3-Dimension geometric modelling, Building Information Modelling plays the role of supplying essential information on vast elements within the entire project cycle right from the design stage, quantities and scheduling, fabrication and construction, all through to facilities and operation management. Hence, a BIM based approach would assist professionals during the conception stage in predicting the outcome of its construction and in minimizing environmental impacts throughout the project's life-cycle.

6D BIM is the dimension in Building Information Modelling system that analyses life cycle sustainability and informs decision making on design, construction and facilities management in relation to creating a green built environment. Using 6D BIM professionals are able to analyse energy right from the design phase and assess carbon emissions. This enables one to select the appropriate mitigation measures and make decisions in the project's initial phases and similarly test alternatives for easier integration into the sustainability model.

Although Building Information Modelling is a current trend in Architectural Engineering and Construction sector, much research is ongoing for enhancement of capabilities of Building Information Modelling in construction and design. This research aims at identifying the potentials of Building Information Modelling software systems in enhancing sustainability in construction and built environments.

1.3. Research questions

1. What are the current trends in BIM usage within AEC and its support for sustainable design and construction?
2. What are the potential capabilities of BIM software in relation to sustainable construction practices?
3. What is role of current BIM trends with respect to sustainable design and construction?
4. What strategies can be put in place to increase uptake of BIM amongst built environment professionals?

1.4. Objectives

This study aims at evaluating and investigating the potential Building Information Modeling and its capacity in support for sustainable design and construction. The main focus will be on the role of BIM methodology and its potential in developing a green built environment.

1. To evaluate the current trends in BIM usage within AEC and its support for sustainable design and construction.
2. Identify the potential capabilities of BIM software in relation to sustainable construction practices.
3. Identify the role of current BIM trends with respect to sustainable design and construction.
4. Identify strategies that can be put in place to increase uptake of BIM amongst built environment professionals.

1.5. Study hypothesis

Null hypothesis: Building Information Modelling does not support sustainable construction practices.

Alternative hypothesis: Building Information modelling supports sustainable construction practices.

1.6. Significance of study

Building Information Modelling is essential for improving the integration between AEC industry professionals and allowing multi-disciplinary collaboration and integration within one model therefore reducing the fragmentation in the industry. Despite the well-known benefits of BIM and sustainable performance analysis, it is still not widely adopted within the AEC industry.

This research paper will carry out an analysis of various BIM systems and current trends and their rating in aid of sustainable construction. It will define important aspects such as drivers of BIM adoption, good sustainable practices, impacts and benefits of sustainability analysis integration in the BIM-collaborative processes as well as the barriers, limitations and deficiencies of current BIM practices in the industry.

1.7. Scope of study

The study will cover the following areas: BIM and its development over time, the concept of sustainability and current trends for sustainable design and construction practices within AEC industry, recent developments to unite BIM and sustainability, the future of BIM and sustainable construction, environmental Analysis software (Green Building Assessment, LEED, Green Globes, CASBEE, BEE and BREEAM)

The study is limited to exploring the interoperability between BIM and sustainability during the design stages as well as construction i.e. BIM and pre-construction, BIM and construction due to time limitations.

Data collection will be conducted through self-administering of questionnaires by the researcher and structured face to face interviews.

1.8.Limitations

The adoption of BIM among construction industry stakeholders in Kenya is still a relatively new phenomenon and as such, the body of knowledge is limited as well. This also affects the number of respondents available to the researcher for data collection.

The time for carrying out the study is limited and does not allow an in-depth study as the author would desire. This also limits the number of project participants approached for the study

1.9. Definition of terms

The following are key terms that will be used in the study:

AEC- Architecture, engineering and Construction

BIM- incorporation of technology, processes and policies in order to generate management methodology important for digital data formatting and design across the entire life cycle of a building project (Pentilla, 2006).

CAD- Computer Aided Design

Sustainable construction- it iscreating and operating a healthy built environment basing on ecological design and efficient resources emphasizing on seven crucial principles throughout a project's lifecycle: focus on quality, applying life cycle costing, elimination of toxic waste, nature protection, use of recyclable materials, reuse of resources, and reduction of resource consumption (Kibert, 2005).

Project cycle- the series of phases that a project passes through from its initiation to its closure (PMBOK).

Sustainable design-iscreating and operating a healthy built environment basing on ecological design and resource efficiency (Kibert, 2016).

1.10. Organization of the study

Chapter one, introduces Building Information Modelling and the need to incorporate and utilize BIM interface for sustainable construction. It states the objectives of the study, research design, hypotheses assumed, scope and limitations and defines major terms that will be used throughout the research.

Chapter two incorporates a review of the relevant literature basing on Building Information Modelling and sustainable construction. It provides an in-depth Building Information Modelling Analysis and how it impacts sustainability in construction. The chapter also discusses sustainable construction in detail and the interoperability between BIM and sustainable construction

Chapter three entails discussion of the research methodology applied in this research. Sources of data are explained as well as methods of its analysis, interpretation and format of presentation. This chapter structures the data collection and sets the sampling criteria of the cases to be considered.

Chapter four focuses on the research findings; it analyses and presents results and data from specific case studies. There is the application of various techniques to present data such as comparative tables.

Chapter five Includes areas for future study, study conclusion, recommendation and findings.

2. CHAPTER TWO-LITERATURE REVIEW

2.1.Introduction

Building Information Modelling (BIM) is a 3D model-based process that provides AEC professionals information and tools to effectively plan, design, construct and manage buildings and structures. It connects stakeholders in the AEC industry and allows them to collaborate and coordinate through 3d digital data models as well as enhancing efficiency and effectiveness in communication

By use of BIM all processes and activities are incorporated as a single process involving the entire project's life-cycle. Maintenance works, timing and execution costs, planning of implementation phases, components, and material properties. Plant, structural and architectural engineering works are as well incorporated.

BIM is not limited to technology. It similarly involves protocols, standards and processes that enhances exchange of data (Kumar, 2005). These BIM elements necessarily operate as a single

unit as shown in figure 2.1.

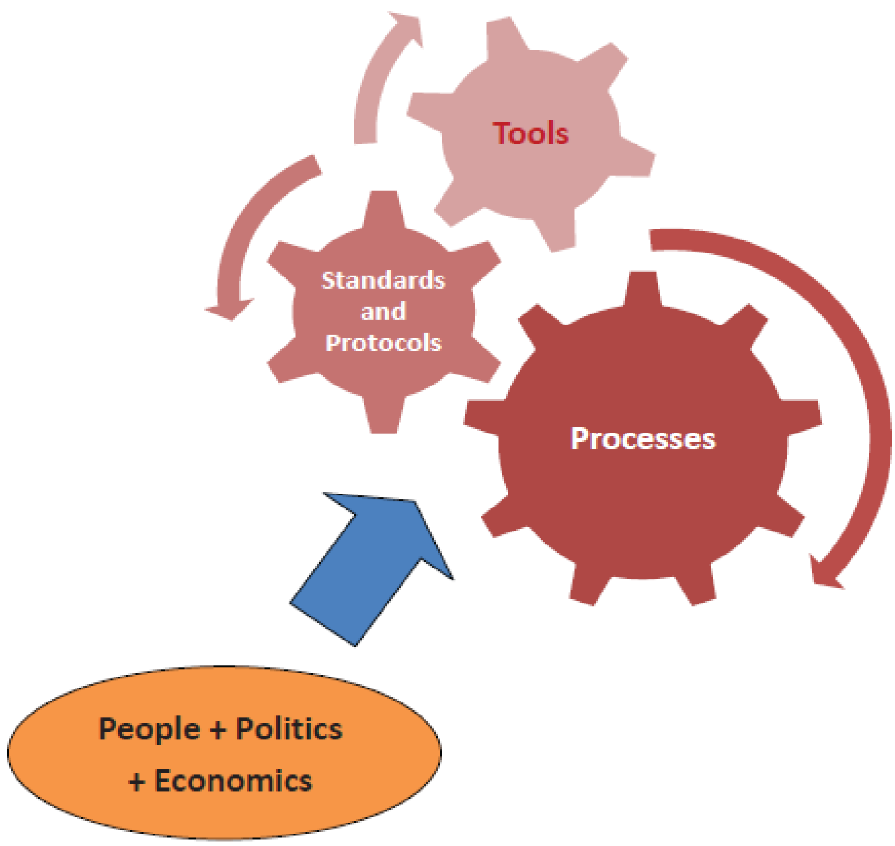

Figure 2.1: Interplay between BIM tools, processes and people

Source: Kumar, 2015

2.2.Historical development of BIM

Conceptualisation of Building Information Modelling was in 1970s. It was earlier referred to as Building Description System (Eastman, et. al., 1974). 1985 marked the first time the term "building model" was used. Ruffle (1985), highlights that this was evident on a design paper by an architect on computer aided design and drawing (Ruffle, 1985). As depicted by Van Nederveen et. al., (1992), a paper on automation in construction in 1992 initially used the term BIM. After ten years: in 2002, there was a publication, "Building Information Modelling" by Autodesk; there was involvement of software vendors and developers in the field thus leading to standardisation of the term to refer to presentation of building processes in digitalised way. In addition, Makers such Bentley Systems and Graphisoft used the terms "Integrated Project Models" and "Virtual Building" respectively. These are terminologies with similar meaning as BIM.

2.3.Theories pertinent to the study

2.3.1. Technology acceptance model

As shown in figure 2.2, Davis (1989) proposed technology acceptance model addressing two factors asserting that a given technology is adopted or accepted if itis easy to use and it is deemed useful. This model is presently parsimonious and classical and it explains IT acceptance or adoption behaviour. TAM's theoretical framework provides that behavioural intentions of an individual affects his/her choice of adoption. One's perception of usefulness and attitude similarly affect behavioural intention towards the use of a given technology thus affecting the use of the actual system.

Perceived ease of use and perceived usefulness influences attitude. Perceived usefulness of technology is similarly affected by perceived ease of use of technology. Additionally, there is an indirect effect on perceived ease of use and perceived usefulness of a given user by an external variables including user intervention and technical features, among other variables (Davis, 1989).

With conciseness and parsimony, TAM accurately explains the behaviour of a user towards a given information system. Therefore transportation (Pratia et., 2014), LNG (Sarah et., 2018), Virtual Reality (Manis et. al., 2019) and Smart Grid (Broman et. al., 2014), among other types of technology acceptance behaviours have been predicted by use of TAM. It is noteworthy that the essence of project owners in the processes of Building Information Modelling adoption was not approached by TAM.

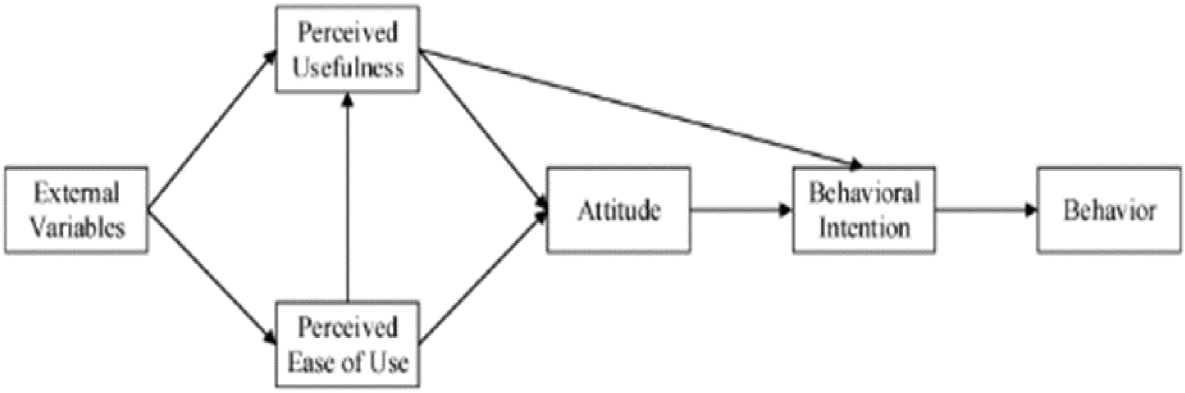

Figure 2.2: Technology Acceptance Model

Source: Davis, 1989

2.3.2. Technology Organization Environmental Framework

In the framework below, each factor influencing adoption of technology and probability of its acceptance are described. Environmental, organizational and technological factors influencing adoption and implementation of a given invented technology is similarly described below.

Figure 2.3: Technology Organization Environmental Framework

Source: Davis, 1989

2.3.3. Sustainability theory

According to Brundtland and Development, W.C.o.E.a (1987), when the needs of the present generation are met without compromising the next generations' potential to meet their needs, this is termed as Sustainable Development. It is therefore essential in construction to identify individuals and their social needs. Further, building and spaces, construction process and the surrounding built environment is referred to as Sustainable Construction (Presley and Meade, 2010).Neighbouring community sharing the built environment, end users of the building, and those directly involved in the construction works are the three stakeholders as highlighted from Sustainable Construction. Emission control, pollution, material waste minimisation, improved material use, and energy saving, among others, are the properties covered by adopting a multiple disciplinary approach. It was suggested that this approach leads to the future achievement of sustainability in building industry (Asif et. al., 2007).

There are vast means for improvement and control of building activities. These means ensure less damage to the environment and increased output. It is suggested that these environmental friendly practices are to be applied within whole building's life cycle thus creating competitive advantage. As depicted in figure 2.4, and provided within the literature review, design for human adaptation, cost efficiency and resource conservation are the three aims shaping the implementation of sustainable construction and building design: the socio-economic and environmental principles of sustainability are adhered to as discussed earlier.

To lesser or greater extent, there is interrelationship among sustainability requirements. Designers face difficulty in merging the various requirements innovatively. Global, regional and local cultural and natural resources are affected by design choice. The effects must be recognised by the new design approach. Demolition stage which entails building waste management, useful life, and design stage within a building life cycle are all dependent on sustainability requirements.

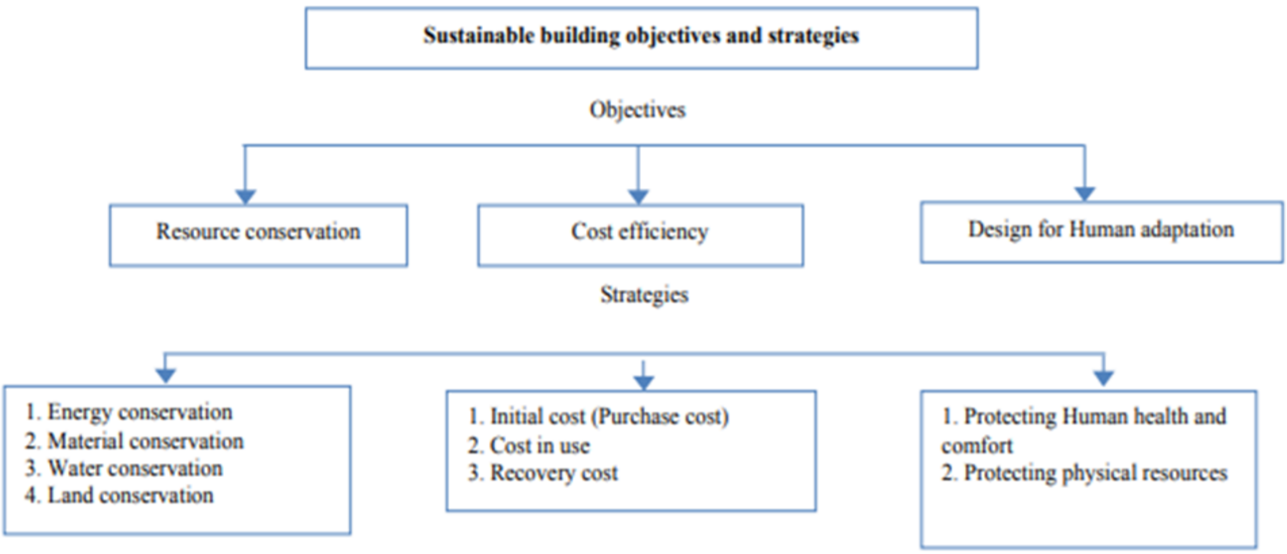

Figure 2.4: Framework for implementation of sustainability in construction

Source: Akadiri et al, 2012

2.4.Subsets of BIM

Figure 2.5 illustrates description of Building Information Technology as a six subset dimensional technology. They are: 8D, 7D, 6D, 5D, 4D, and 3D signifying safety, sustainability, operation, cost, time, and object model respectively (Smith, 2014).

Figure 2.5: Building Information Technology dimensions

Kjartansdóttir (2017) highlights that information model is built up by 3D BIM model containing three dimension objects representing buildings spaces or buildings in virtual reality. As a minimum, information on height, width, and length, among other information that applies are contained within the 3D objects. 3D model is credited for data gathering, visualisation, and effective coordination. Level of development definition and 3 Dimension modelling software are compulsory requirements for 3D modelling.

All the stages within the design process requires visualisation. Spotting any design errors and/or inconsistencies, and facilitation of faster and easier understanding of 3D geometry, are some of the benefits of Virtual 3D. Engineers, designers, and architects use 3D virtual environment in exploration of products prior to the building process, testing of design in reality sense, development of concept variations and exploration of complex ergonometric forms.

Space and time is represented by the concept 4D CAD. 4D simulates construction schedules graphically thus stimulating processes of transformation of space over time. There is thus a clear representation of a project's progress over time on a graph. When construction schedule is linked with 3D graphic model, the result is a 4D animation. Physical model of any constructed facility is represented by a 4D model (Kumar, 2015).

The 3D graphically simulated images in real time and time schedule in every construction activity is linked by 4D model thus giving graphical simulation of construction process. A project's workflow planning and 'buildability' are evaluated by dimension of time. Use of 4D model results to improved productivity: there is improved logistics, site-layout and better schedules. This is because there is effective and easy problem communication (whether temporal, spatial and sequential), analysis, and visualisation. The models are represented financially against time and cost budgets instantly generated due to the 5D model which adds "cost" dimension to Building Information Modelling. To ensue, there is easy value improvement by cost consultants, reduction of chaos initially caused by CAD, and accurate estimates.

Building Information Modelling contains sustainability components incorporated by the 6D model. The 6D model is applied in a project by design experts or other related professionals, since it enhances meeting of carbon target. It further facilitates validation, test and comparison of options for decision making. Addition of elements such as property capabilities, relationships, and geometric descriptions are also enabled through 6D model. These elements are perfectly presented and clearly described. Status of a given building such as its guarantee period, specifications and components can be tracked by use of 6D models.

Similar to 6D model, sustainability components to Building Information Modelling are incorporated by the seven-dimensional model. It enables validation, test and comparison of options by different design personnel and other professionals. Management of database of a given facility thus becomes perfect. The whole life cycle of a project, which ends at demolition and begins at conception, is encompassed by the 7D model of Building Information Modelling.

Construction and design safety is incorporated within the 8D model. The three important task of this model are designed to signal risk control, to indicate substitutes to hazardous options, and to indicate threats as a result of given construction or design solutions.

2.5.Building Information Modelling benefits to AEC sector

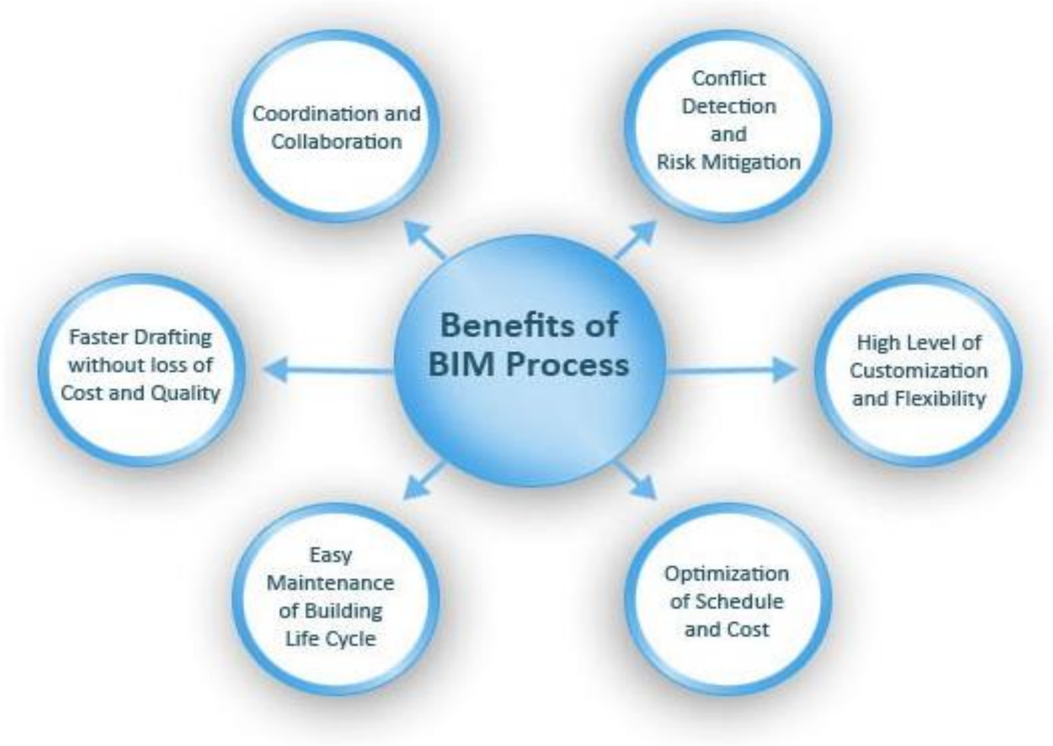

Figure 2.6: Benefits of BIM to AEC industry

2.5.1. Quality control

In Building Information Modelling, Quality Control entails use of computerised evaluation and inspection: confirmation of business quality demands. Construction and design stages, among other stages within the process of Building Information Modelling rely on Building Information Modelling quality checks for validation with the aim of controlling quality (Seo, Kim and Kim, 2012).

Changes are easily made through the use of BIM. BIM enables access to documents and processes of a given design at any time without involving the designers. To ensue, there is reduced manual checking or stakeholders thus spend the time tackling other problems. Management and planning is improved through digitalised records of building renovation. Detailed and technical design executive decisions are less effective in providing of control compared to the preferred common modelling techniques (Laiserin, 2002).

2.5.2. Time control

BIM enables for design and documentation to be done concurrently instead of serially. Schedules, diagrams, drawings, estimating, value engineering, planning, and other forms of work communication are created dynamically while work is progressing. BIM allows for adaptation of the original model to changes like site conditions, etc. (Laiserin, 2002).

2.5.3. Cost control

Building Information Modelling facilities a concurrent documentation and design. Dynamic creation of work communication, planning, value engineering estimation, drawing, and scheduling, among other activities occur while the work is in progress. Adapting original model to changes such as site condition is enabled using BIM (Laiserin, 2002).

Use of BIM models enables a smaller team to do more work.As opined by project managers, there are many benefits that accrued from use of BIM. From 2015 to date, reduction in project schedules, reduced final cost, and improvement in the project performance are some of the benefits highlighted by Dodge Data & Analytics (Novotyny 2018).

During the actual and preconstruction stages, Building Information Modelling allows reduction of cost incurred. Bigger corporations prefer the use of BIM since it is cost saving and rework is avoided. It is approximated that by using BIM before actual project, construction projects reduce rework and this is rated between 40% to 90%. Prior checking of the components of a given project is an advantage of BIM. Minimised costs and reduction of the possibility of on-site inventories is realised since plan and control of the construction processes is made earlier. Building Information Modelling enables tracking through frequent structural and system updates of installation dates of the model. Use of 4 Dimensional model enables virtual view at any stage of the project and graphical visualisation with the schedule.

2.5.4. Conflict reduction

There are many benefits experienced by designers and architects when BIM is used: there are rework and conflicts minimisation. Building Information Modelling design appears better since that are constructible (Novotyny, 2018).

In addition, design retention is an essential benefit architects and designers gained from BIM. There is enforcement of design: ensuring there is similar appearance between the concept and the actual building thus satisfying the need of the owner. This implies that project concept is kept from the initial stages of project to its completion (Novotyny, 2018).

2.5.5. Change management

BIM has vast benefits such as its essence in change order management and the most benefiting personnel from this are the subcontractors. Change orders are impeded by BIM. In case of need, attachment of BIM file with change orders is made to support the reason for such need by subcontractors. It’s possible to check any alteration, addition, or deleted elements of planning. This is achieved by overlaying different variants of plan by subcontractors. They are thus updated on the plan (2018).

Unpredictable circumstances, scope or design changes by the owners, and unresolved or undiscovered issues are examples of the possible changes. Persons involved in the construction works, both owner and other AEC specialist(s), opine(s) that disputes and claims are part of construction processes. However they are subject to wastage of money and time. If there is inconsistency between a thought and reality: when the expectations and status are misaligned, then costs in terms of money is usually lost and time is wasted (Willard, 2007). The aim of BIM is minimisation of these problematic issues by facilitating reconciliation and discovery at initial phases of the project. The chances of participants meeting their expectations are certainly increased as reports of wastes, disputes and claim cases are to the minimum.

2.5.6. Operations

Efficiency in the whole process is realised through the use of the Building Information Modelling in construction. After the building is modelled and building process is terminated, there is ongoing operation of the building which is an additional benefit to the owner. At the project close out, the building model applied during the entire process is acceptable. The model replaces the traditionally and manually documented mechanical and electrical systems. Another benefit to the owner is that the data gathered from the documentation is essential for analysis of equipment layout in a plant to improve efficiency. Furthermore, BIM is essential for automated implementation if the building maintenance.

2.5.7. Improved communication

Characterised by potential stakeholders, Building information Modelling increases understanding and communication. Clear vision of the future impacts and outlook of the building is enabled through quality and digitalised mock ups. Stakeholders probably buy in due to better mastery of the project. Client important issues such as aesthetics, function and cost are better understood and compounded. As a result, client-architect design communication and relation is improved.

Reduction and early detection of clashes and errors enhances communication. BIM's economic value is widely evaluated using clash identification metric. Improved data and accurate cost estimates through the use of Building Information Modelling improves construction processes and activities. The 5D model signifies cost. BIM facilitates cost control since every stakeholder is informed of the cost impacts during the design stages of the project. Furthermore, to praise a client's budget, design improvement is mandatory.

2.6.Uses of BIM in the AEC industry

Building Information Modelling and management occurs throughout the building lifecycle including planning, design, construction and operation in various capacities in order to achieve the desired results (CIC, 2012).

There are four categories of BIM usage which are operation, construction, design and planning which are further categorised as illustrated in figure 2.7.

2.6.1. Planning phase

Adequate attention and care during planning yield project efficiency. A designer must be knowledgeable of essential concepts such insulation, cross ventilation, renewable energy, heat loss, and orientation while aiming at achieving sustainable buildings. At planning phase, more investment and vast design iterations are likely required. This works on one's choice through reduced wastes and cost efficiency. Designing of the planning itself requires BIM (Valentine, 2018).

An architect gathers data for analysing feasibility and planning for determining constraints and external elements leading to interference of the design. Conceptual design analysis is undertaken at the required time since Building Information Modelling is applied and this results to integration of the relevant data in a BIM model (CIC, 2012).

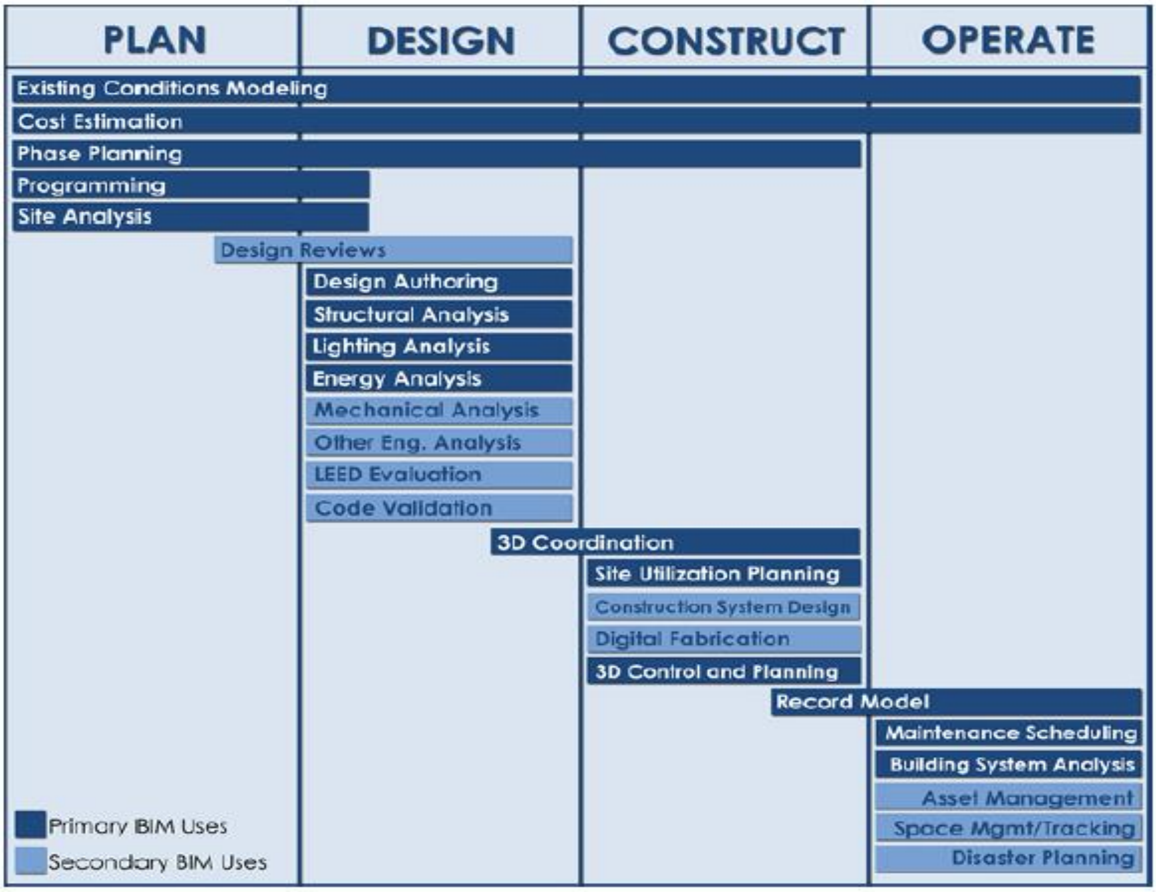

Figure 2.7: BIM uses in lifecycle
Source: CIC, 2012

2.6.2. Design phase

The most important stage in a construction project is the design stage. Design stage is thus greatly influenced by BIM compared to other phases since it is the stage for critical decision making (Eastman et. al., 2011). Project team generate many documents containing critical information and data thus satisfying the set code and customer needs (Sistani, 2013).

Depending on client's need, there should be maintenance of balance between client's needs and budget in relation to cost, schedule and scope. Scheduling and cost estimation is time consuming using traditional techniques. With the use of BIM, a single source is produced containing data on quantity, schedule and design, among other critical data. Accurate design is thus achieved by designers and other stakeholders since they can control the process at any place and time. Building design and documentation can also be undertaken concurrently as work progresses instead of in sequence (Autodesk, 2003). Concurrent undertaking of construction works while preparing documents and designing saves time (Autodesk, 2003).

Availed data through the use of Building Information Modelling enhances improved decision making. This further saves on time thus reducing costs, improving coordination and enhancing speed. The work is therefore characterised by increased profit margin, high quality of output and reduced costs. BIM is credited for its features resulting in collaboration in the design phase. This implies that all the members participate actively in the project by contributing ideas for its improvement. Lack of proper communication and collaboration causes project inefficiency (Valentine, 2018).

Using Building Information Modelling, design sustainability is fully achieved for knowledge and information is shared incorporating elements like sunlight, temperature and weather conditions. Other explanations, such as the building position, are quickly provided as opposed to traditional bulky documents (Valentine, 2018).

2.6.3. Construction phase

BIM develops an accurate and synchronised design. With BIM, at construction phase, data on cost and schedule is availed to the team. This saves on time and facilitates efficiency during execution of a given project. During the construction stage construction materials, individuals and tasks are effectively coordinated by BIM thus reducing delays and conflicts hence maximising output and efficiency (National Research Council of Canada, 2011).

In general, project effectiveness and improved productivity within the construction phase is as a result of using BIM. Amongst benefits of BIM in construction stage include reduction (in length and number) of delays. A few or no delays creates the possibility of operating freely thus minimising footprints inflicted on the environment (Valentine, 2018).

Efficiency can be achieved with ease of waste monitoring during the project. 7D and 6D Building Information Modelling minimises noise and amount of fuel consumed during the project. In addition, for positive impacts on the environment, asset management is optimised and procurement is perfectly controlled (Valentine, 2018).

2.6.4. Management phase

Evaluation of environmental performance determines whether sustainability has been attained or not. With the aid of BIM, Judgement of a project's sustainability occurs over the building's lifespan and all parties share all the data and elements of the project. Companies apply 7D model of BIM in the design and planning phases for prediction of a project's performance. Prediction of the project's performance is possible since construction, design and planning data is accessible (Valentine, 2018).

Using Building Information Modelling, a facility manager is equipped with data on operation matrices and performance. Furthermore, BIM ensures there is readily available data on rental income, tenant, leasable areas, finishes, equipment inventory and furniture, among other physical information to managers.

In the past, there was a challenge of bulky information on construction that used paper to file documents (Hardin, 2009). Controversies arise with rise of differences between the conceptual design (drawing) and the actual work. Building Information Modelling provides any data concerning the building system, composition, and spacing (Akcamete et. al., 2010). Efficiency in facility operation and maintenance is due to the possibility of downstream leveraging of the data (Azhar et. al., 2012).

2.7.Challenges of using BIM models in the construction Industry

Compatibility between software platforms

Apart from its success, BIM models have limitations. Interoperability is identified as one of the greatest issues related to BIM models (Moura, 2007). There is lack of guarantee that all the individual involved in construction processes will use the same software package that was initially created. Nearly every architect, engineer, contractor and subcontractor uses another version of the software package. Most BIM providers therefore aim at addressing interoperability. The providers seek input on useful features for future improvement of BIM software as it evolves gradually. It is identified that many providers differ in preferences of usefulness of various identified features. Many individuals opine that maintenance and documentation are the essential features. Users consequently have vast dissimilar preferences on BIM elements (Sawyer, 2007). Regardless of the software, different model is possibly merged into the same space as other model and the various models analysed as a single model. The potential for limitations must necessarily exist inasmuch as there are claims, there is compatibility between the other model formats and various BIM solutions. To date, conclusions have not yet been drawn on how interoperability impacts BIM adoption. The conclusions may be based on efficiency and/or absolute compatibility.

Lack of interest among AEC professionals

The greatest challenge that must be improved for the betterment of BIM is attitude (Bengtson, 2010). Approximately many architects have better BIM value. This is approximated to 52% of Architectural, Engineering and construction experts. Other individuals support that BIM is mainly essential at the design stage (McGraw, 2009). Owners value BIM to 41% while contractors' attitude is rated at 43%. The study therefore implies that according to architects, high investment returns and benefits accrue from BIM. It is thus challenging to convince AEC experts to embrace BIM.

Training cost

Adoption of any new technology focusing on change on the environment such as BIM requires prior and adequate training (Gu et. al., 2008), Yusuf et. al., 2009). Various researchers have discussed in interviews, the necessity and importance of training (Aranda-Mena et. al., 2008). Regardless of their different fields of specialisation, knowledge of BIM is mandatory to each individual for the successful BIM implementation (Arayici et. al., 2009).

It is further asserted that training in many firms on BIM is costly: it requires more human resource and time (Yan and Damian, 2008). Studies similarly show that the largest impediment to adoption of Building Information Modelling is training for it demands for more human resources and time. It should be noted that any decision making process is profit making and business oriented. Generally, since there is inadequate data on possible financial benefits of BIM, contractors, engineers, and architects, are reluctant in BIM related investment. Another challenge is resistance to change. Many AEC professionals are contented with the familiar processes and tools: they are satisfied and thus develop scepticism towards upcoming technique. This is challenge is termed as habitual and social resistance.

Lack of demand

Lack of demand for BIM among the construction team and clients is one of the major reasons for architects not changing towards BIM. Architects assert that due to the fact design and drafting needs are fulfilled using the usual CAD systems within the entities while conducting surveys, this reduces demand for BIM. BIM's productivity is low compared the level of productivity using the CAD system. Furthermore, downstream application of BIM is at the minimum thus reluctance in adoption of BIM (Tse et. al., 2005).

For BIM to succeed in a project, stakeholders must collectively collaborate and participate. Furthermore, interest of non-designers towards BIM have been hindered by the BIM's underdeveloped potential to handle documents, underrating CAD, focus on BIM as an advancement to CAD and lack of awareness (Gu and London, 2010).

Lack of technical support

Inasmuch as Building Information Modelling can contain data of high capacities, it is opined that expertise is required in extending its potential so as to store data to the maximum amount. In spite of the fastness and efficiency of the software, the models capability lowers with increase in the data contained therein. Using the files created by BIM systems in complex projects, it is challenging to manage and scale BIM data, thus the need for additional expertise to assist in the process due to the complexity and size of the BIM files (Howell and Batcheler, 2009).

2.8.BIM AND SUSTAINABILITY

Sustainability and environmental protection have become key global agendas in recent decades.

Sustainability is a current trend and one of the emerging issues in the Architectural, Engineering and Construction industry. BIM aims to attain sustainability in construction. This is achievable when stakeholders collaborate and share data on time. Sustainability goals are intensely achieved when the BIM is applied in green projects (McGraw-Hill Construction, 2010).

In sustainable construction and design, implementing BIM implies protection to the environment. The following are the uses of BIM in enhancement of sustainable construction:

Analysis of construction and design, energy and lighting, material selection, and building orientation optimisation (Azhar, 2011).

According to Azhar et al., (2011), as BIM evolves, sustainable means for decommissioning, maintenance, construction, and design are possibly attainable. Sustainability in construction refers to the creation and operation of healthy built environment basing on ecological design and efficient resources. The concept 'green' or 'sustainable' expresses sustainability of the AEC Industry (Azhar et. al., 2011). As BIM evolves, there are predictions that there will be social and economic positive impacts of BIM on sustainability of the surrounding. Three classical dimensions are highlighted to explain how BIM contributes to sustainability:

1. **Environmental sustainability**

Building Information Modelling supports various environmental aspects. Physical energy and time is wasted during construction and design processes. This is because the processes entail some valueless activities. BIM is therefore a tool to address such issues (Autodesk, 2005). High quality output, improved performance by avoiding errors, collaboration, improved communication thus reduced wastage, and transparency are other benefits of BIM (HM Government, 2012). Earlier detection and amendment of non-compliant areas leads to a few resubmissions thus avoidance of compromise, for instance building safety. Material wastage is thus minimised and rework is reduced leading to attainment of sustainability in a construction project.

2. **Economic sustainability**

Economically, BIM reduces resource wastage through reduction of design costs. This is because it enhances coordination and improves data management.(Autodesk, 2005).

3. **Social sustainability**

Socially, BIM through complex analyses such as daylight creates improved living and working conditions, this further adds well-being and comfort. Various parameters are analysed and stimulated using BIM techniques which previously was done manually using the traditional tools and was complicated (Autodesk, 2005).

2.1.Green Building Assessment

One of the preferred techniques for improvement of building performance is Building Environmental Assessment Methods (Lockwood, 2006). Across the World, other assessment techniques have developed in the previous decade (Amos and Chan, 2016). In 1998, Leadership in Energy and Environmental Design- LEED developed in the United States. This Green Building Assessment (GBA) method was implemented in China, India, Mexico, Brazil and Canada, among other 36 countries. In 1990, the leading and the best GBA, Building Research Establishment's Environmental Assessment Method- BREEAM was developed in the United Kingdom (Amos and Chan, 2016).Other GBA techniques include; the formerly known as GBA Tool, the International Sustainable Building Tool. In China, the Green Building Label or the ESGB, Evaluation Standard Label was developed. In Germany, the Deutsche Gesellschaft fur NachhaltigesBauen tool was developed. In Singapore, the Green Mark was developed. In Hong Kong, the formerly known as HK- BEAM, the BEAM plus, Green Environmental Assessment Method Plus was developed. In Australia, Green Star was developed and in Japan there was development of CASBEE, Comprehensive Assessment System for Building Environment Efficiency.

The current method to determine sustainability in the built environment is through the use of Green Building Assessment. Every GB tool aims at attaining sustainable construction. It is essential to note that since the criteria items evaluation and data, concept and principles of a particular GB assessment differs from the other, availability of such tools also differs (Sinou&Kyvelou, 2006). The common tools are BREEAM, LEED and CASBEE due to their reliability and since they originate from Japan, UK and US: fully developed countries (Fauzi and Nurhyati Abdul Malek, 2013).

GBA benefits contributing to social and economic sustainability to the environment include use of non-toxic materials, use of recyclable materials, water conservation, and energy efficiency, among other benefits (Ali & Al Nsairat, 2009).Vast non-governmental and government organizations have adopted GBA with the aim of enhancing sustainability in built environment. Using GBA tools, it is easy to distinguish and compare features between the traditional techniques and the GBA tools (Reed, Bilos& Wilkinson, 2009).

2.1.1. Safari Green Building Index (SGBI)

This is a local Green Rating Tool developed specifically for Kenya and the East African region. It is a collaborative effort of a team of experts from the Environmental Design Consultants (EDC) chapter of the AAK, the University of Nairobi, the UN-HABITAT and Green Africa Foundation. The SGBI will provide a green building rating tool that can suitably address the environmental, social, economic and developmental concerns of Kenya's construction industry.

SGBI is suitable for rating all building types in Kenya as well as other regions that experience similar climatic conditions. The tool gives a holistic approach to evaluation of sustainable buildings right from the design stages to construction as well as evaluation of refurbishment of pre-existing buildings. The SGBI is more suited to the Kenyan context unlike the commonly used LEED as it takes into consideration the unique climate of the East African region as well as its socio-economic status (Oduor 2018). It also takes into account the provisions of the laws of Kenya including the Environmental Management and Coordination Act (EMCA), the Building Code, the Physical Planning Act 2012, National Building Regulations 2014 among other local laws and regulations.

The SGBI is based on a percentage-based rating system whereby points are earned out of a possible score of 100% (AAK 2003). The minimum number of points required for Certification is 50. Budlings are classified as follows:

a.	Non- Green Building:	0 to 50 points	=
b.	Class D Green Building:	50 to 59 points	= two stars or Bronze
c.	Class C Green Building:	60 to 69 points	= three stars or Silver
d.	Class B Green Building:	70 to 79 points	= Four stars or Gold
e.	Class A Green Building:	80 to 100 points	= Five stars of Platinum

Areas of assessment and scores

- Pre-requisites 0%
- Building Landscape 5%
- Passive design strategies 45%
- Energy efficiency 10%

- Resource efficiency 30%
- Noise Control and acoustics 5%
- Innovations 5%

Total score 100%

2.1.2. GreenMark rating system

Green Building in the Africa and especially in Kenya is certified and rated using Green Mark. It provides guidelines for independent assessment of the degree of 'greenness' of an existing or proposed building. It has been developed through a rigorous multi-stakeholder process based on professional practice, nationally accepted environmental considerations, and it seeks to elaborate on synergies with regards to international and national concepts and established practices (Green Africa Foundation).

This standard provides requirements for assessment of building's sustainability performance. All the assessment requirements, from the initial to the final phases of a project life cycle are provided by the Green Mark. Sustainability is evaluated at the maintenance, operation, construction, design and preconstruction phases. Development of the standard aid in the assessment or evaluating and designing all buildings. Alterations, new, existing or extended commercial or residential structures or buildings, among other types of premises are rated using the Green Mark. The premises are elaborated as follows:

f. Master plans of neighbourhoods and all residential houses or domestic dwellings and buildings;
g. commercial buildings including eating places, laundries, cafeterias, clubs, lodges and hotels;
h. health institutions such as clinics, health centres, and hospitals;
i. Educational institutions such as schools, and universities colleges; and
j. Small domestic houses as defined in the Building Code made under the Local Government Act.

The standard has been development for Kenya but it will be applicable to other African countries with minor contextual amendments (Green Africa Foundation, 2018).

Standard has been development for Kenya but it will be applicable to other African countries with minor contextual amendments (Green Africa Foundation, 2018)

The standard consists of a definition of the scope, and a series of characteristics with compliance requirements, grouped into the following categories:

a. Sustainable site planning and development

b. Sustainable materials and appropriate technology
c. Renewal energy and energy efficiency
d. Water efficiency and quality
e. Healthy indoor environment
f. Operation, maintenance and decommissioning
g. Innovation (Green Africa Foundation, 2018).

2.1.3. LEED, Leadership in Energy and Environmental Design

Aiming at development in human health by promoting sustainability in the built environment, LEED was developed in 1998 in the US. LEED measures sustainability in six essential elements. These are: innovation and design, indoor environmental quality, resources and materials, atmosphere and energy, water efficiency and sustainable site development (Papadopoulos, Giama, 2007).

Membership summit of the USGBC, US Green Building Council in August 1998, ensued the launching of the first version of the Leadership in Energy and Environmental Design. Since then LEED is an essential tool to development in the construction industry. Leadership in Energy and Environmental Design has renovation projects and wide range of building coverage. The renovation projects include: LEED-ND, Neighbourhood development; LEED-H, Homes; LEED-CS, Core and Shell project; LEED-CL, Commercial interiors projects; LEED-EB, Existing building operations; and LEED-NC, Major renovation projects (Sinou&Kyvelou, 2006).

Certification standards for development of friendly built environmental practices are set by Building Construction Authorities. The certification standards are essential during the construction, design and planning phases. Negative impacts on the building and the environment are thus reduced (BCA Green Mark, 2013).

Contractors, designers, facility managers and building owners use LEED to tackle issues related to implementation and designing during the maintenance, operation and construction phases. Community, residential and commercial buildings use this tool. Neighbourhood development, maintenance, operations, tenant improvements, major renovations and new construction stages benefit from LEED (CSI, 2013).

2.1.4. Green Building Index

Living amenity for end users is represented by this factor. The Built Environment Load: factor L evaluates "Public Property" or   to the outer space. Negative elements affecting the environment and are beyond the space to the outside are represented by the outer space

(CASBEE, 2019). Those involved directly to building structures, planners and developers in Malaysia in 2009 obtained certification as a result of Green Building Index. GBI basically aims at promoting sustainability and creating awareness on environmental issues. As a result of developing GBI to rate sustainability in AEC sector, a country gains the following sustainability characteristics: Greenery features for project development; good transport connection; healthy indoor environment; water savings; and energy saving as well as material reuse and recycling (GBI, 2013).

2.1.5. Comprehensive Assessment System for Built Environment Efficiency (CASBEE)

In 2001, AEC Industry in Japan developed Comprehensive Assessment System for Building Environmental Efficiency-CASBEE, for rating built environment, also known as green building certification. This tool is reliable and reputable as LEED and BREEAM. In Asia, it was among the first tools to be developed (CASBEE, 2013).

Japan uses CASBEE to rate the built environment. CASBEE has various characteristics that can be measured and evaluated during certification. The year 2004 in Japan, marked the first launching of CASBEE by Japan Sustainable Consortium. Building Environmental Efficiency, BEE is the methodology applied in calculating the score. The evaluated aspects are quality and environmental impacts. CASBEE has four distinct versions namely: CASBEE for renovation, CASBEE for existing buildings, CASBEE for new construction and CASBEE for Pre-Design (Saunders, 2008).

CASBEE assessment implementation entails definition of both outside and inside spaces. A virtual enclosed space boundary divides the two spaces. The inner space can be termed as "private property". The Built Environment Quality (factor Q) evaluates the inner space. It represents the living amenity for the building users. The outside space could be considered as a “public property” and evaluated by the factor L: The Built Environment Load. It represents the negative aspects of environmental impact which go beyond the virtual enclosed space to the outside (CASBEE, 2019)

2.1.6. Building Research Establishment Environmental Assessment Method (BREEAM)

The most common GB tools are LEED and BREEAM. Lee &Brunett (2008) highlights three reasons for this and they are as follows: profound differences in assessment criteria and scope, wide scope of coverage buildings, and because it covers environmental issues. Approximately 200,000 buildings have been certified by BREEAM, and over one million buildings enrolled for certification since its launching in 1990 (BREEAM, 2013). All criteria from ecology to energy are among the Comprehensive Assessment for this tool. It thus implies that waste, ecology, pollution, transport, health, water and energy, and aspects of management procedures are inclusive. In Australia, Hong Kong, and Canada, among other countries, BREEAM's methodology is the foundation of the new building assessment technique (Ding, 2008).

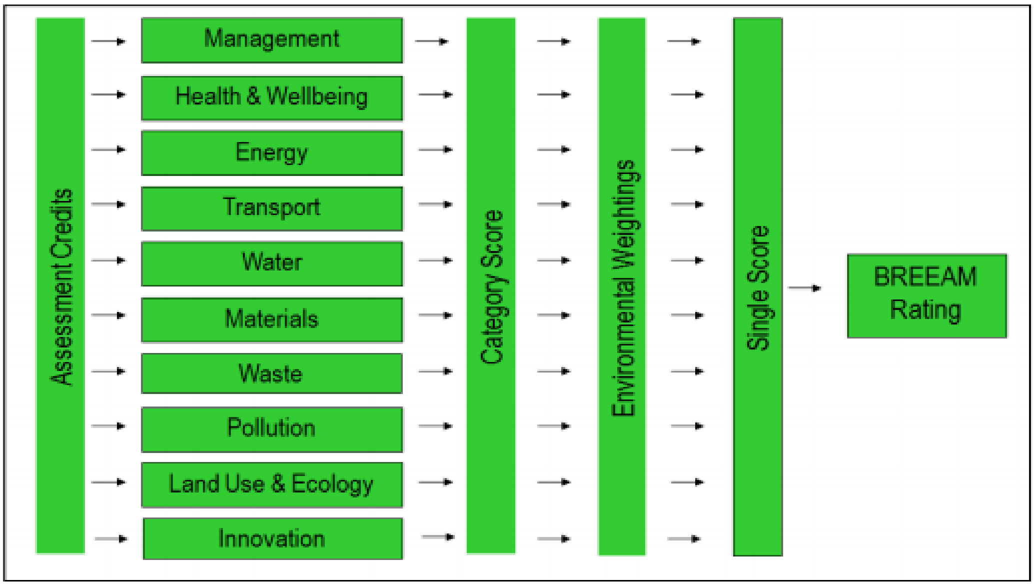

Figure 2.8: BREEAM Assessment process

Source: BREEAM, 2013

2.2.Functions of BIM in support of sustainability and green environments

2.2.1. Carbon emission analyses and evaluation

For the achievement of carbon neutrality, BIM provides evaluation and analysis of carbon emission. Currently, production of hydrocarbons in the construction sites and electricity emission, among other external environment and building system components resulting to energy conversion are incorporated within the BIM software. External global database enhances assessment of how such elements impact carbon emission within a project life cycle. There are a number of BIM software using the standard data emanating from external global database. VE software is an example of software using global database to acquire information on weather (I. E. Solutions, 2014).

Apart from emission analysis, there are other design alternatives arising from the development of BIM software. In engineering and design works, these alternatives reduces carbon emissions thus optimising the original design leading to carbon neutrality. For example, GBS provides any suggestion for selection of local utility providers who use renewable energy to reduce emissions (Autodesk, 2015).A designer chooses and identifies design schemes. The schemes balance costs and emission of carbon and this is enabled by BIM's Multi Objective Optimisation Model (Liu et. al., 2015). The software further estimates operations and embodied carbon during the building processes thus better decision making on material choice (Iddon and Firth, 2014).

2.2.2. Natural ventilation system analyses and optimization

In order to raise thermal comfort level of buildings and to reduce the use of building energy, ventilation is optimised and analysed using BIM software. The software estimates capabilities for natural cooling and heating (Autodesk, 2012). Ventilation modes such as opening controls, chimneys, whole-building ventilation, cross ventilation and single sided ventilation are essential in construction. Evaluation of feasibility by use of ventilation mixed or natural modes. These modes aid in selection of reliable mechanical ventilation system that is targeted by a given project.

2.2.3. Water usage analyses

Fundamentally at design stage, water usage analysis is supported by BIM software. Water usage is estimated by BIM software basing on relevant elements such as number of occupants, type of building. The estimate results are automatically converted into water cost report (Autodesk, 2015). The results are tentative since analysis consider few elements such as user's behaviours and location of project site. Critiques for BIM software highlight that full spectrum of factors affecting water usage should be considered in the future. Water distribution systems during construction project can be optimised by use of BIM software. Basing on water flow recorded information filed in the model, BIM software provides faster test for the capacity of water. This further aids in decision making on how to renovate waste/ water system (M.H. Construction, 2012). AEC industry have innovated LicA, a BIM application able to check automatically the water distribution system of a given building (Martins et. al., 2013).

2.2.4. Acoustic analyses

At early phases of construction, there is simulation of acoustic performance by Architects due to the use of BIM software. There is savings on simulation time because of increased automation when existing acoustic simulation system is connected to BIM data. For example, accuracy is increased or maintained while simulation time is reduced from days to minutes when a BIM prototypical acoustic simulation application is used (Clayton, 2013). Furthermore, results can be instantly re-simulated in case of any updates or changes on the first Building Information Modelling software (Clayton, 2013). In order to provide a better audio and visual experience, it is predicted that there will be integration of emerging of virtual reality among other technological advances with BIM acoustic simulation software. There are other multiple acoustic contributions to the final output. Basing on simulation results, a visualised map can show the acoustic impacts of the building. ODEON for instance represents simulated acoustic results in 3 dimensional audio effects. These effects can broadcasted through a loudspeaker or headphones depending on customised request of the user (Landry and Breton, 2009).

2.2.5. Solar radiation and lighting analyses

Building Information Modelling software facilitates lighting effect analysis for the interior and exterior parts of a building. Solar radiation analysis module is externally incorporated on the building. An engineer or a designer thus understands and optimises the solar impacts on the building. VE for instance tests the external and internal effects of shading. The design expectations are then compared with the simulated results. The results guide engineers and designers in selection of the better shading techniques. BIM software facilitates radiant exchange on the surfaces of buildings, assess temperature changes, and solar gain. BIM software displays the position of the sun and its path subjective to buildings model at any location and time (I.E. Solutions, 2014). It is noteworthy that within the building, lighting condition analyses can be adopted. This improves on visual comfort and improved use of sunlight. For better lighting performance, appraisal on lighting is conducted by the engineers and designers because of prior overview of lighting conditions provided by the BIM software. Comparison of artificial and natural light by BIM software is due to the point by point simulation. In addition, inconsistent weather conditions leads to adjustments or changes in calculation. Design Builder Simulation enables manual parameter settings in the local context, an example of such parameters is radiance level (Wasilowski and Reinhart, 2009).

2.2.6. Energy performance analysis and evaluation

There are four main roles of BIM software on energy performance evaluation and analysis, they are as follows;

1) effective energy fault diagnostic and detection

2) feasibility evaluation of renewable energy

3) a detailed analysis for various measures for energy conservation and

4) energy analysis of the entire building.

First, there are many advantages of BIM software in analysis of energy performance of a building. Standard processes and parameters are used to calculate building energy thus improvement of the software's usability. Substantial amount of effort and time is spent in Modelling especially when CAD techniques are applied. The assessor's experience and skills determine the implementation of the methods thus suffers objective problems (Park and Kim, 2012). This is contrary to BIM software where energy consumed is calculated using standard processes basing on weather conditions, materials, building shape, and building use patterns, among other parameters (Shoubi et. al., 2015). In general, the highlighted parameters are depicted from external databases: from standard practices survey. There is therefore less dependence of the calculations on the knowledge and experience of the user.

Secondly, energy conservation measures are analysed in detail through the support of BIM software. For example, there are influences of an occupant's behaviour on the entire building energy use. For the purpose of evaluation of energy savings basing on a given schedule, occupant’s behavioural effects on energy processes of energy analysis are therefore incorporated in the simulation application of building energy (Hirsch, 2014). Equipment schedules and occupancy, are among the occupant associated elements incorporated with the software. A software user optimises the original solution by comparing the BIM software energy saving measures results.

Thirdly, feasibility of renewable energy adoption such as wind and photovoltaic power, can be estimated using the VE and GBS, among other BIM software. To obtain accurate results in projects, there is need for specific data due to significant influence of local context on estimation results. Consideration and incorporation of certain crucial BIM software elements in the analysis of renewable energy is a challenge by the fact that data collection is difficult. For example, Building Information Modelling software have limited capacities to estimate the co-effects of shelters around the building. As a result, researchers investigate on the concept Inter Building Effect. Through mutual shading and reflection, it was currently discovered that there is a significant impact of surrounding building to the energy performance of the other building (Han et. al., 2014). It should be noted that there are a few research on the effects of Inter Building Effect on potential users of renewable energy in construction projects. However, the study of the concept IBE and its impacts on building energy consumption have been conducted (Pisello et. al., 2012).

Fourth, FDD- Fault Diagnostics and Detection- of building energy, can be supported by use of BIM software. This enhances effectiveness and maintenance of energy performance during the building processes. Information infrastructure provided by the FDD is adaptable and scalable. Exchange of data is streamlined by technologies for simulation and analysis of energy performance. Information gap between designers and managers in various facilities is closed.

During operation stage in construction process, there is gradual degradation of heat transfer conditions. This is a challenge of using BIM with preloaded energy performance properties in a building (Cho et. al., 2015). Thermal BIM reconstruction techniques based on images (Ham, 2015) and automatic point cloud 3D Modelling and other BIM automatic and semi-automatic reconstruction techniques are applied to address this shortcoming (Wang et. al., 2012). To reduce the gap between building conditions and energy performance data, BIM energy analysis is necessarily required (Ham, 2015). Designers have developed a reliable energy performance analysis technique: a modification of the currently used analysis of energy performance of buildings. To reduce the gap between building conditions and energy performance data, BIM energy analysis is necessarily required (Ham, 2015). Furthermore, BIM software presents data on energy analysis is variety of approaches. The results on energy analysis can be hourly, daily, monthly and yearly presented. Building Information Modelling software is user friendly. It neither requires expertise in computer programming nor energy analysis. Through the use of default utility rates, estimated energy are automatically converted into energy costs as evident with GBS and other BIM software (Autodesk, 2015). It is however noted that Energy Plus, one of the BIM software, provides user interface in a text form, implying that the software only reads and outputs the data.

2.3.Interoperability between BIM and sustainability

Interoperability is the ability to exchange data between applications to streamline workflows and facilitate automation (Eastman et. al, 2011). There is no super BIM tool that includes all functions to facilitate the technological implementation of BIM hence models are created to enhance exporting and importing smoothly among different BIM applications to achieve better performance (Wang, 2011).

To integrate engineering tools and design models, the Green Building XML schema or gbXML facilitates the transfer of data within the BIM models. (Kumar, 2008).

Currently there are three commonly used BIM-based sustainability analyses software in the market. These are: Autodesk ECOTECT, Autodesk Green Building Studio (GBS) and Integrated Environmental Solutions (IES) Virtual Environment (VE). Some authors have emphasized on the integration of BIM with GBS or VE (Azhar et al., 2011; Stumpf et al., 2009; Rundell, 2007)

For project performance assessment, there is a necessity to merge BIM with the analysis software applications. It was earlier depicted that the applications have no relevance to BIM. This is contrary to the present situation where interoperability is maintained by merging BIM to the performance analysis software. The gbXML is the common exchange file enabling the connection.

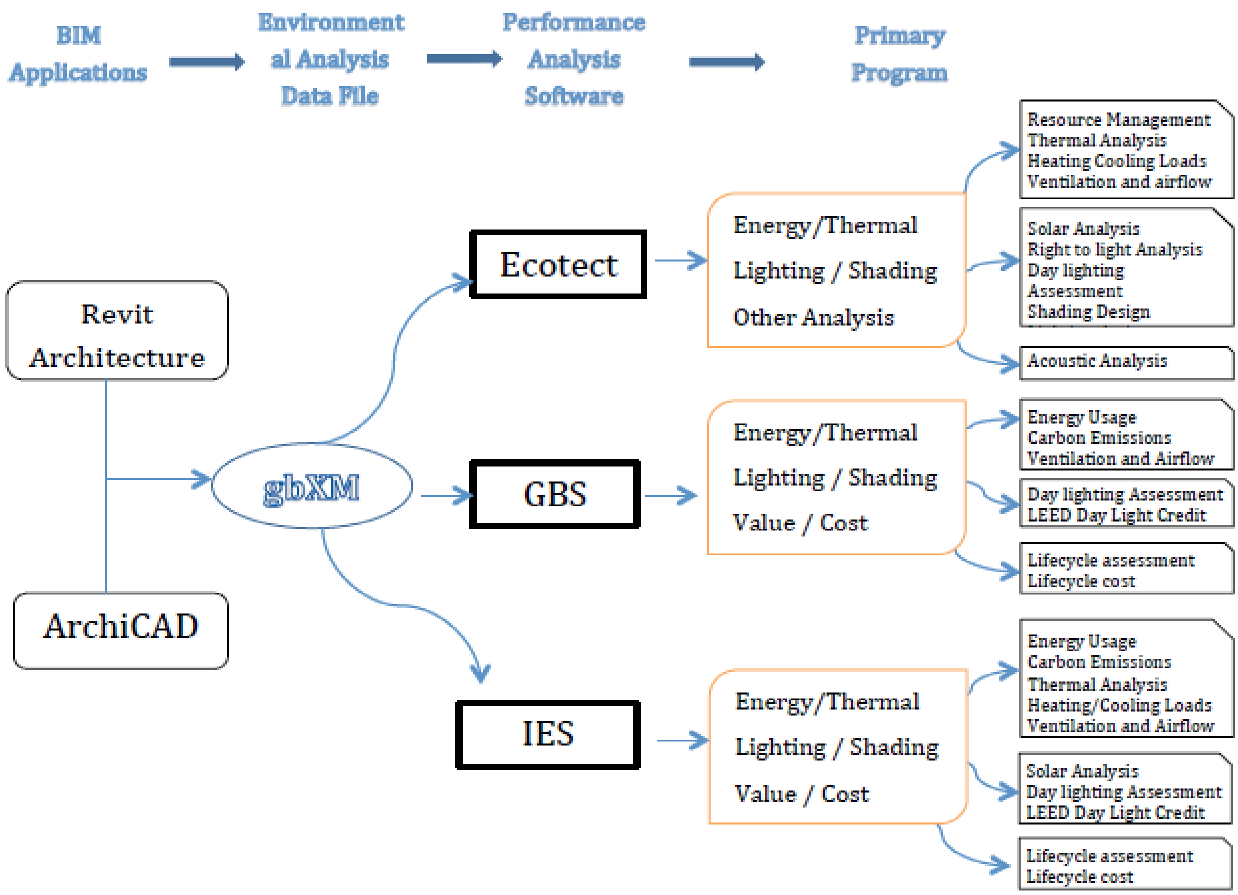

Figure 2.9: Interoperability between BIM applications and performance analysis tools

Source: Moakher and Pimplikar (2012)

2.3.1. Ecotect

Ecotect is defined as GB software that provides data on the preconstruction and design stages of a construction project. It uses three dimensional platform thus allowing for analysis and simulation though the vast sustainable analysis and design tools thus gaining of insight into performance of building from the project conceptualisation. Based on thermal, acoustical, daylighting, and solar energy, among other perspectives, functions are provided by the Ecotect for the analysis of the entire building. On a single platform, the 2011 analysis software, Autodesk Ecotect enhances analysis and simulation. The software is characterised by detailed and comprehensive concept as far as analysis tools for sustainability. Direct importation of Revit design models to Autodesk Analysis and exportation of Revit design model to Green Building XML schema format occurs at every phase of the project.

Resource management, ventilation, thermal analysis, lighting design, solar analysis and shading design are the main features of Ecotect. The functions of Ecotect ranges from environmental analysis and building design. It covers both analysis and simulation roles thus creating an easy working environment to designers in the three dimensional context (Autodesk, 2009). Contribution of solar analysis to energy saving, is presented in this piece of work, as a single illustration of how BIM promotes sustainability in building design.

Ecotect enhances assessment of incident solar radiation that falls on targeted or other surfaces due to its capacity to visualise and calculate at any time. The following are the means by which a designer can optimise his/her design:

- Optimization of location of garden layouts and vegetation
- Determining of mechanical cooling and heating
- Shading design

The intensity of solar radiation on objects, rate of reflection and shading can be calculated using Ecotect. This gives better results while determining solar panel orientation and location. With the possibility of calculating solar radiation incident on solar collector, this promotes easy estimation of energy produced annually. To ensue, it optimises total energy consumed in a building construction.

Seamless translation of data is a contribution of IFC and gbXML. Within its platform, it applies sustainable design criteria. Basically, Ecotect plays an essential role towards sustainability in construction and design, and use of BIM.

2.3.2. Green Building Studio

The leading carbon analysis tools and building energy are found in the web-based service: Autodesk Green Building Studio. Evaluation of carbon footprints and energy profiles by designers and architects are facilitated by use of Green Building Studio tools. The Autodesk Green Building Studio determines the equipment, system, construction and material defaults basing on factors driving water and electricity costs; location; type and size of the building. This uses regional codes and standards to derive the assumptions (Autodesk, 2009).

2.3.3. Graphisoft EcoDesigner

EcoDesigner is a plug-in provided by Graphisoft that analyses and models energy performance during the design stage, the initial stage of construction projects. Interoperability is enhanced since it runs seamlessly. This is a quality of plug-in for Graphisoft ArchiCAD software platforms. The program provides vast features for assessment and analysis of construction projects. It is noted that this program is regarded as an incomplete tool for analysis (Thoo, 2010).

2.3.4. eQuest

The United States Department of Energy designed a building energy simulation tool named Quick Energy Simulation Tool, abbreviated as eQUEST. The DOE-2 software packages contain this tool. This is an online tool for analysis of energy performance. It is accessed free of charge. Together with the inbuilt modelling capacities, Quick Energy Simulation Tool is used during initial design stages. For additional descriptions for base building, Energy Efficiency Measures wizard offers an alternative. Inasmuch as there are many views asserting that eQUEST is fully internalised, enhances importation of DWG filed documents into its interface. It should be noted that energy analysis for eQUEST presents data in tabular form for comparison. The presented data are the total gas consumed and energy used annually (Energy Design Resources, 2009).

2.3.5. Virtual environment (VE)

Virtual Environment software, derived from Integrated Environmental Solutions suites the tools for integrated performance analysis. Egress, costs, energy, lighting, and solar are among the issues that are analysed by these tools. Airflow/ventilation evaluation, cooling/ heating load evaluation, thermal analysis, carbon emissions, and energy usage are some of the thermal/ energy functions of the tools. LEED, daylighting assessment, and solar analysis are the shading functions of the tool (Azhar, 2009).

2.3.6. Integrated Environmental Solutions (IES)

The global leader in sustainability measurements is the Integrated Environmental Solutions (IES, 2008). IES can integrate other BIM tools such as Autodesk Revit; in analysing sustainability, there is wide usage of their virtual environment (Azhar, et. al., 2011). In using

IES there is direct sustainability analysis, and files are exported in the Green Building XML format from BIM modelling tools. For instance, vertical fins and overhangs are the solar control features that are quantified by the solar energy gained inside the buildings. Direct sustainability also occurs during visualisation of the path of the Sun and solar analysis. Simulation by IES creates a real three dimensional photo rendering and a foot candle map on the floor plan. By use of operable windows, IES assesses the performances of natural ventilations. In addition, creation of shading overhangs and insertion of additional windows into various models are among the possible design modification processes and geometrical editing. The original format of the gbXML model on the other hand is unalterable and its format is unidirectional. Designers and architects can apply Integrated Environmental Solutions in conducting assessment opposing the LEED rating system. The Integrated Environmental Solutions further checks whether the model complies with Part L of Building Regulations.

2.3.7. Energy plus

In construction, Energy Plus is commonly applied in performing simulation. In order to provide an interface for streamlining calculation of energy efficiency for LEED and BREEAM rating system, Energy Plus links with other software tools. For instance, for calculating energy efficiency issues, Ruiska, DesignBuilder, EcoDesigner and MagicCAd are approved by BREEAM. AECOsim Energy Stimulator is used by LEED since the entire system has been rationalised by Energy Plus for simulating building performance (DOE, 2013; Oy, 2013).

2.4.Strategies to promote uptake of BIM

2.4.1. BIM education, training and research

Building Information Modelling training and education are crucial in driving evolution and implementation in a given sector. In tertiary level, education ensures that the incoming graduates are equipped with BIM skills and knowledge. Natspec (2013) asserts that slow adoption of BIM in Architectural, Engineering and Construction Industry is as a result of shortage of trained personnel and reluctance towards change. There is therefore the need for incorporation of BIM education into the syllabus through the industry and government support. The sector will therefore be equipped with ready graduates able to work within the BIM environment.

2.4.2. Appropriate legal framework

Global and consistent standards are crucial in achieving effectiveness as visioned by Building Information Modelling. There are many approaches and differences towards the uptake of Building Information Modelling thus making it nonsensical. With the aid of global leadership, there can be collaboration in every nation. There is need of adoption of common standards if the future international projects will depend on BIM. IFCs- Industry Foundation Classes will be essential in this case (NBS, 2013).

2.4.3. Government incentives

It is the interest of the government that grants for BIM uptake are established. This enhances long term economic gains by the government. The government is the biggest client in the AEC sector. Technical support and grants should emanate from the government. Medium and small sized firms therefore cater for the installation costs (Omar, 2015).

It is essential that government leaders comprehend that though it may be that large amounts of money will be dedicated to this cause, the long-run savings will more than triple the initial spend due to economies of scale (Omar, 2015).

2.4.4. Enhance cooperation between BIM expert's, academia and researchers

Regulatory bodies and the government, and other stakeholders should collaborate to promote the adoption of BIM by providing guiding standards and regulations, implement and strengthen the later to enhance faster adoption Building Information Modelling (Naim, 2018).

2.5.Conceptual framework

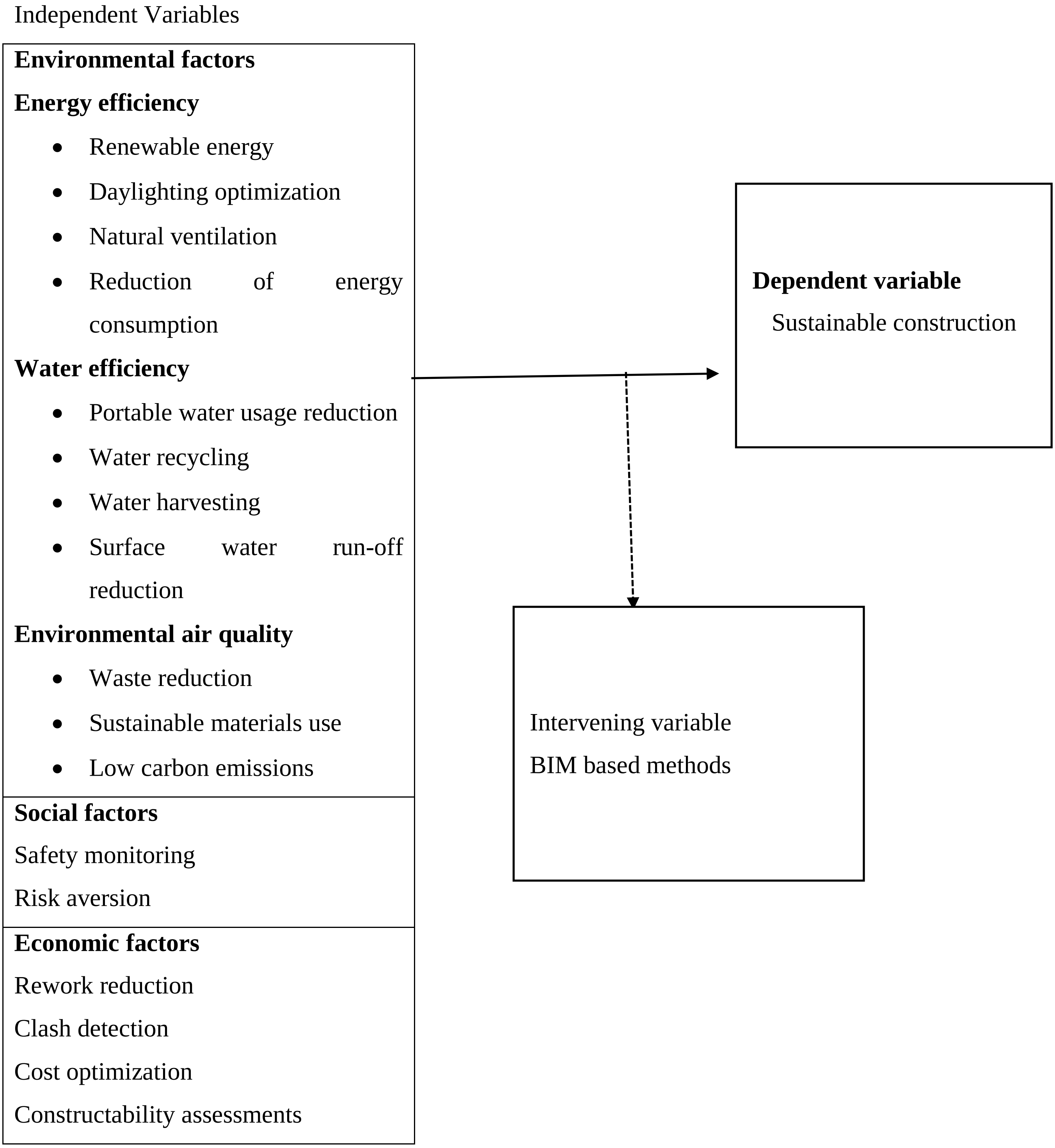

Figure 2.10: Conceptual framework

Source: Author, 2020

Concept	What to measure	How to measure
ENVIRONMENTAL FACTORS Energy efficiency	Renewable energy Natural ventilation Daylight optimization Energy consumption reduction	Ordinal measurement Using 5-point Likert scale [5] Highly effective [4] Effective [3] Neutral [2] Ineffective [1] Highly ineffective
Water efficiency	Portable water usage reduction Water recycling Water harvesting Surface water run-off reduction	Ordinal measurement Using 5-point Likert scale [5] Highly effective [4] Effective [3] Neutral [2] Ineffective [1] Highly ineffective
Environmental air quality	Waste reduction Sustainable materials use Low carbon emissions	Ordinal measurement Using 5-point Likert scale [5] Highly effective [4] Effective [3] Neutral [2] Ineffective [1] Highly ineffective
SOCIAL FACTORS	Safety monitoring Risk aversion	Ordinal measurement Using 5-point Likert scale [5] Excellent [4] Good [3] Average [2] Below average [1] Poor
ECONOMIC FACTORS	Rework reduction Clash detection Cost optimization Constructability assessments	Ordinal measurement Using 5-point Likert scale [5] Excellent [4] Good [3] Average [2] Below average [1] Poor

Source; Author, 2020

3. CHAPTER 3: RESEARCH METHODOLOGY

3.1.Introduction

The research methodology employed to answer the research questions in Chapter 1 is discussed in this chapter. This includes the research design, sampling design, data sources, data collection tools and techniques and data presentation and analysis.

3.2.Research design

The research was conducted through a cross sectional survey design. Oso and Owen (2005) describe survey as a study which employs present oriented methodologies to investigate populations by selecting samples to analyse and discover occurrences. Questionnaires were administered to the study population, as well as the use of interviews that helped obtain information on the current trends in BIM usage within Kenya's AEC and how it supports sustainability in construction and design: A case of Nairobi City County. Available secondary data was also used to help fill in the gaps that were not possible to obtain using the primary data.

3.3.Data sources

The study used primary and secondary data in an attempt to solve the stated problem and address the objectives. In this research, the primary data was derived from professionals in the AEC industry that are using BIM systems.

Mugenda & Mugenda (1999), states that target population is a whole group covered by the study. In this study, architects, quantity surveyors, engineers, construction project managers, and Green building practitioners who have used BIM were the target population.

Primary data involve the use of questionnaires and interviews. The questionnaires included closed and open-ended questions which sought views, opinion, and attitude from the respondents which might not have been captured by the closed ended questions.

Secondary data was collected through review of past work, journal articles, text books and from the internet.

3.4.Sampling design

3.4.1. Location of research

The study was confined to the Nairobi City County because it has been the hub for ICT in East Africa. It is also the most dynamic and fast-growing city in Kenya. It is also Kenya's largest city with a population of 3.36 million as at 2011. In Africa it is also one of the rapidly growing cities. Time constraints on the researcher were also taken into account.

3.4.2. Sample Population

The initial sample frame for the population included all construction professionals involved from the design stage up to facilities management and close out. However, after reviewing the literature and conducting a pilot it was evident that majority of the interventions towards sustainability using BIM was applied during the conceptualization and design stages. As such the sample frame was limited to professionals involved in the design stages i.e architects, engineers, quantity surveyors, construction project managers as well as green building practitioners. Majority of the project data is defined during the design stages hence this is where BIM interventions are most effective. Time limitations in carrying out the research also influenced the researcher to limit the study population to this.

3.4.3. Sample size

The main objective of the research is evaluation and investigation of the capability of Building Information Modelling and its capacity in support for sustainable construction and design. The major focus is on the role of BIM methodology in developing a green built environment. As such the sample frame included construction professionals as well as green building practitioners as the researcher’s population of interest. From this sample frame, only those who have used BIM were selected as respondents for the survey questionnaire and interviews. As BIM is fairly recent phenomena in Kenya the number of respondents for the study was 55 construction professionals and Green Building Practitioners.

3.4.4. Sampling technique

The study employed non-probabilistic method of sampling using purposive sampling technique. Professionals in the industry were pre-vetted to ensure that they use BIM systems and processes before administering the questionnaire. According to Mugenda & Mugenda (2003), this technique of sampling enables selection of respondents knowledgeable on the objectives of the study.

3.5. Data collection tools and techniques

The use of multi-choice questionnaires was employed to collect data from the sample population. The questionnaire was designed to meet the stated research objectives. Close ended questions were used to record professional's perception on integration of BIM for sustainable construction. The distributed questionnaires were designed in Likert scale 1 to 5, the respondents were requested to express their opinion in the degree tabulated on the questionnaires. A scale 1 to 5 will adopted, with 1 representing highly ineffective, 2- being ineffective, 3- being average, 4- being effective and 5- highly effective.

The questionnaires were categorised into two parts; the first part addressing the general information of the respondents as the other part represents the main issues of the study variables.

Before the main study commenced, a pilot study was conducted on three pre-selected AEC professionals using the questionnaire in determining the reliability and validity of the questionnaires. The pilot study tested the logic, clarity and objectivity of questions in the questionnaire. The piloting was the determinant whether analysis and processing of the variables that were collected could be easily undertaken.

The data collected during the pilot study served as key pointer as to whether the questionnaire was structured to fit the objectives of the study. After the pre-test, the researcher amended the questionnaire based on the respondents' opinions provided during the pre-test for improvement of the questionnaires prior to actual data collection.

3.5.1. Validity and reliability

According to Mugenda and Mugenda (2003), the accuracy of data to be collected is largely dependent on the data collection instruments in terms of validity and reliability. For the measurement of validity of the instrument, a content validity test was introduced. The degree of representation of a given content, concept or domain by an instrument basing on data collected is measured by this type of validity test (Mugenda and Mugenda, 1999).

The data obtained from the pilot study was used to estimate reliability of each instrument. For estimation of reliability of the questionnaires, Cronbach`s alpha coefficient was introduced. Reliability coefficient of 0.70 and above was considered reliable enough in achieving the objectives of the study (Frankeland Wallen, 2000).

3.6.Data analysis and presentation

Following the closure of the survey, there was analysis of data from the respondents by use of standard statistical techniques. In addition, there was calculation of charts and descriptive statistics and charts. The primary data was systematically organized and analysed using descriptive statistics of weighted averages. This was done by using means, standard deviation and percentages. There was evaluation of categorical data by use of Chi-square tests. Each test was evaluated at a 0.05 alpha level. SPSS and Microsoft Excel (2017) was used for the analysis.

The findings were presented using tables, percentages and pie charts with interpretations being given in prose after each figure and table. Qualitative data collected from the open-ended questions in the research were organized and analysed by way of content analysis.

Consequent to the analysis of the research data, the findings were compared with theoretical approach and themes in the literature review. The analysed data was then interpreted with respect to research objectives and theory. The summary of findings, conclusions and the recommendations were documented and presented in chapter five.

3.7.Ethical considerations

From the field researcher obtained, from each respondent, an informed consent prior to collection of data. On approaching the respondents, the research objectives were explained by the researcher so as to obtain informed consent. Every piece of the information gathered from the field and as shared by the respondents remained strictly confidential. An introductory letter from the institution to show that there is need to collect data for this study was also obtained.

4. CHAPTER 4-DATA PRESENTATION, ANALYSIS& INTERPRETATION

4.1.Introduction

The findings of the research are thematically reported in this chapter. They are presented according to the four objectives of the study outlined in chapter one. These objectives were to identify the current trends in BIM usage within AEC and its support for sustainable design and construction, possible capabilities of Building Information Modelling software related to construction sustainability techniques, role of current BIM trends with respect to sustainable design and construction and strategies that can be put in place to increase uptake of BIM amongst built environment professionals. The researcher distributed80 questionnaires to solicit for a response from different professionals in the construction industry. 69% of the questionnaires were received from the respondents tallying to 55. The distribution of this rate is represented is as follows:22 Architects, 8 quantity surveyors, 19 engineers, 8 construction/project managers and 8 green building practitioners.

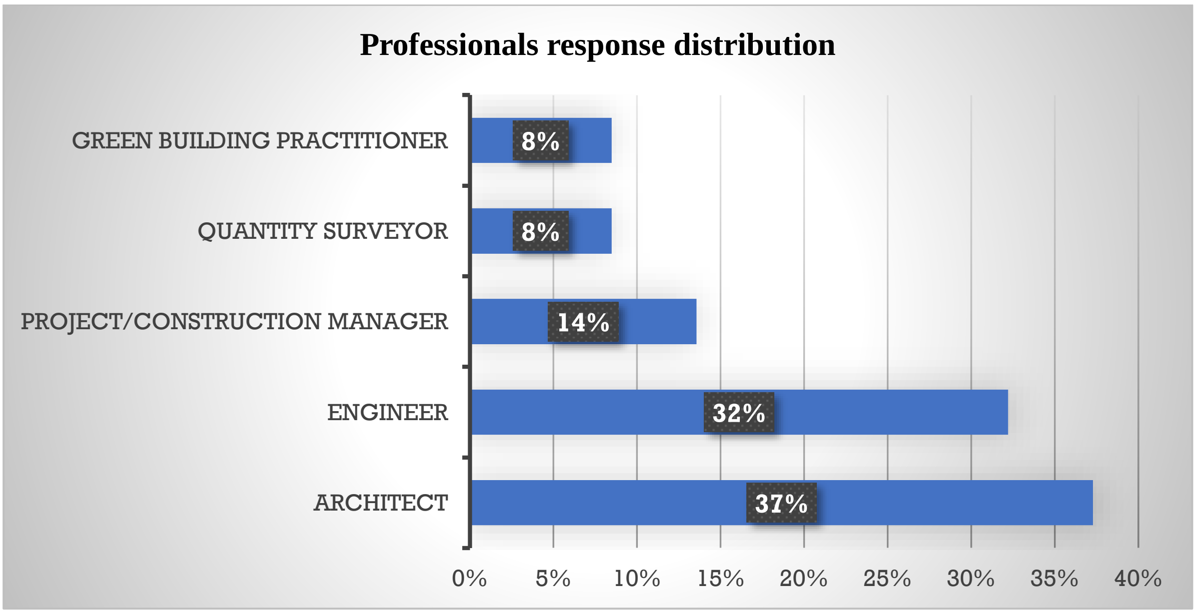

Figure 4.1: Professionals response distribution

Source: Field survey, 2020

4.2.Current trends in BIM usage within AEC

Objective one of the study was to identify the current trends in BIM usage within AEC. 85% of the respondents use BIM to evaluate projects sustainability during design and construction while15% do not use BIM as shown in figure 4.2.

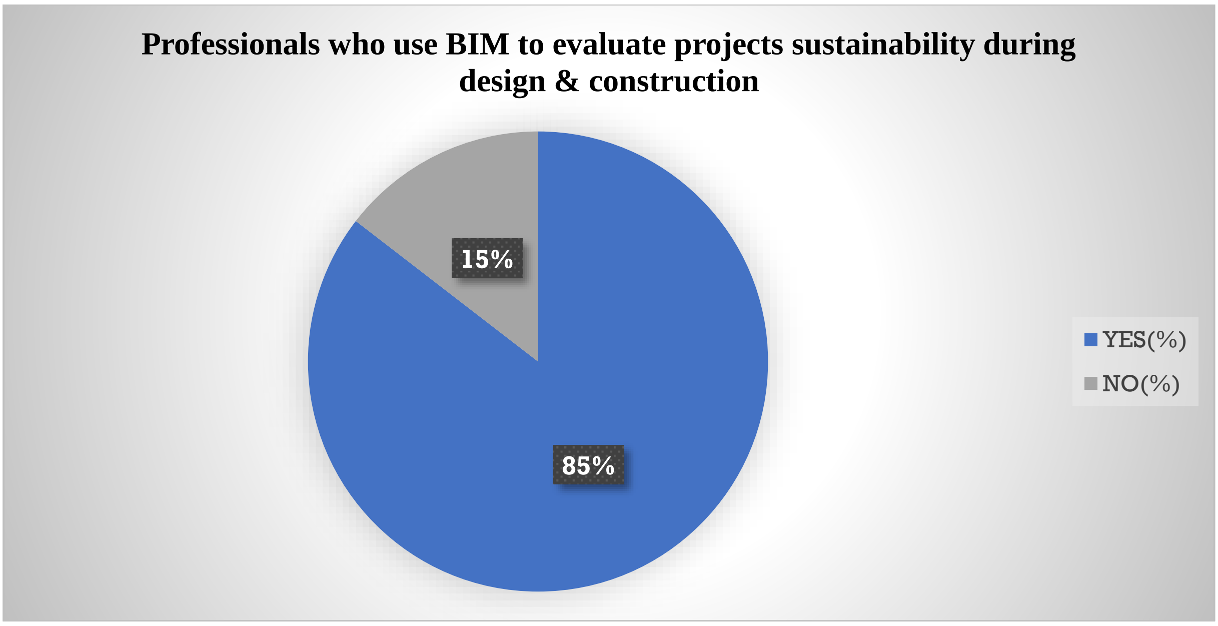

Figure 4.2: Professionals using BIM to evaluate projects sustainability

Source: Field survey, 2020

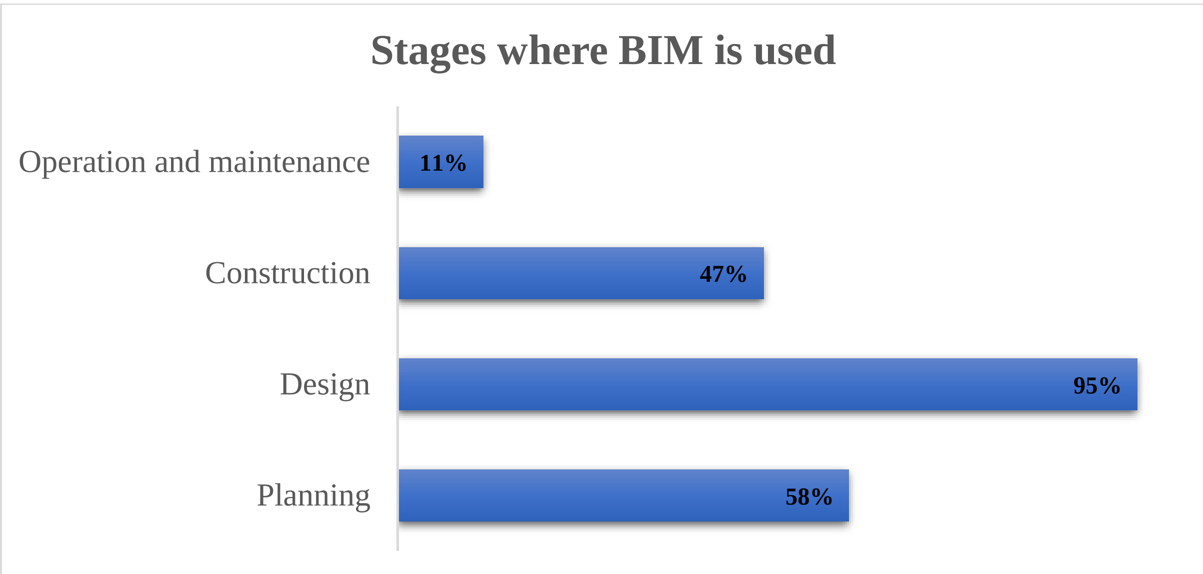

Figure 4.3: Phases where BIM has been used

Source: Field survey, 2020

Findings in Figure 4.3 on stages where BIM has been used indicate that 95% of built environment professionals use BIM at the design stage, 58% during planning, 47% during construction and operation and maintenance stage was the least ranked with only 11% of professionals using BIM during this stage.

These findings are supported by Sistani (2013) who indicates that design stage is the core phase where majority of information of a project is defined. This is further supported by Eastman et al. (2011) who also highlights that critical decisions are made during design phase thus BIM influences this phase more than any other phase.

Information dissemination concerning importance of BIM usage during the operation and maintenance stage is however required to increase the level of usage during this phase. This is because environmental performance of a project continues even after completion of construction. Additionally, evaluation of project sustainability is rather a lifespan task as highlighted by Valentine (2018).

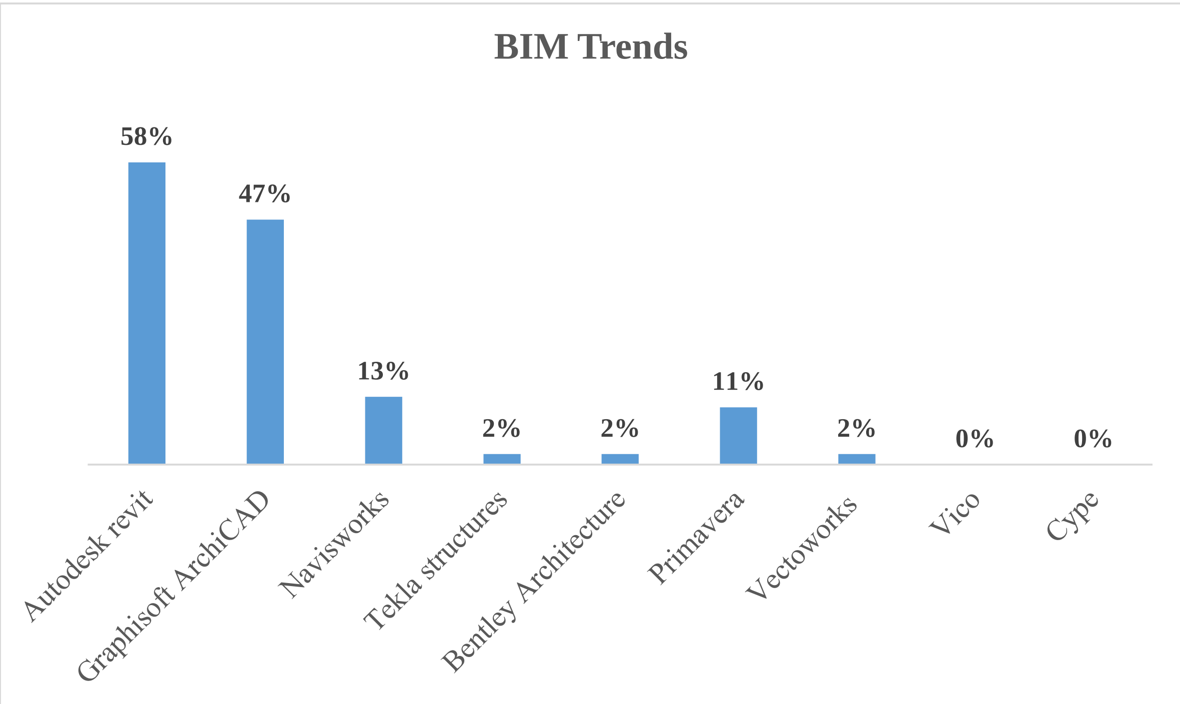

Figure 4.4: Current BIM trends

Source: Field survey, 2020

Findings in Figure 4.4 revealed that 58% of respondents use Autodesk Revit, 47% use ArchiCAD while Vico and Cypehasn’t been used by any of the respondents. ArchiCAD and Autodesk revit is majorly used during design stage and 95% of the respondents had indicated they use BIM during the design stage thus a high percentage of usage of these two BIM trends can be attributed to that. Majority of the respondents were also engineers and Architects and these are the major programmes they use. It is also worth noting that Navisworks and Prmavera usage is being taken up by built professionals in Nairobi City County which shows a good progress on BIM usage.

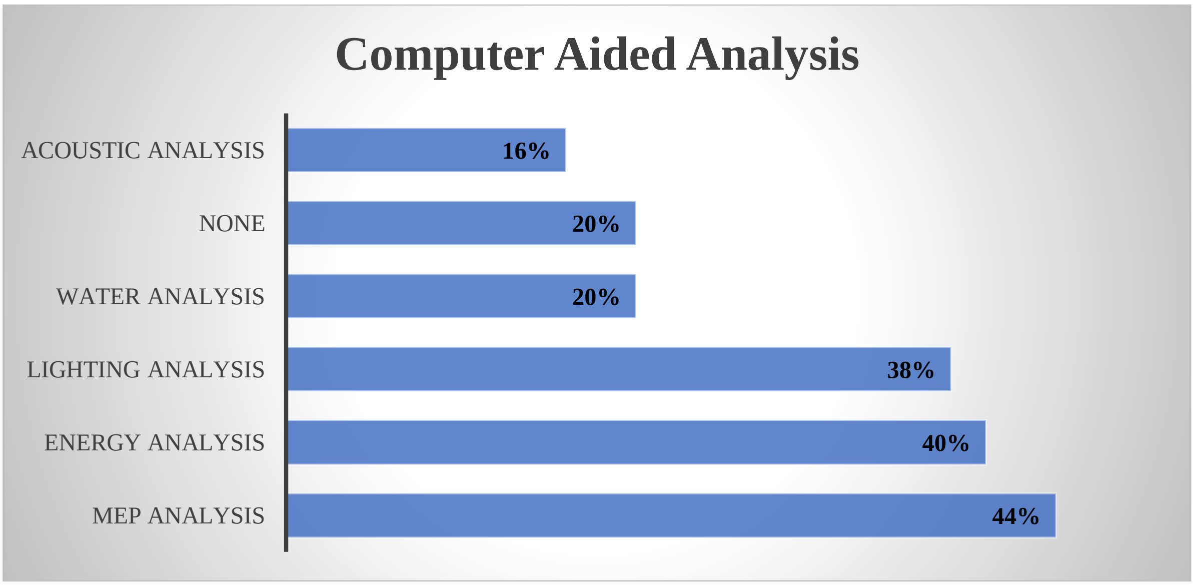

Figure 4.5: CAD Analysis

Source: Field survey, 2020

MEP analysis is the most commonly used CAD analysis among built environment professionals with 44% while acoustic analysis is the least used CAD analysis with 16% as highlighted in Figure 4.5.

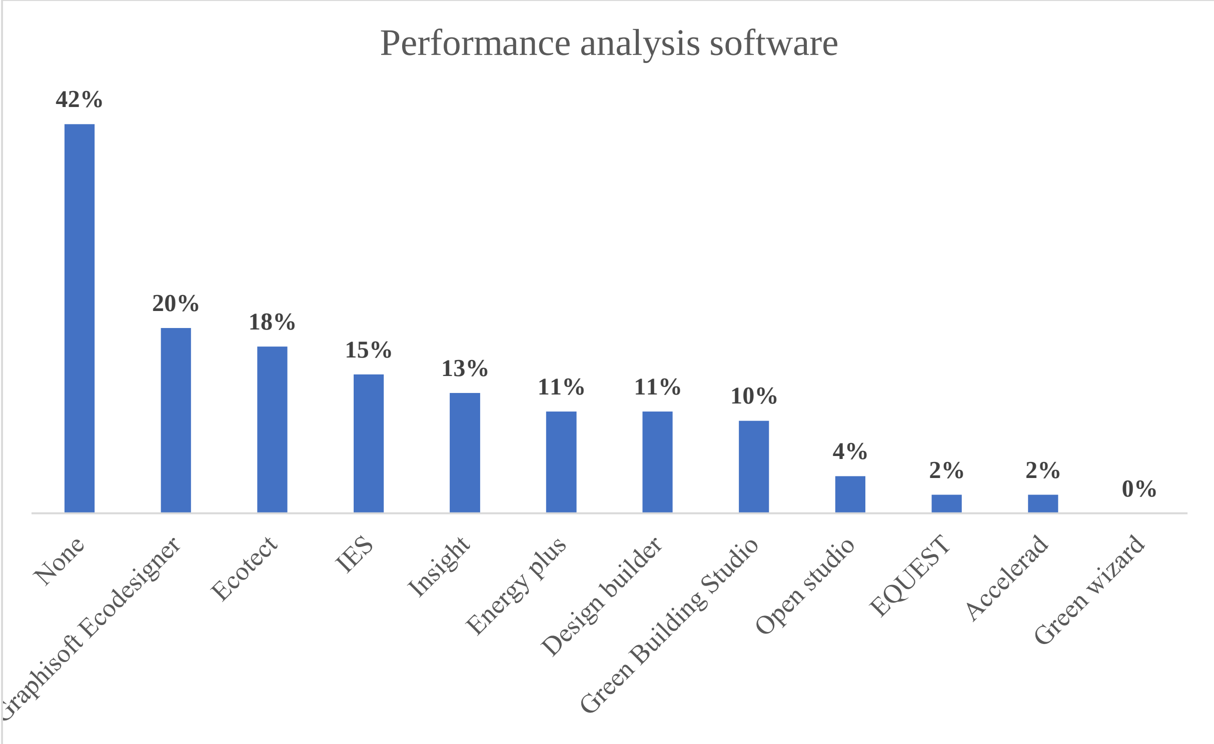

Figure 4.6: Performance analysis softwares

Source: Field survey, 2020

Findings in figure 4 revealed that 42% of the respondents have not used any performance analysis softwares. Graphisoft Ecodesigner however had the highest percentage among the performance analysis softwares used. This can be attributed to its seamless running and the fact that it is the Graphisoft ArchiCAD software platform plug-in thus interoperability as depicted by Thoo (2010) and that it has numerous features hence quick analysis of every aspect of a project.

Due to the extensive tools of performance analysis software, a Building Information Modelling model is accurately analysed. However, since the software is relatively costly and as a result of interoperability, there is failure of companies to implement completely the usage of a given environmental simulation software as a practice. Hence the low rate of usage among respondents.

4.3.Potential capabilities of BIM Software

Objective two of the study was identification of the possible BIM software capabilities with reference to practices leading to sustainability in construction. Three major variables were investigated: Water efficiency, Energy efficiency and Environmental quality. The respondents rated BIM software packages effectiveness in achieving various sustainable features. It aimed to validate impact of the three variables identified.

4.3.1. Water efficiency

The parameters analyzed in this category were water harvesting, reduction of portable water usage, water recycling and reduction of surface water run-off. The responses to these are depicted in Figure 4.7 and Table 4.1 below.

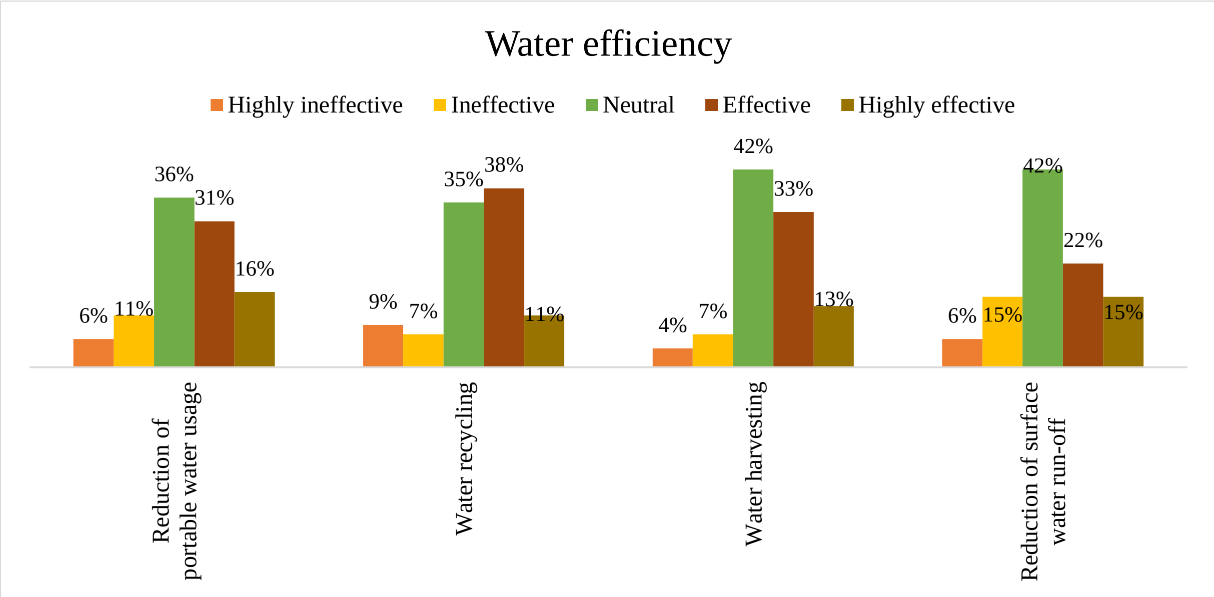

Figure 4.7: Water Efficiency
Source: Field survey, 2020

Water efficiency

	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
Water harvesting	55	3.49	.121	.900
Reduction of portable water usage	55	3.42	.139	1.031
Water recycling	55	3.42	.132	.975
Reduction of surface water runoff	55	3.27	.138	1.027
Valid N (listwise)	55			

Table 4.1: Mean score and standard deviation for water efficiency
Source: Field survey, 2020

Results in Table 4.1 revealed that water harvesting was the most effective factor with standard deviation and mean of 0.121 and 3.49 respectively and reduction of surface water run-off was the least rated with a standard deviation and mean of 0.138 and 3.27 respectively.

These results are supported by Autodesk (2015) that indicates BIM software packages are of critical importance during the design stage in analysing the water usage.

4.3.2. Energy efficiency

The parameters analyzed in this category were natural ventilation, reduction of energy consumption, renewable energy analysis and daylighting optimization. The responses to these are depicted in Figure 4.8 and Table 4.2 below

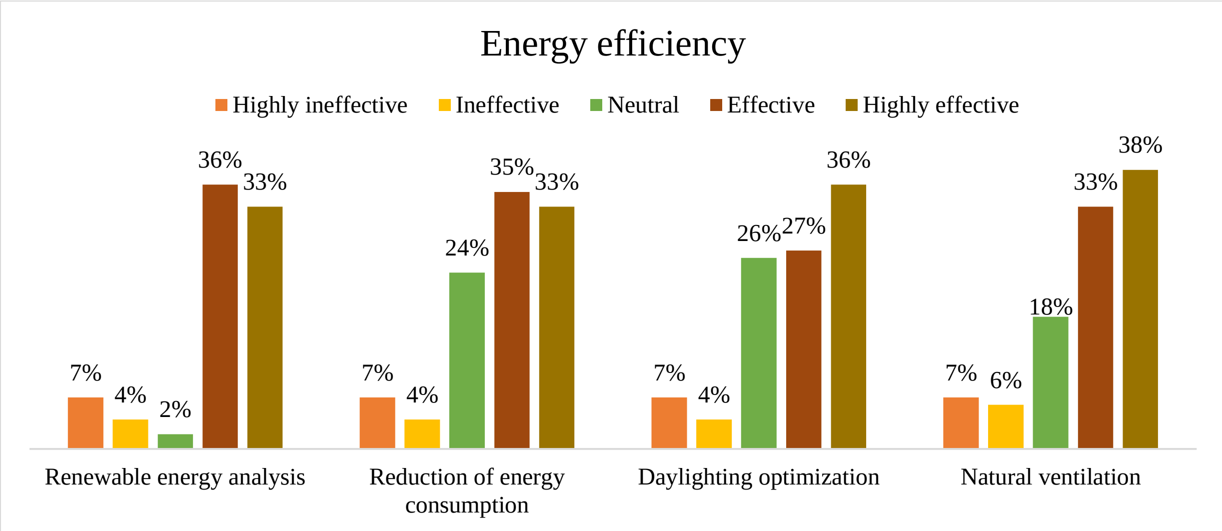

Figure 4.8: Energy Efficiency

Source: Field survey, 2020

Energy efficiency

	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
Natural ventilation	55	3.91	.154	1.143
Reduction of energy consumption	55	3.89	.146	1.083
Renewable energy analysis	55	3.89	.148	1.100
Daylighting optimization	55	3.84	.151	1.118
Valid N (listwise)	55			

Table 4.2: Mean scores and standard deviation for energy efficiency
Source: Field survey, 2020

Results in Table 4.2 revealed that natural ventilation was the most effective factor with a standard deviation and mean of 1.143 and 3.91 respectively while daylighting optimization was the least rated with standard deviation and mean of 1.118 and 3.84 respectively. a mean of 3.84 and standard deviation of 1.118. These findings are supported by Wasilowski and

Reinhart (2009) who explains that with Building Information Modelling software there is provision of consistent simulation in details: both artificial light and natural light are compared. Based on various weather conditions of weather, calculation adjustments are guaranteed.

4.3.3. Environmental quality

The parameters analyzed in this category were selection of sustainable construction materials, reduction of carbon emissions, reduction of waste and low toxic material usage. The responses to these are depicted in Figure 4.9 and Table 4.3 below

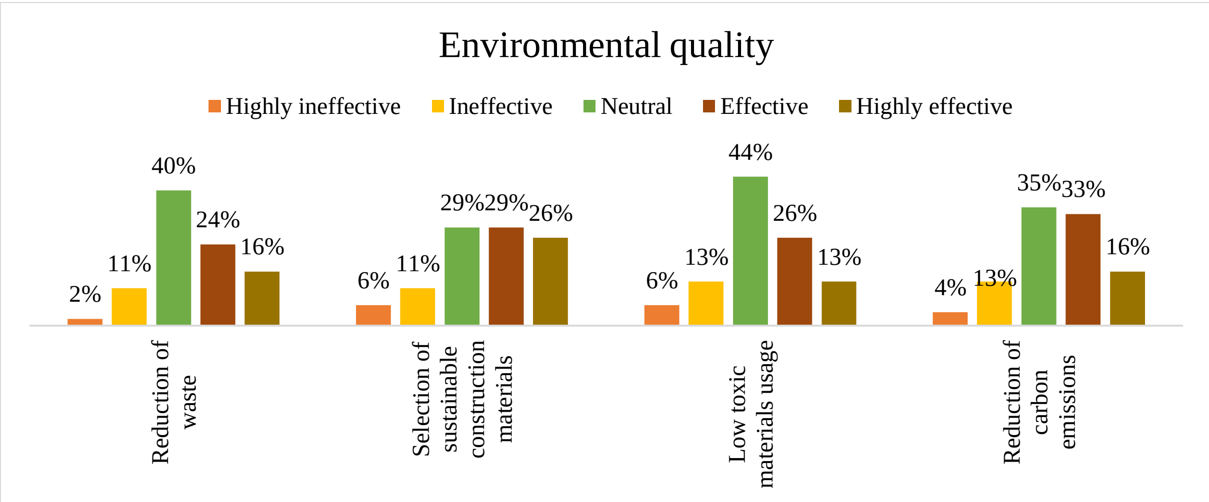

Figure 4.9: Environmental Quality
Source: Field survey, 2020

Environmental quality

	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
Selection of sustainable construction materials	55	3.64	.150	1.112
Reduction of carbon emissions	55	3.51	.135	.998
Reduction of waste	55	3.35	.150	1.109
Low toxic materials usage	55	3.33	.135	1.001
Valid N (listwise)	55			

Table 4.3: Standard deviation and mean scores and for environmental quality
Source: Field survey, 2020

Results in Table 4.3 revealed that selection of sustainable construction materials was the most effective factor with standard deviation and mean of 1.112 and 3.64 respectively while low toxic materials usage was the least rated with standard deviation and mean of 1.001 and 3.33 respectively.

These results are supported by I.E Solutions (2014) who states that “BIM software provides carbon emissions analyses and evaluations to help the project achieve carbon neutrality”. Apart from analysing carbon emissions, Building Information Modelling software similarly provides other designs that reduce emission of carbon. Engineers and designers assert that optimising original designs towards neutralising carbon is enhanced by the software (Autodesk, 2015). Improved decision making while selecting materials, by design experts, is as a result of perpetual and simultaneous estimation of operation and embodied carbon within a given building. This is another advantage of Building Information Modelling software (Iddon and Firth, 2014).

4.4.Role of BIM trends with respect to sustainable design and Construction

Objective three of the study was to investigate the role of current BIM trends with respect to sustainable design and construction practices. In determining this, built environment professionals rated the role of Building Information Modelling trends towards achievements of sustainability.

Descriptive Statistics

	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
Project visualization	55	4.33	.116	.862
Project planning and coordination	55	4.25	.111	.821
Clash detection	55	4.05	.133	.989
Rework reduction	55	4.02	.134	.991
Optimization of schedule and cost	55	3.98	.123	.913
Customization of building system	55	3.98	.123	.913
Flexible project changes	55	3.89	.109	.809
Constructability assessments	55	3.85	.133	.989
Risk aversion	55	3.71	.129	.956
Safety monitoring and improvement	55	3.65	.130	.966
Valid N (listwise)	55			

Table 4.4: Role of BIM trends with respect to sustainable design
Source: Field survey, 2020

Findings in Table 4.4 revealed that project visualization had the highest rating with a mean of 4.33. These finding are supported by various authors. The 4D aspect of BIM not only allows for graphical visualization of BIM with the schedule but alsogives the possibility to visualize the virtual view of the project at any time of the project. Project planning and coordination had the second highest mean of 4.25. HM Government (2012) indicates that BIM enhances collaborative work and transparency among stakeholders which results into an improvement in communication leading to waste reduction and avoidance of future errors. Furthermore, in the design processes, there is early amendment and detection of any area of non-compliance. Building safety and other compromises are avoided due to fewer design and resubmission cases. During construction process, material wastage is minimised as rework is reduced by this approach hence sustainability. Rework reduction was rated with a mean of 4.02.

BIM also ensures optimization of cost is attained as highlighted by Autodesk (2005) by reducing design cost, improving information management and enhancing coordination, with the result that fewer resources are wasted. Optimization of cost and schedule had a mean of 3.98.

Flexibility in project changes was rated with a standard deviation and mean of 0.109 and 3.89 respectively. According to Laisern (2002), flexibility is exploring changes in design due to Building Information Modelling. BIM results to reduction of manual checking and coordination time. Time is therefore allocated for resolving real architectural matters. During the construction phase, reduction of delays, in terms of length and number, is the main BIM benefit. It is possible to minimise footprint inflicted on the environment (Valentine, 2018).

4.5.Strategies to increase uptake of BIM

The final among the research objectives was determine the approaches that can be put in place to increase uptake of BIM usage amongst built environment professionals. Using five-point Likert scale each respondent was expected to rate the degree to which the enlisted strategies would help to increase uptake of BIM. Table 4.5 indicates the responses and the mean scores.

Descriptive Statistics

	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
Education and training focusing on BIM and sustainability	55	4.42	.103	.762
Introducing BIM as a study course inbuilt environment courses	55	4.22	.139	1.031
Enhance cooperation between BIM expert's academia and researchers	55	4.13	.145	1.072
Investment in BIM related research	55	4.04	.127	.942
Public awareness and campaign	55	4.02	.141	1.045
Policies that require BIM evaluation for projects to enhance usage	55	4.00	.142	1.054
Clear measures and requirements for achievement of sustainability in projects	55	3.95	.126	.931
Establishing better practice models for sustainability and BIM	55	3.95	.117	.870
Post use evaluation	55	3.84	.112	.834
Government incentives for the development	55	3.78	.163	1.212
Develop appropriate legal framework for BIM use	55	3.71	.157	1.165
Valid N (listwise)	55			

Table 4.5: Strategies to increase uptake of BIM

Source: Field survey, 2020

Results in Table 4.5 revealed that education and training focusing on BIM and sustainability was the key strategy in increasing uptake of BIM among built environment professionals with a standard deviation and mean of 0.762 and 4.42 respectively. Introducing BIM as a study course in built environment courses was second with a standard deviation and mean of 1.031

and 4.22 respectively. Developing appropriate legal framework for BIM use was the least rated strategy with a standard deviation of 1.165 and a mean of 3.71 (Table 4.5).

4.6. Hypothesis testing

T-test at interval confidence level of 95% and α 0.05 with 41 degrees of freedom (df) was performed.

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
WATER EFFICIENCY	55	3.4000	.82440	.11116
ENERGY EFFICIENCY	55	3.8745	1.01420	.13675
ENVIRONMENTAL QUALITY	55	3.4727	.93004	.12541

Table 4.6: One sample statistic for variables

Source: Field survey, 2020

One-Sample Test

	Test Value = 3					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
WATER EFFICIENCY	3.598	54	.001	.40000	.1771	.6229
ENERGY EFFICIENCY	6.395	54	.000	.87455	.6004	1.1487
ENVIRONMENTAL QUALITY	3.770	54	.000	.47273	.2213	.7242

Table 4.7: T-test results for variables

Source: Field survey, 2020

There is rejection of null hypothesis following the results presented from the t-test in Table 4.7. This is because water efficiency t (54) =3.598, p value of 0.001<0.05 thus the conclusion that BIM supports sustainable construction practices (water efficiency aspect).

The null hypothesis is similarly rejected since energy efficiency t (54) =6.395, p value of 0.000<0.05. This leads to the conclusion that BIM supports sustainable construction practices (energy efficiency aspect).

Finally, there is rejection of null hypothesis since environmental quality t (54) =3.770, p value of 0.000<0.05 thus the conclusion that BIM supports sustainable construction practices (environmental quality aspect).

5. CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

Chapter five entails the recommendations and conclusion of the research with respect to the objectives if the study. Evaluation of Building Information Modelling for sustainable construction was the major objective of the research. In addition, it aimed at evaluation of the current trends in Building Information Modelling used by architectures, engineers and constructors. It further evaluated its support for sustainable design and construction, BIM software possible capabilities related to construction sustainability. The role of current BIM trends with respect to sustainable design and construction was evaluated. Finally, strategies that need to be put in place to increase uptake of BIM amongst built environment professional were evaluated.

5.2.Summary of major findings

5.2.1. Objective 1

In identifying if BIM supports sustainability, knowing the current BIM trends within AEC was important. The study revealed three major trends in BIM usage i.e. use of Revit, ArchiCAD and Navisworks. However, it is evident that BIM is not yet used to its fullest capacity. MEP, energy analysis and lighting analysis on the other hand were the main Computer Aided Analysis being used by the respondents. Majority of the respondents had implemented BIM in the design stage.

Currently, there are various user designed software for environmental performance analysis for analyzing sustainability of a building in AEC sector which are not fully utilised. 42% of the respondents indicated they have not used any of the performance analysis softwares while Platforms such as Graphisoft ecodesigner has been used by only 20% of respondents, Ecotect 18% and IES Virtual Environment 15% with extensive equipment for analysing Building Information Modelling software; since there are soft relative costs and interoperability related issues, a company does not implement the usage of environmental software as a practice.

Additionally, although not utilized optimally, CAD analysis utilized by majority of the respondents were MEP (44%) energy (40%) and lighting (38%) analysis.

5.2.2. Objective 2

Objective two of the study aimed at identifying the possible capabilities of Building Information Modelling software with reference to sustainability practices in construction. Three sustainable construction practices were investigated: Water efficiency, Energy efficiency and Environmental quality which were further divided into various subcategories and subjected to a mean item rating scale. A higher mean meant that the BIM software was extremely effective in supporting the sustainable construction practice whereas a lower mean meant that BIM software was ineffective in supporting the sustainable construction practice.

Water efficiency was categorised into water harvesting, reduction of portable water usage, water recycling and reduction of surface water run-off. The study revealed that water harvesting was the most effective factor with a mean of 3.49whereas water recycling was the second most effective sustainable construction practice supported by BIM software with a mean of 3.42.

Energy efficiency was categorised into natural ventilation, reduction of energy consumption. Renewable energy analysis and daylight optimization. The study revealed that natural ventilation was the most effective factor with a mean of 3.91 while renewable energy analysis was rated as the second most effective factor with a mean of 3.89.

Environmental quality was categorised into selection of sustainable construction practices reduction of carbon emissions, reduction of waste and low toxic materials usage. The study revealed that selection of sustainable construction materials was the most effective factor with a mean of 3.64 whereas reduction of carbon emissions second most effective sustainable construction practice supported by BIM software with a mean of 3.51.

5.2.3. Objective 3

Objective three of the study was to determine the role of current BIM trends with respect to sustainable design and construction. Basically, due to its visualization (4.33) the use of Building Information Modelling is currently referred, project planning and coordination (4.25), clash detection (4.05) and rework reduction (4.02) capabilities.

5.2.4. Objective 4

Objective four was to determine appropriate strategies for uptake of BIM amongst built environment professionals. The study through mean item rating scale ranked education and training focusing on BIM and sustainability (4.42), as the first strategy that would promote uptake of BIM. Developing appropriate legal framework for BIM use (3.71) was the least rated ranked strategy.

5.3.Conclusion

The usage of Building Information Modelling as an impetus by architectures, engineers and constructors for sustainability in the field of construction and design is at its early stages. Currently, the majority of the built environment professionals within the Architectural, Engineering and Construction sector use BIM. It supports project planning and coordination due to its capacity thus enhancing faster project delivery. Due to emergence of new technologies in the AEC sector, the use of BIM is expected to increase gradually within companies. To ensue, the currently underutilised environmental analysis software will fully be used to its fullest capacity.

In terms of supporting sustainable construction practices, the majority believe that BIM software packages effectively supports sustainable design practice like water efficiency, energy efficiency and environmental quality.

5.4.Contribution to knowledge

The research contributes to practice in providing the current trends of BIM and highlighting a number of softwares that have not been used optimally especially the environmental performance analysis software. This information is crucial to organisations in helping them guide their development to increase their chance of achieving the desired sustainability benefits of BIM by exploring the use of the wide range of software models available in the market.

This research contributes to academic knowledge by producing a validated link between Building Information Modelling and sustainability practices in construction.

5.5.Recommendation

Building Information Modelling technology has currently emerged within the Kenyan AEC sector. However, it is not fully utilised. BIM must increase its capacity to integrate environmental analysis and improve interoperability. The built environment professionals must aim at implementing the performance tools into their practice standards. In addition, cooperation among the involved parties is essential for the provision of best joint effort for sustainability within construction projects.

5.6.Areas of further research

Research investigating academic institutions in regards to education and training focusing on BIM and sustainability software applications enhances the provision of feedback with regards to the future of Building Information Modelling within AEC sector.

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6. APPENDICES

SURVEY QUESTIONNAIRE

INTRODUCTION

Dear respondent,

This questionnaire aims to collect information related to the management of sustainability through BIM, the current trends in BIM usage within AEC and its support for sustainable design and construction, the relationship between Building Information Modelling and sustainable construction practices and their relation to built environment and strategies that can be put in place to increase uptake of BIM amongst built environment professionals.
The information given is for academic purpose only and will be treated with utmost confidentiality.

Please tick (√) the box that matches your answer to the questions and give the answers in the spaces provided as appropriate.

SECTION A: INFORMATION ON RESPONDENT

1. **Profession**

Architect Quantity surveyor Project manager Engineer Green Building Practitioner

{ } { } { } { } { }

Others (Please specify)

----

2. **Level of experience**

Below 5years 6-10years 11-15years 16-20 years Above 20 years

{ } { } { } { } { }

SECTION B: SPECIFIC QUESTIONS

Please tick (√) the box that matches your answer

1. **Current trends in BIM usage within AEC and its support for sustainable design and construction**

1.1. Do you use BIM to evaluate a project's sustainability during design and/or construction?

Yes [ ]   No [ ]

If yes, for how long?

< 2years [ ]	2-5yrs [ ]	5-8 yrs. [ ]	8-11 yrs. [ ]	Over 11 years [ ]

1.2. Indicate the current BIM trends you use in your company to ensure sustainable design and/or construction.

1. Autodesk Revit	[ ]
2. Graphisoft ArchiCAD	[ ]
3. Naviworks	[ ]
4. Tekla structures	[ ]
5. Bentley Architecture	[ ]
6. Primavera	[ ]
7. Vectorworks	[ ]
8. VICO	[ ]
9. Cype	[ ]
10. Others (Please specify)	[ ]

1.3. Indicate the stages where BIM has been used.

Planning [ ]	Design [ ]	Construction [ ]	Operation& Management [ ]

1.4. Which of the highlighted Computer Aided analysis has been used in your company?

Lighting analysis [ ]

Energy analysis [ ]

Acoustic analysis [ ]

MEP analysis [ ]

Water analysis [ ]

None [ ]

Others (Please specify) ---

1.5. Which of the stated performance analysis software has been used within your company?

Ecotect [ ]

eQUEST [ ]

Energy plus [ ]

Green Building Studio [ ]

Integrated Environmental Solutions [ ]

Graphisoft Eco-designer [ ]

None [ ]

Others (Please specify) ---

2. The management of sustainability through BIM

In your opinion how would you rate BIM software package effectiveness in achievement of the following sustainable features, using 5-point Likert scale rate their significance, where: 5=Highly effective, 4=Effective, 3=Neutral, 2=Ineffective, 1=Highly ineffective. Tick accordingly.

	Water Efficiency					
		1	2	3	4	5
	Reduction of portable water usage					
	Water recycling					
	Water harvesting					
	Reduction of surface water run-off					

	Energy Efficiency					
		1	2	3	4	5
	Renewable energy analysis					

	Reduction of energy consumption					
	Daylighting optimization					
	Natural ventilation					

	Environmental quality					
		1	2	3	4	5
	Reduction of waste					
	Selection of sustainable construction materials					
	Low toxic materials usage					
	Reduction of carbon emissions					

OTHERS (SPECIFY)

3. **Relationship between sustainability in construction and BIM in ration to built environment.**

3.1. Sustainability in construction and design would be most likely attained if BIM is implemented at what phases of a project stated below?

i. Planning [ ]
ii. Construction [ ]
iii. Design [ ]
iv. Management/operations [ ]

3.2. How do you perceive the role of the current BIM trends in respect to sustainable design and construction considering project lifecycle in stages of planning, designing, construction and operation: (Note: 5=Poor; 4=Below Average; 3=Average; 2=Good; 1=Excellent)

	1	2	3	4	5
1. Clash detection	[ ]	[ ]	[ ]	[ ]	[ ]
2. Project planning and coordination	[ ]	[ ]	[ ]	[ ]	[ ]
3. Constructability assessments	[ ]	[ ]	[ ]	[ ]	[ ]
4. Project visualisation	[ ]	[ ]	[ ]	[ ]	[ ]
5. Customization of building system	[ ]	[ ]	[ ]	[ ]	[ ]
6. Optimization of schedule & cost	[ ]	[ ]	[ ]	[ ]	[ ]
7. Rework reduction	[ ]	[ ]	[ ]	[ ]	[ ]
8. Flexible project changes	[ ]	[ ]	[ ]	[ ]	[ ]
9. Safety monitoring and improvement	[ ]	[ ]	[ ]	[ ]	[ ]
10. Risk aversion	[ ]	[ ]	[ ]	[ ]	[ ]

4. **Strategies can be put in place to increase uptake of BIM among built environment professionals**

Which of the following strategies do you think would promote uptake of BIM among built environment professionals in Kenya? Using a 5-point Likert scale, rank the strategies, where: 5=Very great extent, 4=Great extent, 3=Moderate extent, 2=Little extent, 1=Not at all,. Tick accordingly (√)

	STRATEGIES	**1**	**2**	**3**	**4**	**5**
1.	Education and training focusing on BIM and sustainability					
2.	Investment in BIM related research					
3.	Public awareness and campaign					

4.	Government incentives for the development and implementation of BIM technology					
5.	Post use evaluation					
6.	Enhancement of collaboration among researchers, academia and BIM specialist leading to awareness and exposure of BIM to upcoming professionals					
7.	The government should develop suitable legal BIM framework deployed or used in a project					
8.	Establishing and implementing sustainable and good BIM practice models					
9.	Clear measures and requirements resulting to achievement of project sustainability					
10.	Introducing BIM as a curriculum/study course for built environment courses					
11.	Policies / regulation that require BIM evaluation for projects to enhance BIM usage					

OTHERS (SPECIFY)

THANK YOU