# A Review of the Application of Building Information Modeling (BIM) in Mitigating Building Construction Accidents in Kenya

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## Abstract

*Around the world, collaborators in the construction industry have endeavoured to mitigate accidents by imposing numerous safety precautionary measures such as safety warning signs, fire drills and employment of personal protective equipment, for instance, hard hats, safety boots and safety harnesses. Concurrently to the existing precautionary safety measures, information visualization techniques such as Building Information Modeling (BIM) have been delved into to advance the current safety management practices. However, the level of BIM uptake in developing countries such as Kenya is low even though the innovation possesses the ability to shape the construction industry to become a substantially more aggressive, secure, and high-yielding industry. This can be partly attributed to the limited nature of research on the capability of BIM in construction safety management. If firms and professionals in the construction industry are unaware of the advantages of transitioning to the new norms, they are less disposed to embrace the transformation. Hence, the need to examine the fundamental areas of BIM application in mitigating building construction accidents. Accordingly, this study recommends that, awareness of BIM through workshops and conferences should be created as well as BIM training incorporated in the curriculum of tertiary institutions.*

***Keywords*: Building Information Modeling; Employment of Innovations; Construction Accidents; Designing for Safety; Model-driven Prefabrication; Workers' Safety Training; Safety Inspections; Job Site Monitoring; Kenya**

## Introduction

The construction industry has been known as a vulnerable industry with hazardous activities at the workplace which delineates a comparatively high number of injury and fatal accidents. Agwu and Olele (2014) indicated that, universally, construction employees are 3 times prone to fatal accidents and doubly bound to be harmed as employees in different trades. According to Golizadeh (2019), there are in excess of sixty thousand casualties reported each year in the construction industry around the globe. In 2014 alone, the construction industry in the United States of America experienced 885 deaths (Jazayeri & Dadi, 2017). In developing nations, for example, Kenya the situation is also worse. Data from the 'Directorate of Occupational Safety and Health Services (DOSHS)' safety records in 2020 revealed that 199 non-fatal accidents were recorded in Nairobi City County with 7 fatalities.

Throughout the years, numerous strategies have been executed to forestall/reduce accidents in building construction projects. Examples of precautionary safety measures that have been utilized include safety warning signs, fire drills and employment of personal protective equipment, for instance, hard hats, safety boots and safety harnesses. Furthermore, while examining the status of construction safety from the perspective of the Swiss Cheese model, the issue may probably not be the openings or even the slices. The construction industry needs to acquire a new chunk of cheese to fit into the 'new normal' in the industry. The Project Management Institute (PMI) has created construction additions to the PMBOK Guide (2016) that gives development explicit direction to the project governing practitioners. The construction extensions include the deliberation of rising patterns and improvements in the construction industry such as Building Information Modeling (BIM), cloud technology, Virtual Reality (VR), Augmented Reality (AR), Radio Frequency Identification Devices (RFID) among others. Behringer (2013) posits that, there has been considerable interest in improving worksite safety through safer design and work method statements using Building Information Modeling.

The fundamental areas where safety professionals can use BIM include: designing for safety, model-driven prefabrication, workers safety training, safety inspections and jobsite monitoring (Alomari et al., 2017; Koutsogiannis, 2019; Mordue, 2020; Morrison, 2020; Triax, 2021; S. Zhang, 2014). Marefat et al. (2018) acknowledged that the ability to influence safety is high during the pre-construction phase of a project. However, research conducted by Kemei (2019) in Kenya revealed that, safety is usually not incorporated from the initial stages of construction (during design) and this causes concerns about how safety is managed on construction sites. Hence, more attempt is needed to create a link between design and construction to holistically address safety. It is also evident that limited research has been carried out in Kenya regarding the use of BIM in construction safety improvement. A study by Mwero and Bukachi (2019) investigated BIM adoption in structural design and the findings informs that, BIM is majorly used in structural analysis, design documentation (drawings), interpretation of design and conceptualization, clash detection and scheduling of work. However, the study appears to be limited to one fundamental safety area (design) thus leaving model-driven prefabrication, workers safety training, safety inspections and jobsite monitoring unexplored. It is therefore sensible and timely, to investigate the application of Building Information Modeling in improving construction safety through review of appropriate literature to determine its effectiveness in addressing accidents at building construction sites.

## Scope of the Study

The scope of this paper is to examine the fundamental areas of BIM application in mitigating building construction accidents.

## Study Justification

Accidents are the dreadful actuality in the construction industry and they happen each day (Health and Safety Executive, 2020; Kemei, 2019; Kiconco et al., 2019). The Health and Safety Executive (HSE) in the United Kingdom indicated that, the stake of falling accidents is the largest, representing 59%, struck by falling/moving objects at 3%, collapse/overturn at 5%, hit by vehicle at 10% while electricity hazard was 7% (Mordue, 2020). In Kenya, data from DOSHS monthly reports in the period of 2020 revealed that, injuries due to falls were the greatest contributor to the recorded building construction accidents. Arachchige and Ranasinghe (2015) observed that, the cost consequences of construction accidents are often referred to as significant drivers for enhancing safety performance. On this account, the need to reduce compensation costs, expenses of tidying up after the accident, staff turnover, costs of training new workers, absenteeism of workers, loss of public confidence, loss of morale among employees, family suffering due to the death of their loved ones, legal costs, disruption of work/closure of construction sites among other accident consequences calls for a paradigm shift in construction safety management. In reference to Thomas Kuhn's arguments on paradigmatic shifts and substitution (2013), this study will work to understand alternative perspectives from other researchers/experts on the fundamental areas of BIM application in mitigating building construction accidents to determine what paradigm(s) may suffice the problem at hand.

## Employment of Innovations

One of the key components in achieving the Sustainable Development Goal 9 is innovation through technological development (Lekan et al., 2020). This study will predominantly focus on Building Information Modeling (BIM) since the construction industry needs to acquire emerging safety management innovations to fit into the "new normal'. However, BIM is no silver bullet to solve all safety issues across the construction industry. Integration of BIM with other innovations such as cloud technology, laser scan technology, among others can probably widen the scope of safety management within the construction industry.

## Building Information Modeling (BIM)

BIM implies divergent things to various experts and doubtlessly, the construction industry has not yet understood its full abilities. Some professionals state that BIM is a program application; some mention that it is a procedure for planning and recording data on facilities and others comment that it is a comprehensive technique to deal with design, construction and servicing of a structure (Kjartansdottir et al., 2017). In spite of the fact that there are various meanings of BIM, there is a typical agreement that BIM is 'an integrated model-driven process that furnishes architecture, engineering and construction experts with the understanding and tools to proficiently plan, design, build and oversee assets in the construction industry' (Autodesk, 2020). In this way, the interpretation adopted in this research is one that accentuates the three primary pillars of BIM: the process, people, and technology.

By definition, the process incorporates generating, accumulating and manipulating an intelligent three-dimensional model to illuminate and convey decisions all through the venture lifecycle (Golizadeh, 2019). BIM does something amazing in the construction industry since individuals make it work by characterizing and sorting out the BIM outputs. Kjartansdottir et al. (2017) acknowledged that behind each prosperous BIM undertaking there are qualified individuals (architecture, engineering and construction experts) with the right technology that permits them to team up viably. The technology pillar of BIM is central to the processes of generating, accumulating and manipulating information models (Kirby et al., 2017). Accordingly, BIM is intertwined with technology (both software and hardware) and since technology is constantly being improved and made more efficient, BIM will also continue to grow at a breakneck pace. Regardless of the formal definition adopted in this research, the following points that represents the true essence of BIM concept should be considered.

**Building:** The term is regarded as a verb "to build" rather than just referring to buildings. The idea is applicable to any asset in the construction industry, both vertical and linear including; buildings, railways, highways, bridges, tunnels and utilities (Kjartansdottir et al., 2017).

**Information:** The most valuable feature of BIM lies in the 'I' of BIM, which can be shared and communicated transparently to all stakeholders involved, created once and may be reused many times throughout the life cycle of an asset (Ciribini et al., 2015). An 'information model' consists of the three-dimensional parametric model, non-graphical information, and linked documents.

**Modeling:** While geometric delineation is significant, one should have the option to simulate the different aspects of design (for instance; structural, architectural, mechanical, electrical, and plumbing), construction (4D and 5D) and the operation phase of the asset (6D).

The information model creates the premise of a digital database, where data (about a specific asset) is supplied and pulled out. Information kept as "machine-readable parametric objects" can be perused by BIM programming instruments, fit for accumulating models of assets in their virtual structure (Ruikar, 2016). The word 'parametric' portrays a procedure by which a component is altered and a contiguous part or component (for example, a window connected to a wall) is automatically acclimated to keep an earlier settled relationship (Azhar et al., 2012). The accompanying kinds of computerized models, as listed below, don't fall under the classification of BIM:

Models that consist of 3D information with no object attributes (missing the 'I' of BIM); Models with no support of behaviour; Models that are created using different 2D CAD reference documents to represent the asset; and Models that are not automatically displayed in different views to permit changes to measurements in a single view.

## BIM Maturity Levels

The 'Bew-Richards BIM maturity model' displayed in Figure I, divides BIM into an introductory level and three clear-cut development levels, advancing from the conventional construction worldview to full integration of BIM. Ruikar (2016) indicated that each stage (maturity level) should be executed progressively and in a rational sequence of augmentation, because of the significance of their outcome in determining 'transformational' advancement. The maturity levels as presented in Figure 1 are further discussed below:

**BIM Level 0 – 'Unmanaged CAD':** Advances zero collaboration and utilizes paper-based 2D CAD drafting methods to create production information as paper or electronic prints or a combination of both (McPartland, 2014). This is an outdated level that is infrequently adopted by construction industry experts these days.

**BIM Level 1– 'Lonely BIM':** Includes some essential 3D elements as the stage forms the beginning of BIM. Normally, in level one, there is a blend of 3D CAD for abstraction work and 2D CAD for documentation and item data (Kjartansdottir et al., 2017). 'Lonely BIM' entails naught or low cooperation among the accomplices as every person model and governs his/her own data.

**BIM Level 2 – 'Collaborative BIM':** Having created a sole-disciplinary modeling mastery during level one executions, level two participant effectively team up with other specialty players. Any CAD application that each stakeholder utilizes ought to have the potential of sending out to a typical document format, for instance, the Industry Foundation Classes (IFC) format. Collaborative BIM is highly characterized by the incorporation of 4D (3D plus time) and 5D (4D plus cost estimates) information.

**BIM Level 3 – 'Intelligent BIM':** It entails the whole unification process of the BIM model into the life cycle of an asset (incorporation of 6D information). Intelligent BIM recommends utilization of a coordinated arrangement centered around open standards such as, the Industry Foundation Classes (IFC) where a solitary server stocks all the project information.

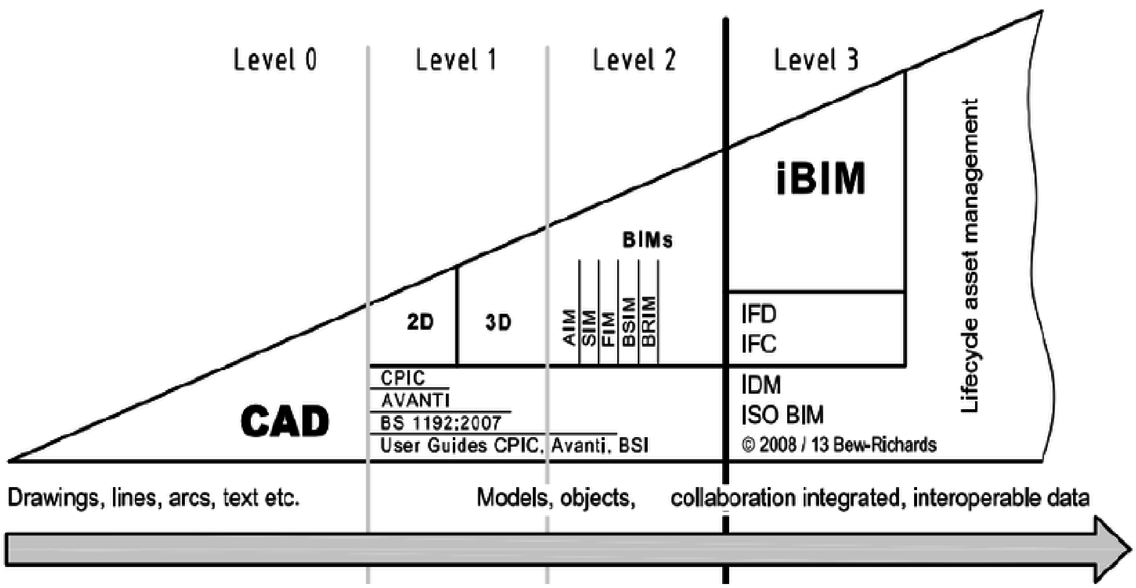


*Figure I: Bew-Richards BIM Maturity Model*

***Source: Adapted from Mordue (2017)***

## Legal Aspects of BIM

Countries such as the USA, UK and the Netherlands have embraced BIM as a requirement in design and execution of construction projects as presented in Table I. Exceptional accomplishments have been registered in the United Kingdom construction industry in relation to BIM uptake gains. Consequently, BIM standardizations have emerged, specifically in line with this study (safety administration) is the BSI: PAS 1192–6, 2018 specification (Hamma-adama & Kouider, 2019). In 2015, Germany established a digital building platform mandating the use of BIM for all transportation projects by the end of 2020

(Kalfa, 2018). In Kenya, Mwero and Bukachi (2019) indicated that, there is no mandate governing utilization of Building Information Modeling for any type of construction undertaking. The only establishments giving publicity to BIM uptake and executing connected activities, for example, workshops are the venders of BIM applications with the help of the parent organizations like Autodesk, Bentley and Graphisoft (Mumbua, 2016). Building Information Modeling adoption in Kenya is, therefore, purely market-driven and based on the organizations' policies and preferences. Hence, the findings of this research will seek to provide crucial information that can be used as a basis for the regulation and adoption of BIM in Kenya

***Table I: Summary of BIM in the USA, UK, and the Netherlands***

| | **Countries** | | |
|---|---|---|---|
| | **USA** | **UK** | **The Netherlands** |
| ***Regulatory framework*** | BIM obligatory for government projects from 2008, | BIM mandate for public procurements, obligatory for government projects by 2016, development of standards | No governmental mandate, state agency today in tenders require BIM standard development |
| ***Financial framework*** | Indirectly through governmental projects, | BIM projects reflected in budget and financial support of institution | Indirectly, through governmental projects |
| ***Other elements*** | Support from federal governments, private stakeholders and universities supporting education | Development of institution and support of BIM community development, construction industry is involved in BIM definition through UK Task group | Marketing campaign, BIM weeks organized by private companies, standard development based on technological experiences |
| ***Focus*** | Initial focus on public service buildings | Focus on infrastructure and private buildings | Initial focus on private buildings, designed by architects etc., public projects focus on infrastructure |
| ***Timeframe*** | Start in 2003, BIM mandate 2007 | Start in 2011, BIM mandate 2016 | Start of debates in the 90s, early projects leading to standards by 2003, 2012 open BIM standards |
| ***Leading Stakeholders*** | Public entities and organizations | Government with the support of a Task Group including leading BIM companies | Led by construction industry stakeholders |

***Source: Adapted from Mwero and Bukachi (2019)***

## BIM-Enabled Software

Building Information Modeling is a process enabled by technology, both hardware and software. As of now, there is a wide assortment of BIM tools used by the AEC industry as illustrated in Table II (Asnafi, 2016). Kjartansdottir et al. (2017) noted that there is no software that can be able to fully realize a BIM project alone; hence, it is crucial to select the right software for a particular task.

*Table II: BIM-Enabled Software*

| Tools | Purpose |
|---|---|
| **Design Authoring Software:**<br>❖ Revit, AutoCAD, Tekla Structures, SketchUp, MicroStation, ArchiCAD, Digital Project, Vectorworks Designer. | Provides the ability to aid the design and construction by generating data for multiple uses, in 2D and 3D. Tools may be specific to a discipline and use parametric capabilities using a combination of graphical information and data. |
| **Scheduling software:**<br>❖ Navisworks, Vico Office, ProjectWise, Synchro Pro, Innovaya Visual Simulation. | Provides the ability to schedule works and by contractors on a project. Some software integrates the graphical model with time-based capabilities to provide construction sequencing (often referred to as 4D Modeling) |
| **Cost tools:**<br>❖ Navisworks, Vico Office, Solibri, Procore, PriMus IFC. | Provides for quantity takeoff and estimating. Costing capabilities may be linked to Design authoring tools via plug-ins. |
| **Model Review Software:**<br>❖ TeklaBIMsight, BIM 360 Design, Trimble Connect, ProjectWise, Solibri Model Viewer, Navisworks, Rendra, Procore. | Provides ability for project team members to view, navigate and interrogate model information. Some software also offers additional functionality, such as model checking for clash detection. |
| **Field Management Software:**<br>❖ BIM 360 Build, Trimble Field Link, Procore. | Provides the ability to collaborate, report and feedback to a project model, using a combination of mobile and cloud technologies. |

***Source: Adapted from Hergunsel (2011), Kjartansdottir et al. (2017), Kalfa (2018) and Golizadeh (2019)***

The range of programs/software used within the 'Architecture, Engineering and Construction (AEC)' industry can make data collaboration challenging. To solve the interoperability issues, BIM models can be shared in universal formats, for example, IFC and Building Collaboration Format (BCF). IFC provide an information rich model which empowers all stakeholders in design, construction, and management cycles to trade data in a coordinated information pool

(Clemen & Grundig, 2006). BCF, on the other hand, is an open file format that enables BIM workflow communication by exchanging lean 'topics' and not the entire bulk BIM model between software applications. It also permits inclusion of textual comments and images for enhanced communication among cooperating actors (FINALCAD, 2016).

## The Role of BIM in Mitigating Building Construction Accidents

Alomari et al. (2017) acknowledged that, inspecting Building Information Models makes it feasible for the project team to find clashes and safety issues in advance thus, improving safety performance during the project execution phase. For example, utilizing four-dimensional scheduling with workplace logistics planning can undoubtedly help distinguish traffic contemplations and possible perils around the workplace before kicking things off. Safety might be up to the mark through 'model-driven prefabrication' as this renders the opportunity to fabricate materials off-site in a secure and controlled setting (Mordue, 2020). Zhang (2014) indicated that safety knowledge of best practices is hard to transfer through safety guidelines alone. Utilizing an information model in safety training permits construction site workers to comprehend the physical settings of a project. According to Morrison (2020), with a BIM platform that integrates cloud innovations, safety officials can capture visual data straightforwardly from the place of work during safety inspections and sort it out progressively to create dossiers and site updates. At the same time, modern BIM platforms can send real-time alerts to safety managers in case workers are injured or experience safety incidents. The automatic notifications inform the managers in charge on who, when, where and what including the distance of falls and other types of safety events, resulting into faster response to contain the incidents (Triax, 2021). Following this discussion, it is evident that the fundamental areas where safety professionals can use BIM include ***designing for safety, model-driven prefabrication, workers' safety training, safety inspections and job site monitoring***.

**Designing for Safety:** Nasila and Cloete (2018) argued that, employment of BIM in design is more feasible compared to the construction period of a project. For instance, Xiaer et al. (2016) posit that safety perils can be dodged at the design stage of a construction project. Li et al. (2018) confirmed by indicating that the virtualization of the building site and the unique programming of a wide range of safety aspects can be achieved successfully by BIM. Golizadeh (2019) and Marefat et al. (2018) also concur that the ability to influence safety is high during the design phase of a project as shown in Figure II. According to Teo et al. (2016), the concept of Designing for Safety (DFS), which is also referred to as Prevention through Design (PtD) was first mandated in the UK through the 'Construction (Design and Management)' regulations of 1994. The potential of BIM during the design phase of a project rests with its capacity to execute simulations to distinguish the most secure building arrangements and determine the conceivable safety perils.

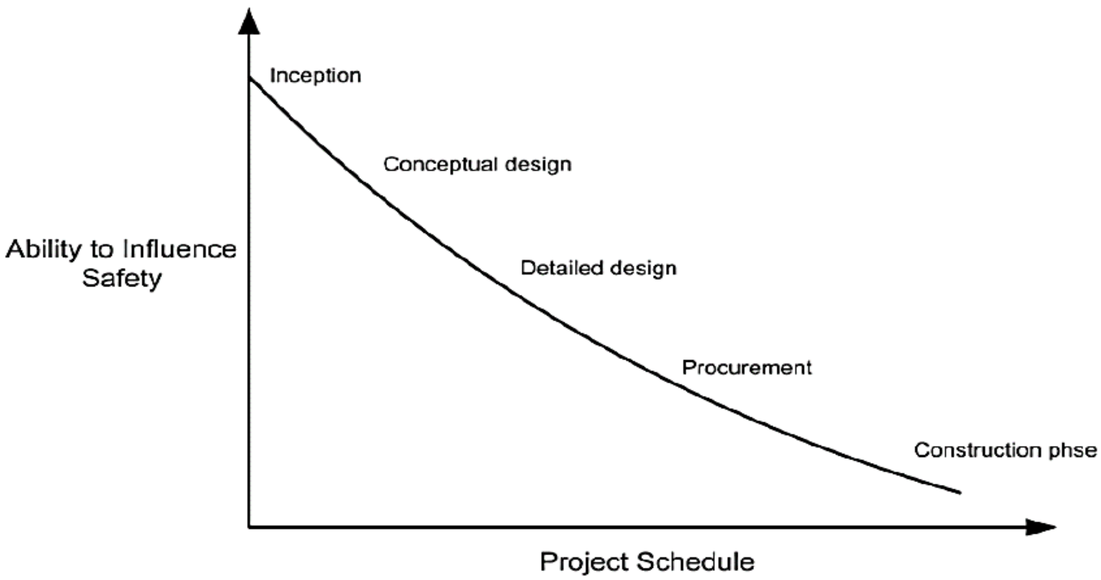


*Figure II: Ability to Influence Construction Safety*

***Source: Adapted from Golizadeh (2019)***

Shih et al. (2012) provide a rule-checking system to address safety problems during design and the system comprises three main elements: (1) an interpretation of safety regulations and best practices; (2) BIM models in a specific format (for example the ArchiCAD, Tekla Structures, MicroStation or Revit format) or/ and Universal format (such as the IFC format) and (3) schedule information of workforce, equipment and material. The integration of a schedule (prepared using MS Project or Primavera) into the rule-checking system provides measures of cost (5D) and time (4D) performance. Zhang et al. (2013) presents a framework in Figure III for implementing a BIM rule-based safety checking system. The existing construction safety checking system is limited to falling from height hazards. When the system is checking for possible risks, it begins by defining the specific area that may cause a fall hazard from the digital model. Corresponding rules are executed and visualized, showing a protection method (with additional information such as the cost of equipment and the schedule for installation and removal) in the detected area. Hence, concerning DFS, stand-alone BIM has limited value; therefore, 4D and 5D BIM is necessary in supporting the conventions identifying with a more secure design and the authoritative obligations on designers (British Standards Institution, 2018). Furthermore, it is worth noting that the effectiveness of a BIM-enabled rule-checking system can be achieved when the BIM model is created with a fitting naming convention and to the appropriate degree of details (Teo et al., 2016).

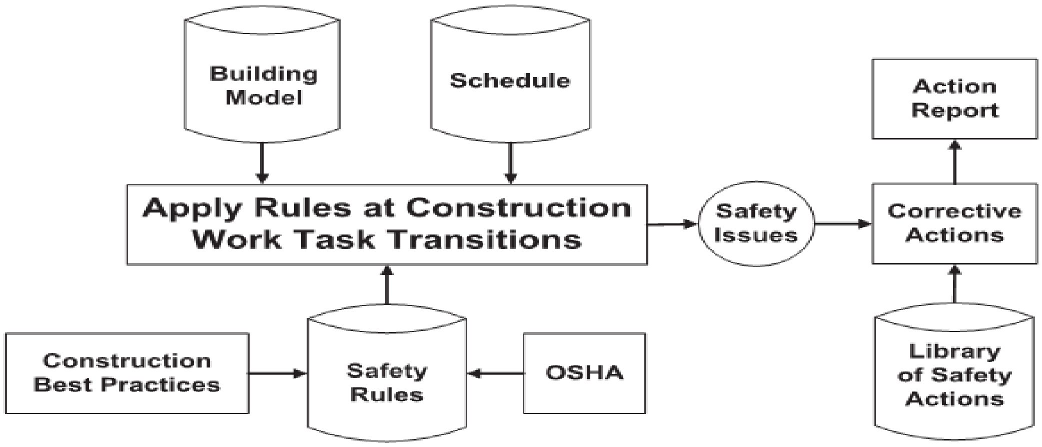


*Figure III: A Rule-based Safety Checking System*

***Source: Adapted from Zhang et al. (2013)***

**Model-driven Prefabrication:** Transpiring disruptions in the construction industry, for example, the digitalization of processes, products and new entrants have and will certainly continue to drive change and transform construction praxis. Shifting a considerable number of construction activities to a production line/godown can altogether diminish a portion of the day-by-day dangers for construction laborers such as tumbling from stature, material handling hazards or risk of electrocution. Besides, prefabrication can extensively add to the normalization of the construction operations which implies more significant levels of consistency and less chance for mistakes (Koutsogiannis, 2019). According to Morrison (2020), rework is emphatically related to the recordable place of work accidents. This is likely on the grounds that laborers when pushed by the schedule setbacks, may attempt to work rapidly through revisions and subsequently, be more susceptible to compromise or hold back on safety measures to meet cut-off times. In this manner, eliminating unnecessary rework through the model-driven prefab concept is one route for organizations to set aside time and cash while improving workplace safety. As an account of basic math, fewer laborers at the place of work implies a less congested working environment and organizations can reduce the danger of inadequate supervision of laborers, especially those with health conditions such as respiratory issues and phobia from heights. The move towards off-site fabrication and on-site erection mechanization will be significantly more important as the COVID-19 epidemic further spreads out. Moreover, workers who have been affected by the mechanization of construction activities can be deployed to other projects.

**Workers' Safety Training:** Wang et al. (2018) indicated that, as a result of the evolving techniques embraced in the construction industry, availing adequate training programs to enhance the day-by-day endeavours of workers has assumed a significant role. While theory and information can be dispatched through conventional learning techniques, it is accepted that shaping a right mentality toward workplace safety and accidents should successfully be possible through innovative techniques. This involves the creation of an atmosphere in which employees can experience what is recognized as "unsafe acts or conditions" (Soemardi & Erwin, 2017). According to Holzer (2015), innovation technologies can be integrated with BIM to address construction safety issues. For instance, Virtual Reality (VR) can allow site workers to practice and come into contact with different field contexts that cannot be conveyed through a classroom environment with slide presentations (Ahmed, 2019). Figure IV shows a site operative training on safety issues through Virtual Reality. Rice (2018) confirms that safety training by way of Virtual Reality allows for endless repetition. Additionally, Rice (ibid) puts forward that a VR training setting can enable trainers to observe and assess their learners.

*Figure IV: Worker Training on PPE by VR Technology*

***Source: Adapted from Ahmed (2019)***.

**Safety Inspections:** Traditionally, managers control job sites through their working experiences and visual observation (Chen et al., 2019). For instance, safety managers rely upon visual assessment and checklists in printed form to manage hazardous situations, a methodology that does not provide immediate feedback. The capacity of BIM to empower the location of conceivable safety issues in the course of construction through virtualization permits the utilization of BIM to be in accordance with the rule of Design for Safety/Prevention through Design (PtD), which targets to take into account safety at the soonest convenience (Teo et al., 2016). Instead of carrying out safety assessment based on intuition as cited by Chen et al. (2019), a safety manager can conduct site inspection every day using the reporting features of BIM applications to guarantee that safety execution carefully observes the designed safety plan. The automatic reports generated by Autodesk BIM 360 Build can be utilized to file safety issues and be included in the project safety records (BIM 360 Field maintains an audit trail of what has been done - audit trails show authors, dates, and times). Concurrently, employment of Augmented Reality in safety inspections is now becoming a commonplace within construction. For instance, safety professionals can link ‘GAMMA AR with Autodesk BIM 360 Build’ to identify and address any discrepancies on a construction site immediately and in real-time. If errors are noticed or conditions on the workplace that don't line up with the design, the safety professionals can quickly generate RFIs, jot remarks and attach photographs to explicit areas in their BIM models.

**Job Site Monitoring:** All through the construction phase, the BIM manager should constantly revise the information model so that it mirrors the current situation on site (Azhar et al., 2012). With advances in mobile technology (smartphones and tablets), construction teams can constantly utilize BIM models in job sites for purposes of information extraction and collaboration. A portion of the outstanding BIM applications, as highlighted by Hergunsel (2011), Kjartansdottir et al. (2017) and Kalfa (2018), include BIMX, Bentley Navigator, Navisworks, Autodesk BIM 360 Build, amongst others. A field management software like Autodesk BIM 360 Build permits clients to share information models in a web setting and execute different assignments in site, for example, walk-throughs. In a building site, workers wearing 'Radio Frequency Identification Devices (RFID)' tags can be represented in a 3-D model and their location can be receive some form of shading to signal a dangerous condition or a case in which the labourer may have wandered outside the assignment zone. For instance, in Figure V, the site operative in red shade implies a dangerous condition. Conversely, the site operative in blue shading implies somebody that is not at the assigned area on the job site.

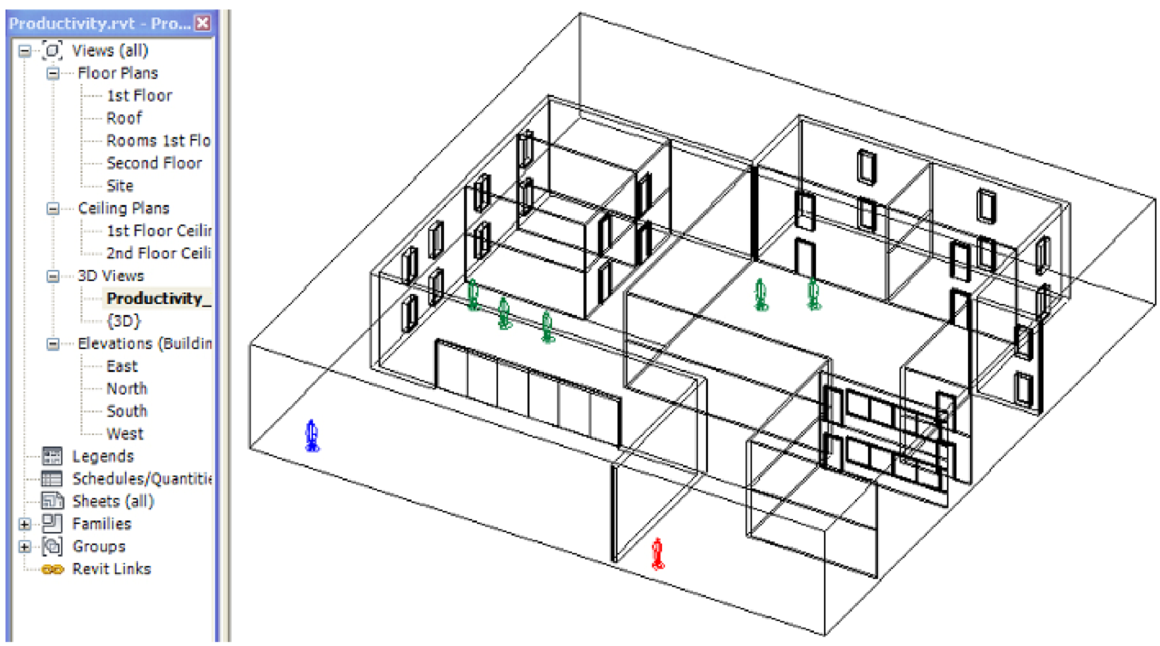


***Figure V: RFID Tag Tracking in an Autodesk Revit Model***

***Source: Adapted from Sattineni and Azhar (2010)***

Laser scan technology can as well be used to create a productive relationship between the place of work and the planning group by scanning the built structure and contrasting it with the designed (three-dimensional) model. This capability can be used to improve safety management by gathering critical hazards points (Asnafi, 2016). Chen et al. (2019) present the use of Unmanned Aerial Vehicles (UAVs or Drones) in construction safety in Figure VI. Drones are capable of close-up surveillance and can aid safety professionals to guarantee that all tasks are executed in line with the safety regulations. Also, survey equipment (laser scanners with Light Detection and Ranging system) mounted on UAVs can accurately reproduce a computerized 3D model of a workplace, permitting construction actors to appropriate safety complexities and devise workarounds early (Chen et al., 2019).

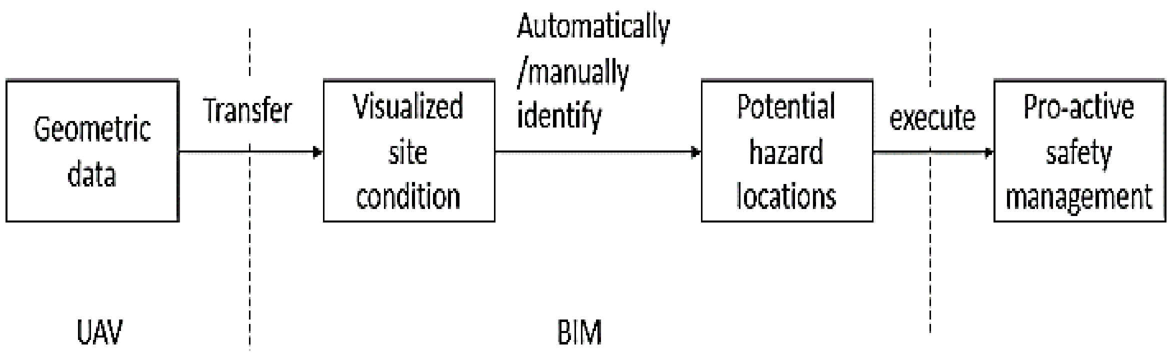


*Figure VI: A BIM/UAV System*

***Source: Adapted from Chen et al. (2019)***

## Theoretical Framework

The study is founded on the diffusion of innovations theory due to the transpiring disruptions in the construction industry, for example, the digitalization of processes and products as well as new entrants.

## Diffusion of Innovation Theory

The procedure of taking up innovations has been examined for more than 30 years and Everett Rogers depicts quite possibly the most mainstream innovation uptake models in his book, 'Diffusion of Innovations' (Sahin, 2006). Following the Everett Rogers' theory, 'innovation is an idea, process or technology' that is seen as state-of-the-art or unknown to people within a specific region or social framework. At the same time, diffusion is the procedure by which the knowledge about the development streams from one individual onto the next over a certain period within the social network (X. Zhang et al., 2015). Adoption of a new idea (for example, Building Information Modeling) doesn't occur synchronously in a social framework; instead, it is a cycle whereby a few individuals are more well-suited to embrace the transformation than others (LaMorte, 2019). The researcher further highlighted that a significant number of people tends to fall in the middle adopter classes. Zhang et al. (2015) and LaMorte (2019) categorize the members of a social system into 5 classes based on their mindset regarding innovations: 'innovators, early adopters, earlier majority, later majority and laggards' as shown in Figure VII.

**Innovators (Venturesome):** Represents the first and venturesome class to adopt an innovation. They are extremely eager to face challenges and practically nothing, regardless, should be done to attract this populace. According to Zhang et al. (2015), innovators can comprehend and apply modern specialized information fundamental for acquiring the innovation from outside the social system.

**Early Adopters (Respectable):** They are in general knowledgeable about the innovation, very comfortable adopting new ideas and different individuals come to them to get guidance about the change.

**Early Majority (Deliberate):** They ordinarily need to see proof that the advancement works before they embrace it (LaMorte, 2019). However, they do choose new ideas before the average person.

**Late Majority (Skeptical):** These individuals are not effortlessly persuaded to accept change and will just take on an innovation after most of their peers have taken it.

**Laggards (Traditional):** These individuals are limited by customs and in view of their restricted resources and lack of information about the innovation, they first need to ensure that an advancement works (for example, by looking at past statistics) before they adopt it.

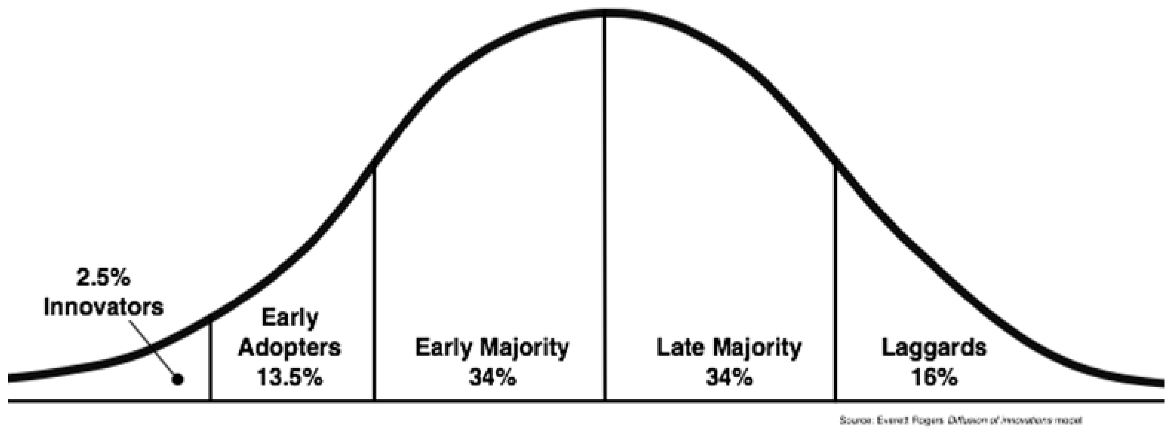


*Figure VII: Innovation Adopter Categorization*

***Source: Adapted from LaMorte (2019)***

The "innovation-decision process" comprises of a progression of activities and decisions over the long run through which a person or an establishment assesses a ground-breaking thought and chooses whether or not to include the original design into the current practice (Rogers, 2003). The approach incorporates five logical/sequential stages as shown in Figure VIII: '(1) knowledge, (2) persuasion, (3) decision, (4) implementation and (5) confirmation'. Following the steps sequentially, with regards to the last affirmation stage, the advancement is not called into question by partners who were not adequately counselled on its worthiness (Rush, 2019).

**Knowledge:** This happens when a person or an organization is introduced to the advancement's existence and acquires some comprehension of how it works (Rogers, 2003). Skipping the 'knowledge stage' can cause challenges within the transformation cycle, leading to disagreements in the second phase (Rush, 2019).

**Persuasion:** This happens when a person or an organization is establishing the expected benefit of embracing an advancement and further investigating its capacities. While the information stage is more psychologically focused, the "persuasion stage" is more effective centered (Sahin, 2006).

**Decision:** This happens when a person or an organization takes part in actions that culminate to a choice to embrace or dismiss the advancement (Rogers, 2003). Participation helps to cultivate the feeling of inclusion in making choices, even though an official choice is held by top managers or an individual.

**Implementation:** This happens when a person or an organization puts the advancement into practice. Commonly, this step includes a group with an undertaking administrator to manage the process (Rush, 2019).

**Confirmation:** Happens when a person or an organization looks for support of an advancement choice previously made, however the individual/organization may reverse the decision whenever presented with clashing decisions about the advancement (Rogers, 2003). In a conventional project management system, the 'confirmation stage' is essentially an assessment dependent on whether the rules formulated for the undertaking have been achieved (Rush, 2019). It is noted by Rush (ibid) that achievement in the 'confirmation stage' becomes apparent when individuals do not anymore create workarounds and falling back on old practices.

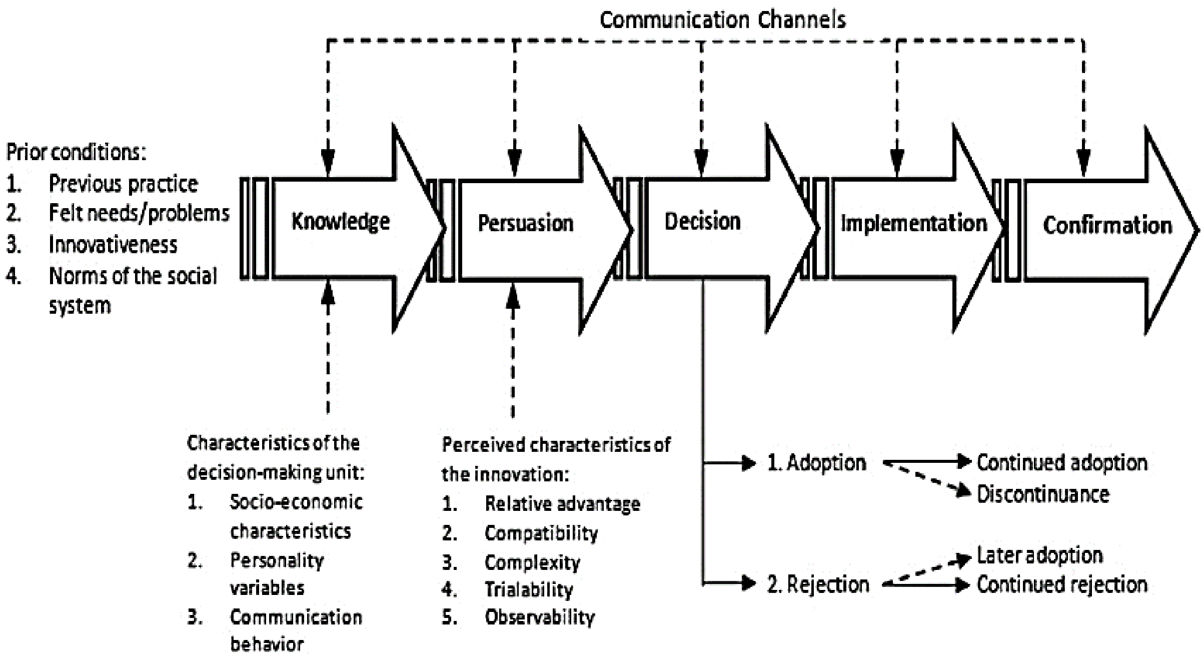


*Figure VIII: The Innovation-decision Process*

***Source: Adapted from Rogers (2003).***

## Implication of the Theory to the Study

Thompson (2020) acknowledged that, being proactive and using outside-the-box thinking can further building construction safety substantially. The **employment of innovations** such as Building Information Modeling (BIM) is considered 'outside-the-box thinking', as pointed out by Thompson (ibid). However, when compared to other industries like transportation, finance and health; the construction industry is frequently viewed as being relaxed to execute ground-breaking innovations which can possibly make it more competitive, safe, and productive industry (Enshassi et al., 2016). This statement falls under the confines of the diffusion of innovation theory. LaMorte (2019) had vividly described that, adoption of innovations such as BIM does not occur synchronously in a social framework; instead, it is a cycle whereby a few individuals are more well-suited to embrace the transformation than others

## Findings and Discussion

Most BIM studies analyze critical aspects of construction safety from an individual viewpoint instead of an inter-connected point of view to identify the impact on construction safety performance. For instance, studies by Qi et al. (2011), Shih et al. (2012), Sulankivi et al. (2013), Zhang et al. (2013) and Teo et al. (2016) concentrate on designing for safety (DFS) while disregarding its inter-relationship with other fundamental safety areas such as model-driven prefabrication, workers' safety training, safety inspections and job site monitoring. Accordingly, the rule-checking systems proposed by the DFS studies appear to be limited to working on height or fall hazards. Little has been accomplished to develop rule-checking systems that address construction safety perils holistically, for instance, systems that include risks such as the 'collapse of structure or machine (due to inadequate structure), the failure of support (as a result of unsafe formwork erection), struck by moving vehicle (owing to improper planning of layout), trip and fall (on account of obstacles and uneven surfaces), crane colliding with building structure/other cranes, hit by falling objects, electrical hazard and fire outbreak (in view of unsafe means of access and egress)'.

When contrasted with other industries like transportation, finance and health, the construction industry is frequently envisioned as being slow in adopting innovations, which possess the ability to shape it to become a substantially more aggressive, secure and high-yielding industry (Enshassi et al., 2016). The situation is worse in developing countries which are often languishing on the disadvantaged side of the digital divide (BIM Africa, 2020). A study by Musyimi (2016) on the adoption of BIM in construction project management in Kenya indicated that, only 25% of construction project management practitioners had adopted BIM in their projects. This can be partly attributed to the limited nature of research on the capability of BIM in construction safety management. If firms and professionals in the construction industry are unaware of the advantages of transitioning to the new norms, views the innovations as perhaps too sophisticated for the Kenyan construction industry or perceive the employment of BIM and the related technologies as costly, they are less disposed to embrace the transformation. Architects and Engineers have been at the forefront in utilizing BIM applications such as Revit, while BIM employment in the construction stage isn't exactly as common yet. Furthermore, artisan training institutions like the National Industrial Training Authority (NITA) have not yet included such content (employment of BIM and other related technologies) into their curriculums. Another reason as cited by Mwero and Bukachi (2019) is that, in Kenya, there is no mandate governing utilization of Building Information Modeling for any type of construction undertaking. Oyuga et al. (2021) revealed that, barely four out of the forty-seven Counties in Kenya have advanced e-submission services for construction permits and they employ BIM level 0 (unmanaged CAD) which advances zero collaboration as drawings are shared in pdf format. The National Construction Authority (NCA) as well provides e-submission services for compliance certificate before construction, and it also utilizes the lowest BIM maturity level.

Kunwar (2020) disclosed that, BIM training programme was the topmost important factor for the effectuation of Building Information Modeling in developing countries. Hence, education and training show beyond doubt to be the best method of obtaining knowledge and skills to adopt emerging innovations. According to Amuda-Yusuf (2018), the three highest ranked success factors for adoption of Building Information Modeling and related technologies include: standard platforms for integration and communication to promote interoperability of data in the Architecture, Engineering and Construction (AEC) industry, cost of development (for example, cost of infrastructure to support computerization) and training of industry practitioners and company staff. A study conducted by Oyuga et al. (2021) in Kenya suggested that, a legal BIM mandate should be created and an implementation body established to govern utilization of BIM amongst building contractors.

## Conclusion and Recommendations

In reference to the scope of the study, the reviewed works have revealed that Building Information Modeling possesses the ability to shape the construction industry to become a substantially more aggressive, secure, and high-yielding industry despite its low levels of adoption. Consequently, the Kenyan construction industry safety regulators such as the National Council for Occupational Safety and Health (NACOSH) should actively review safety regulations to cater for the employment of innovations such as BIM in construction safety management. Whereas bodies such as the Directorate of Occupational Safety and Health Services (DOSHS) can formulate strategies to support the implementation of the BIM mandate in attempts to enhance construction safety performance. Besides, professional bodies such as the Board of Registration of Architects and Quantity Surveyors (BORAQS) should be encouraged to incorporate training on BIM in their 'Continuous Professional Development' programmes. Awareness of BIM through workshops and conferences should also be created as well as BIM training incorporated in the curriculum of tertiary institutions.

## Future Research Directions

This being work in progress, the study will extend this research by taking into consideration the viewpoints of construction industry professionals regarding the level of BIM penetration in building construction sites in Nairobi City County, Kenya.

## Disclosure Statement

No potential conflict of interest was reported by the authors.

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