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# BUILDING INFORMATION MODELING (BIM) TOWARDS A SUSTAINABLE BUILDING DESIGN: A SURVEY

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**ABSTRACT**

*Environmental sustainability has become ingrained in the engineering profession to mitigate the effects of climate change. In such a context, BIM provides an efficient tool that integrates various dimensions that underpin the sustainable design performance of civil infrastructure. In its current architecture, BIM is subdivided into seven dimensions being the 6th focused on sustainability. BIM is also a platform for interdisciplinary collaboration at all levels, which enables modelling, design, operation and maintenance of systems throughout their life span. Benefits of BIM include time-saving, quicker cost estimation, minimization of processes to implement changes, integrated sustainability and life cycle cost, optimization in the use of energy including through daylight analysis, thermal design, timely detection of human errors, efficient risk management, operations and maintenance, and quantity take-off during the pre-construction phase. BIM therefore enhances conventional design approaches while embedding the sustainability aspect for improved building prototyping. In the present paper, a survey review was carried out to quantify the importance of BIM for the creation of environmentally sustainable designs. The investigation also reports on a thorough review of literature to assess its viability and relevance. The scope of this paper is therefore to provide a complete overview of BIM from a research perspective.*

## 1. INTRODUCTION

The global environmental concerns have for decades highlighted major challenges to societies. The impacts of future built environments are a key consideration as stakeholders should commit to enforce sustainability across the board. The United Nations stringently promote international Sustainable Development Goals (SDG) [1]. The development of sustainable cities and communities has been identified as a key target of SDG 11 where sustainable buildings have been prioritized [1]. The sustainability of the buildings is highly based on optimal use of materials reinforced with accurate quantification of efficiency [2]. Although there is increasing pressure in ensuring that buildings are environmentally friendly, it is worth noting that sustainability is not a straightforward concept. The designs and the unique nature of each building present a major challenge towards standardization of construction procedures and proper use of energy [3]. It is acknowledged that traditional approaches of promoting the sustainability have not been thoroughly effective hence allowing a growing need of developing more sophisticated tools that optimise design. The building information modelling (BIM) technology presents one of the best ways of predicting issues, managing and monitoring projects, by utilizing visualization technologies [4]. In addition, the BIM presents an opportunity for processing a vast amount of data that informs urban developers right from the very beginning of each project [5]. The fact that the best opportunity to influence the cost and sustainability of a project is at its initial stage, this is one principal factor that makes BIM a tool of choice when embedding sustainability in a project.

The BIM tends to consider sustainability from the economic, environmental as well as the social perceptive [4,5]. At the economic level, the BIM helps in providing constant feedback throughout the lifecycle of the project. It also makes the estimation of the different costs easier, timely, more accurate and economical [6]. It is easy to perform the quantity take offs and developing the necessary cost estimates. With regard to the environmental aspect, the BIM tends to consider impacts of the various materials that are used in the construction. Overall, the BIM is seen as a powerful tool for solving the building sustainability and safety issues mysteries. It is an ideal tool for delivering the right information to designers that can also help managing building performance during their life span. The findings of the present research aim to contribute to mitigate existing knowledge gaps related to the utilization of the BIM as a tool for promoting sustainable building design [7]. Furthermore, this study aims to provide key insights to engineers, architects and other stakeholders in the building industry on how they can apply the BIM as a key tool in promoting sustainability of the future buildings and infrastructure.

## 2. LITERATURE REVIEW

### 2.1 Sustainability

Sustainability refers to the ability to meet the current and future needs amongst human generations. It can be defined in terms of three major dimensions namely, environmental, social and economic [8]. The economic dimensions revolve around reducing carbon emissions, protecting biodiversity and reducing pollution. The social dimensions consider the needs of small and large communities with focus on equity, quality of life and wellbeing [8]. The economic dimension covers the cost factor and money flow that underpin a project.

With the growing popularity of sustainability, different rating frameworks have been adopted. Amongst the popular ones we count the Leadership in Energy and Environmental Design (LEED), BREEAM, CASBEE, and Green Globes [9]. LEED is a US rating system developed in 2000 by the U.S Green building council (USGBC). The LEED was established as a rating system for design and construction practices that would help in defining the green building in the US. LEED is used in the North American Region and 30 other countries. There are more than 21,000 projects under LEED registration [9]. More in depth, LEED is based on 7 key categories of water efficiency, site selection, innovation in design, indoor environmental quality, energy efficiency as well as prioritization of the region. The BREEAM was launched in 1990 as a move towards sustainability in design. It was the first green building rating system in the world. BREEAM is a UK system that focuses on green building rating and certification. The verification process is done through independent third parties that oversee new construction and refurbishments [10,11]. It is managed by the BRE Global and its main focus is on energy, transport, water, waste, land use, pollution, transport among others.

The Green Globes is a Canadian based rating systems introduced in the US in 2004 by the Green Building initiative. It is a 1,000-point scale that uses 7 categories to classify the site, water, indoor environment, energy, emissions, and project management. The users complete a self-reported survey at the different stages of design and construction. The framework includes following-up past construction works to confirm the claims made in the original survey [10]. The CASBEE is a Japanese rating system that is made of assessment tools of the building life cycle. CASBEE rules the pre-design, new construction, renovation and interventions in existing buildings and are used in every stage of the design [10,11]. The different CASBEE tools suit a wide range of uses such as in office apartments and apartments. Furthermore, the CASBEE covers other areas such as outdoor spaces, local environment, efficiency in resources, and energy efficiency among others.

### 2.2 BIM in the AEC industry

BIM has over time emerged as a key tool in the digitalization of construction processes and monitoring of impact in the built environment. A growing number of states are proactively implementing measures to ensure the adoption

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of BIM for construction purposes and for the operation of public goods in a way that enhances the economic, social, and environmental status [12]. Charles Eastman coined the term "Building Information Model" in the 1970s, describing it as "a modelling technology and associated set of processes to produce, communicate, and analyze building models " [13]. In particular, BIM is a shared data whose domain divides into seven dimensions [14-15] as shown in Figure 1. This is discretization supports flexible lifecycle stages that align with design stages.

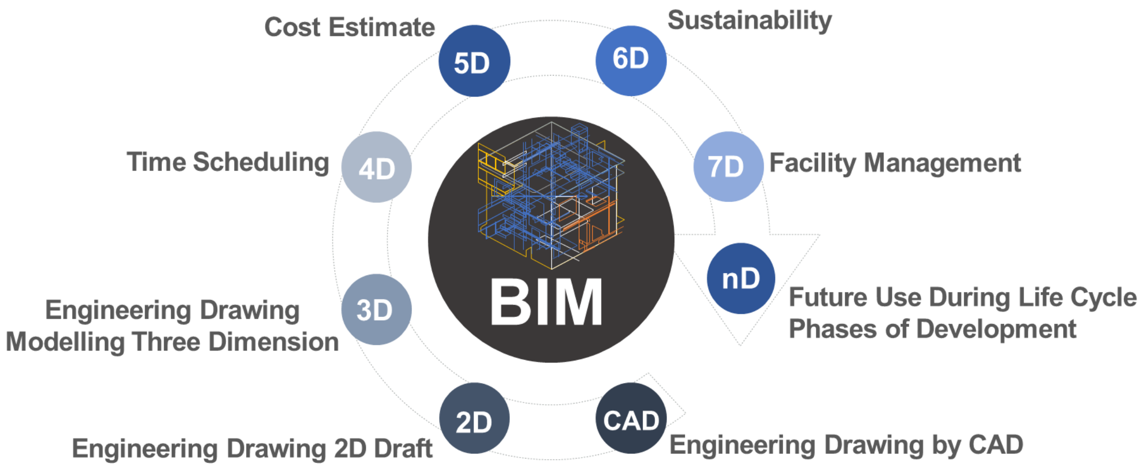


Figure 1. Dimensions BIM shared data environment.

**3. METHODOLOGY**

An extensive analysis of information drawn from past studies conducted on BIM applicability for promoting sustainability is the first objective of the present study. To achieve this, a search was conducted on the web of science database about academic publications executed between 2010 and 2021. Papers that were published in the last decade were evaluated and analysed. The search keywords utilized to collect the articles in this study are "Building Information Modelling" and "sustainability", or "BIM and sustainability buildings" and a combination of how BIM promotes sustainability, with a focus on the civil engineering field. The development of the right keywords was mainly informed by some preliminary research whereby synonyms and a combination of the keyword string were identified. The keyword research returned a massive amount of results that had to be queried based on their relevance to the research topic. Additional fields were added to refine the research. The end results were further assessed in terms of relevance through a quick scan of the abstract to confirm their relevance to the research topic.

After the identification of the key articles for the study, we proceeded to identify core information from each article to be bundled with the Metadata extraction. The extraction Metadata phase was involved in evaluating the selected articles related to the keywords that were collected because they can be used in citations as well as in the recommendation of articles. The study results, conclusions, and study limitations, will also be considered. The analysis of the key insights are useful in identifying the research gaps as well as the key areas that have been covered in the existing research.

**4. RESULTS AND DISCUSSION**

A literary search for the articles, highlighted that BIM continues being a growing field of interest underpinned by a series of publications on a range of topics of interest. The search totalized 73 articles spread in different categories as outlined in Table 1. The number of articles was narrowed down after a scan of the abstract and only 34 articles were used for the final analysis. The 34 articles were selected because they were relevant to the study and contained the right information needed for the research.

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| Field: web of science categories | Record Count | Percentage |
|---|---|---|
| Construction building technology | 42 | 57.534% |
| Engineering industrial | 9 | 12.329% |
| Energy fuels | 6 | 8.219% |
| Engineering environmental | 4 | 5.479% |
| Green sustainable science technology | 4 | 5.479% |
| Management | 4 | 5.479% |
| Computer science interdisciplinary applications | 1 | 1.370% |
| **Total** | 73 | 100 % |

Table 1 : Categories of Civil Engineering field.

of the analysis of the 34 articles shortlisted as outlined above, shows some limited applicability of the sustainability ratings described in previous sections. The number of publications involving sustainability ratings is relatively low as seen in Figure 2.

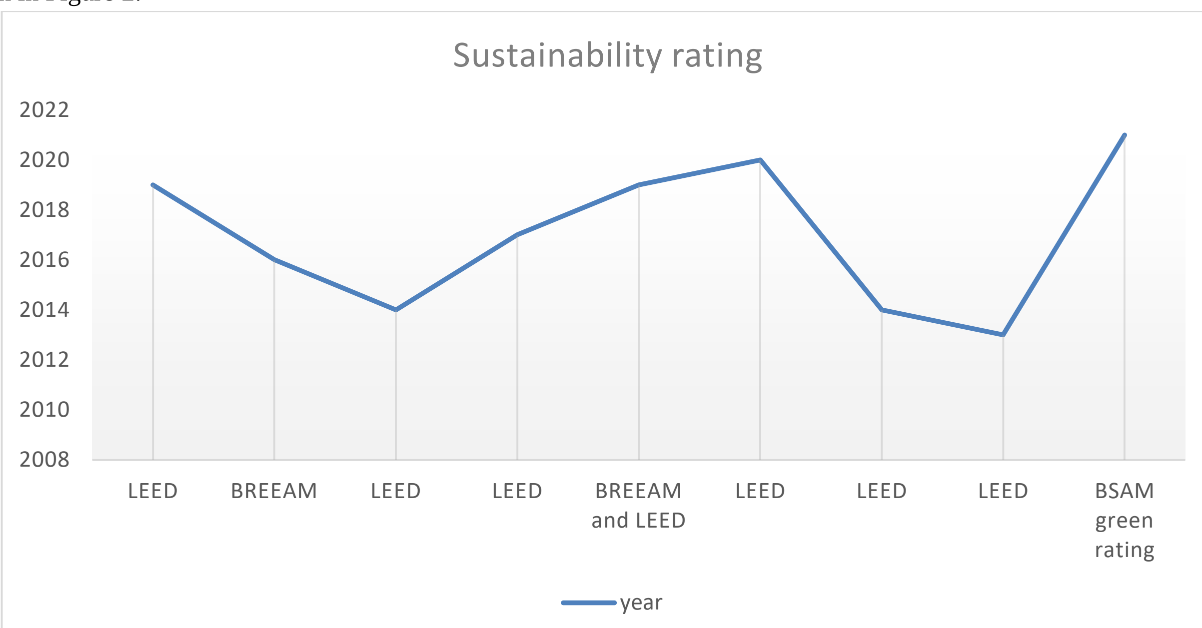


Figure 2. Sustainability rating used in publications.

The BIM is an important element in the formation of models that helps in the design of sustainable buildings. Its scope includes BIM-Based design iterations for optimizing the selection of processes, systems, techniques, and materials (PSTM) for the different building designs [16]. The usefulness of BIM can be assessed in terms of how it improves the delivery of information for improving the designs of the buildings. One of the most interesting aspects is how BIM enables 3D modelling that could help visualizing the whole process of construction plus the impact of all life stages on the environment [16]. BIM tools are also useful for assessing carbon footprint. Based on the model developed in this study, BIM enabled solutions that would in turn help with reducing energy consumption, with the above-referred visualization capabilities facilitating the decision-making process [16]. The current study intends to highlight ways in which BIM contributes to sustainability through PSTMs processes. BIM is ideal for iterating combinations and design pathways. A by-product of BIM development is that the related software could help in

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embedding sustainability within education curricula [17], see for example cases cited in [18]. In [19] the way that the selection of sustainable materials can integrate into the supply chain is presented, and hence accommodating trade-offs involving environmental and economic impacts in supply chain decisions. The BIM also supports the AEC to help stakeholders to complete the selection of building materials without human interference [20-21]. BIM-related tools can play an integral role in the selection of the best materials for any project. This was supported with automation of processes for reducing the costs of sustainability certifications e.g., by enabling certification at an early stage of the project [22].

Benefits of implementing BIM extends to the promotion of holistic design and modelling approaches spanning the whole duration of the project [22-23]. Noting that the design phase of any construction project is a key opportunity in influencing the cost engineers are keen on further developing decision support tools that would provide information at the design phase - when it is possible to accommodate given changes with minimum consequences [23,24]. It is worth to note that, BIM can be applied alongside other data modelling technique as well as for correlating BIM and sustainability ratings [24]. Table 2 provides a summary of our partial findings, based on the 34 sources of information shortlisted for the present study.

| Author | BIM software used | Rating of sustainability | Impact of use of BIM on sustainability |
|---|---|---|---|
| [24] | BIM Revit | LEED | It enabled the analysis of different energy saving solutions and enabled the achievement of the most sustainable energy solution. |
| [23] | Revit | BREEAM | BIM can help in capturing testability related information that can be used in decision making. |
| [25] | SBI tool | N/A | BIM could be integrated with BSA and LCA, and this led to improved sustainability based on local standards. |
| [26] | N/A | N/A | The BIM support various functions that are related to sustainability aspects such as energy saving, lighting, water, materials among others. |
| [41] | Revit | N/A | BIM contributed to a more sustainable built-in environment. |
| [44] | Autodesk Revit based ROI | N/A | BIM offered high rates of sustainability and, it is a formidable tool that can be used in construction of roads, bridges and other engineering products. |
| [34] | Autodesk Revit based ROI | LEED | BIM is an important tool in a achieving sustainability ratings in the US, but in the Hong Kong context BIM based BEAM only a achieved 26 out of 80 credits. |
| [36] | N/A | N/A | Implementing the BIM is one of the best ways of promoting sustainability in high rise buildings. |
| [45] | BIM related technologies | LEED | BIM improved the building rating and it also improved the sustainability reporting. |
| [37] | Revit and ArchiCAD | N/A | Offered a support system that will enable better decision making. |
| [38] | Revit and Navisworks | N/A | It allows efficient management of resources. |
| [41] | SBToolPT-H | BREEAM and LEED | BIM provided one of the best ways of optimizing energy efficiencies in buildings. |
| [27] | N/A | BREEAM and LEED | It is a suitable digital representation of a building that would help in achieving sustainability. |
| [19] | N/A | N/A | Enhanced the sustainability in the supply process of the construction materials. |
| [46] | Revit | N/A | BIM helps in introducing the development of sustainability indicators. |

Table 2 : Overview of the articles analyzed.

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| | | | |
|---|---|---|---|
| [42] | Revit | N/A | BIM capabilities enabled the integration of the BSA approaches in the BIM collaborative process and this contributed to a more sustainable built-in environment |
| [12] | Revit | LEED | BIM was found to be useful in achieving high energy savings of up to 50 percent. BIM was found to be a tool that can help in making buildings sustainable |
| [17] | BIM Curriculum Integration Toolkit | N/A | The students gained advanced skills on how the BIM tools can be applied in the construction sector to help in making decisions related to capital use and energy efficiency. |
| [30] | N/A | N/A | The BIM supported sustainability led designs |
| [11] | Green BIM | N/A | The BIM helped in the development of a sustainable built environment |
| [7] | N/A | N/A | BIM is a futurist tool that can help with the assessment of economic sustainability. |
| [43] | N/A | N/A | BIM has helped a lot in shifting the industry towards sustainability. |
| [31] | ArchiCAD | N/A | The BIM model helped in the achievement of error free energy model. |
| [6] | Revit | N/A | BIM leads to a successful environmental outcome. |
| [20] | Revit | N/A | BIM was found to be a useful tool in selection of the building components that will boost the sustainability aspects in terms of energy saving and cost reduction. |
| [39] | N/A | N/A | BIM can reduce the errors and even promote construction ability and therefore, BIM education should be promoted. |
| [40] | Autodesk Revit | N/A | The BIM environment helped in the adaptation of the formwork design and this is one factor that allowed changing of ventilation, heating and lighting. |
| [18] | N/A | N/A | BIM provides a new paradigm shift that will help the engineers and architects to visualize design models and incorporate sustainability aspects. |
| [28] | N/A | LEED | BIM offers a tool that can be used to simulate the performance of a building throughout its operation years. |
| [35] | BIM tools | N/A | BIM sustainable practices were found to be beneficial to the project itself and the construction project. |
| [29] | BIM-enabled VR technology | N/A | The BIM was found to be a useful tool for tracking the carbon footprint, reducing costs and emissions. |
| [5] | ISTRAM | N/A | BIM led to significant cost reduction when compared to the traditional approaches |
| [33] | N/A | BSAM green rating | The BIM helped in establishing a cost-effective sustainability appraisal. |
| [32] | Autodesk Revit | LEED | BIM was useful in the selection of materials and systems that were utilized in the building. |

*(N/A) is not applicable

Table 2 : Overview of the articles analyzed (Continue)

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**4.1 The integration of BIM with sustainability ratings**

According to the conducted study in [25], the building industry should contribute to the negative environmental impacts, which demands sustainable buildings. There are different methods for building sustainability assessment that are being utilized by designers in optimizing the sustainability levels of buildings [25] such as the researchers managed to create a framework that would calculate the credits earned from the building at the conceptual stage, the data was extracted from the BIM through the gbXML file format model into the energy analysis application. The Ecotect was applied in analysing the energy requirements in this study. The study linked the BIM with the certification systems at the initial stages and developed a plugin to calculate and estimate the LEED credit [47]. Other studies having the Revit Insight 360 software were utilized to analyze natural light in the BIM model by utilizing customizable and automatic configurations [12]. The developed plugin was used to analyze LEED 2009 IEQCc8 option 1 and the LEED v4 EQc7 option 2. LEED v4 EQc7 option 1 corresponded to sustainability criteria. The applicability of the BIM in this analysis is one factor that will help improve and calculate the green building certifications requirements. In addition, there has been a growing interest in the BIM application in the LEED certification systems.

The research utilized Revit software to compute the LEED ratings. The different tools were used in the creation of digital building models [12-20]. The Revit allows the users to develop and write different programs. It is possible to create and implement various applications based on the modeling environment. The modeling framework that was adopted combined the LCC, carbon footprint, and ecological footprint. The work serves as an extension of the BIM scope in the appraisal of sustainability [20]. In addition, the BEAM plus guidelines were developed using Revit architecture and all the procedures for conducting sustainability analysis were included [33]. The BIM-based-BEAM that was developed provided a new role for scheduling using Revit functions and the BEAM plus credits were documented. It is eminent that the BIM and the BEAM plus rating systems are now gaining popularity and they will help in the sustainability analysis of future buildings [33]. The BIM-BEAM integration that was developed played a key role in optimizing the existing resources and this helped in time-saving for the BEAM plus submissions.

The BIM is a tool that is mostly used in supporting the LEED assessments regarding the atmosphere and even materials [12, 40]. There has been growing interest in BREEAM integration. The BIM SB tool has been used as a method of assessment for the LEED and the BREEAM [40]. The SBTtool has also provided a generic model that is supporting different categories related to the creation of new buildings and their renovation. The SBTtool is comprehensive in a way that it supports 25 parameters three main dimensions related to economy, society, and even environment [40]. The LEED and the BREEAM are the most common sustainability assessment methods that are integrated into the BIM models. The GBAT tools help in promoting a model for assessing sustainability. It was possible to estimate the costs that are related to the LEED certifications based on the plugin that was integrated by the BIM model [44]. The BIM 3D model can be integrated with Revit as one of the sustainability tools. The plugins such as the GBS and the IESVE were easily loaded using Revit and this clearly shows the applicability of BIM in sustainability analysis [48]. In other studies, the LEED and the BREEAM were successfully integrated into EUREF HAUS 12 – 13 [48].

In addition, the role of BIM in integrating the green building certifications is well expounded in other studies. In a case study conducted in an office building in Switzerland, the BIM model was applied in the first case [49]. The model of the building was developed through Autodesk Revit 2019. BoQ data was exported with the LCA for LEED and BREEAM evaluations using the SBTtoolCZ. The LCA software supported the BREEAM and the LEED, made it possible to import data that was obtained from the BIM through Autodesk Revit. The BIM provides one of the most comprehensive databases that could inform different designs [49]. The BIM framework that was adopted was tested in a case study and it was found to be an effective tool that would help in mapping the BIM and LCA. In addition, the BIM models are useful in analysing green building performance. They are used on the energy simulations, a model for water conservation as well as in optimizing the daylight alternatives. In addition, the BIM tools also enable sustainability outcomes through prefabrications as well as simulation of constructions [49].

The researchers successfully integrated the BIM with other modules such as lighting and energy. A significant proportion of projects are currently benefiting from BIM-sustainable integration. Furthermore, the viability of applicability of BIM in the LEED, BEAM, and BREEAM was explored in detail. It was found that the BIM fully supported all requirements of sustainability.

### 4.2. Sustainable building designs and energy saving

Modern engineering practice incorporates the principles of sustainability at the initial stage, for example for designers to identify materials and components that set solid basis for achieving green building certifications [30]. BIM's integrated modelling and visualization tools are to help engineers to achieve sustainability targets [31]. Those tools allow developing design alternatives hence track evaluate different design options. Entrepreneurs also identify BIM as a useful tool that enables decision-making capturing views and comments by project stakeholders [32]. There BIM integrated with the Hong Long BEAM plus systems to support sustainability rating through well conducted strategies [33-35]. The researchers recognize BIM as a new possibility in the advancement of sustainability practices in the construction sector and recommend the applications of this technology in the design stages of infrastructure projects [35]. It also reaffirmed as a viable solution in promoting environmental sustainability in high-rise buildings [36].

The usability of BIM in promoting energy savings in the buildings is through the application of BIM 6D methodologies [41]. The model would allow the simulation of energy behaviours and feeds data for real-time monitoring of lighting and similar operations systems [42]. BIM 6D could also assist in the rehabilitation of buildings, which lately incorporates sustainable methodologies for structural interventions. The application of BIM 6D has reported a 50 % energy saving in general with 13 % of it related to savings on lighting systems [43]. The AEC sector is now embarking on a journey to achieve green buildings while still meeting the global sustainability guidelines as well as environmental and economic needs. through its multidisciplinary capabilities.
The above suggests that BIM 6D will lead future infrastructure developments as it covers all three pillars namely environmental, social, and economic [43]. This foresees more integration of 6D BIM models in all stages of the building ranging from designing, implementation, monitoring, maintenance, and even renovation [44]. With the help of 6D model buildings and infrastructure could therefore achieve sustainable performance in terms of energy efficiency and lighting. The ability of the 6D BIM to enable the designers to test the alternatives even before the project takes off is one aspect that will ensure that sustainability measures are achieved. Therefore, it is concluded that the 6D BIM holds the future of achieving sustainability in buildings and infrastructure.

## 5. CONCLUSION

The growing need to achieve environmental sustainability in the urban habitat has gained popularity among the players in architecture, engineering, and construction sector. This is because of the growing need of reducing environmental pollution and mitigation of climate change. In addition, the BIM is an invaluable tool that can integrate the design models so that sustainability can be underpinned in the construction process. The 6D BIM dimension primarily focuses on sustainability matters. The above analysis of literature shows that the BIM 6D has a positive influence on the attainment of sustainability aspects in building and construction. Furthermore, some of the elements that make the BIM 6D an alternative resource for attaining sustainability in the AEC industry are its capabilities to visualize the project before construction has commenced. It allows testing different alternatives including pre-selection of materials. The advanced capabilities enable stakeholders to comment and decide on social, environmental, and economic aspects of a project. Notwithstanding, although BIM has proved to be an important tool in promoting sustainability, there is no universal sustainability standard to date that can be applied for all projects. More research is needed to develop a standard tool that will promote sustainability in all projects.

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