Adoption of Building Information Modeling (BIM) on Construction Projects in Rwanda

Enock Musabyimana, Abedenego O. Gwaya, Titus Kivaa

***Abstract:** The construction industry is experiencing fast and adaptive innovations, new construction technologies such as 3-Dimensional printed structures using robots and different platforms are increasingly developed laid by Building Information Modeling (BIM). The technology is transforming the way that buildings and infrastructure are designed, constructed and operated and it is helping to improve decision making and performance across the buildings and infrastructure. Where BIM has not been fully applied to the infrastructure life cycle like our case of Rwanda, the industry has to undergo these technologies to be in line with others. BIM adoption on construction projects in Rwanda is an issue discussed in this study. Results revealed that only 29.1% of the total respondents were aware of BIM existence, 82.9% of those who were aware have been using it while 17.1% have not. 2D and 3D are the most frequently BIM dimensions used in Rwanda. The study validated the current shortage of building design professionals trained in collaborative design and construction practices. The study also addressed the need for BIM full adoption on construction projects in Rwanda. A process of adopting BIM on the construction project was elaborated. The Ministry of infrastructure would benefit from implementing the process for adoption discussed in this study. It was therefore recommended to fully uptake BIM on construction projects life-cycle and facilities management in Rwanda.*

***Index Terms:** Building Information Modelling, BIM Adoption in Rwanda, Construction Projects, Construction Technology.*

I. INTRODUCTION

The construction sector plays a major role in the economic and social development of Rwanda and substantially contributes to 51% of the total of industrial GDP [1]. Due to this role that the industry plays, the government of Rwanda developed supporting policies to encourage and facilitate the development of the sector [2]. Rwanda is a country with limited resources, to ensure its development, it is essential to invest in appropriate technologies. Worldwide, Communication and documentation within the construction industry has to be improved, it is better to mandate appropriate process of adopting new technologies such as Building Information Modelling (BIM), an intelligent 3D model-based process that gives AEC professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure for the purpose of visualization, engineering analysis, conflict analysis, code criteria checking, cost engineering, as-built product, budgeting and many other purposes [3].

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As going hand in hand with new technologies is substantial for any construction project delivery, the study focused on investigating the current level of use of BIM in Rwanda, and elaboration of a process that could enable the industry to adopt and implement the technology on its construction projects life-cycle and facilities management as well.

II. BACKGROUND

In addition to the country's limited resources, lack of full adoption of appropriate technologies in the construction industry is continuously affecting the development of the sector. Besides, the current shortage of building design professionals trained in collaborative design and construction practices remains a barrier to universal adoption of collaborative working practices in the industry. Neither research conducted on the need and use of BIM nor a process elaborated for its adoption on construction projects in Rwanda. The main objective of the study was to investigate and address the need of adopting BIM on construction projects in Rwanda. The Specific objectives of the study were to explore of the current level of BIM usage, to examine of benefits and barriers due to use of BIM, to highlight experts' views for enhancing BIM adoption, and to elaborate of a process for BIM adoption in Rwanda. Thus, this study brought together ideas of key players comprising registered professionals comprising of construction project managers, engineers, architects, quantity surveyors, and urban planners in order to get their concern on how BIM can impact the industry and rate technological implementation related barriers.

BIM as modern technology might be considered as the best initiative within the construction industry and has been thriving for the industry with the aim of improving the cooperation and collaboration between involved parties during the realization and maintenance of construction projects [4]. Due to lack of BIM practices in Rwanda, this research examined the extent BIM is used by in the construction industry and a process of adoption in Rwanda was elaborated. Specifically, Ministry of Infrastructure, private and public institutions, investors, partners (non-government organizations, donors), contractors, consultants, higher learning and citizens of Rwanda in general would benefit from this research through being aware of BIM need, impacts and barriers, and a process of applying the model on construction projects life-cycle and facility management. In order to get more insights about BIM adoption process and practices, it was crucial to explore and understand how other countries have implemented them through review of literatures.

III. LITERATURE REVIEW

A. History of BIM

The concept of BIM has existed since the 1970s, the idea was conceptualized and initially called the Building Description System (BDS) [5]. Graphisoft developed early system solutions longer than the competitors in the market and was responsible for ArchiCAD, which was then one of the most mature BIM solutions in the market; it was regarded as the first BIM implementation in 1987 and was the first CAD product on a personal computer able to create 2D and 3D geometry, and the first commercial BIM product for personal computers [5]. Autodesk became the to the top of BIM deal when it acquired Revit in 2002, late in 2012 also developed FormIt, a mobile-based application that enables the conception of BIM model on portable devices [6].

B. Global trends in BIM Uptake

BIM is currently hailed as a solution that will eventually make collaborative working a reality, the UK Government has recently announced that BIM would be compulsory on all public sector projects from 2016, in addition, the Ministry of Justice announced in April 2011 that contractors on its framework should use it by the middle of 2013, therefore, there have been strong push for the industry to adopt BIM but very limited appreciation of the issues that need to be resolved, e.g. cultural, procedural, contractual, process-related, so that BIM becomes the vehicle for collaboration [6]. A Survey conducted on the usage of BIM and IFC revealed that compliant applications stood at 33% and that 93% and nearly 60% of architects and engineers respectively, used BIM in some parts of their projects, and 50% of architects, 29% of clients and 40% of engineers used BIM for some parts of their projects in 2008. In January 2007, Denmark launched an initiative called Det Digitale Byggeri which means Digital Construction for mandatory use of BIM in government projects [6] , while these countries have already established BIM mandatory requirements, Morrel reported that the UK's first BIM mandatory requirements would come into force in 2016 [7], nearly 9 years later as argued by Wright, despite immense benefits of BIM already noted in these countries, and others, industry experts have often argued that BIM only becomes a vehicle to delivering better value if parties truly collaborate [8].

C. BIM Levels

GenieBelt argued that on any construction project, there are commonly four (4) different levels of generating and exchanging data known BIM maturity levels [9]. They vary based on the increase of parties involved shared collaboration. The first is the BIM level zero or low collaboration, which is the simplest step of the information generating process because it doesn't practically involve any level of cooperation (CAD drawings are used during this level, but there is no sharing of the generated information models) [8]. The second is the BIM level one (partial collaboration), which focuses on the transition from CAD to 2D and 3D pieces of information where a large number of companies are at the moment conducting their work on the partial collaboration level using online shared tools [8]. The third one is the BIM Level two (Full Collaboration), here the main focus of interest on this level is the way in which the information is shared across the various project members and collaborative working is at the core of BIM Level 2 [8] And the fourth one is the BIM Level 3 (Full Integration) which is the ultimate goal for the construction industry, its main point is the attainment of full integration (iBIM) of the information in a cloud-based environment. This will be achieved by the use of a common shared model [8].

D. BIM Dimensions

Goubau defined BIM dimension (nD) as the capacity or ability of a specific BIM product or platform to process attributed data (inputs) in order to achieve useful information (output) [5], nDs are ultimately digital files that describe every aspect of the project and support decision-making throughout a project cycle as argued by Arnal (2018), BIM has been thought that is nothing more than 3D modelling but it actually involves more than that in the past 20 year [10]. BIM and the subsets of its systems and similar technologies feature more than just 3D (width, height, and depth (shape)) but include further dimensions such as 4D (time), 5D (cost), and even 6D (as-built operation or performance), 7D (sustainability), and even 8D (safety), the ninth dimension is about introducing Lean Management Philosophy into Building Sector, it is all about integration of Emergency Reponses into the designs, the tenth dimension is to industrialize construction and transform the construction sector into a more productive sector by integrating the new technologies through its digitization [11] [5] [6].

E. BIM Tools

Karul et al. argued that it is imperative to understand the technological, practical and methodological challenges impeding the uptake of BIM so as to provide a way forward for its full-scale adoption [13]. A review of the different BIM tools was undertaken; what makes BIM unique, is a representation of a design as an amalgamation of objects (meaning that any change of the object automatically affects the design), BIM tools allow the extraction of different views from a model for production of drawing among other things. There are plenty of BIM products, some of these products was identified such as Revit, Microstation, Allplan, Bentley Building Suite, AutoCAD, Vectorworks, ArchiCAD, Trimble SketchUp, and so many others. Some of these them are integral and capable of scheduling, cost estimation, modelling, analyze, and design.

F. The uses of BIM

A BIM Use can be defined as a method of applying BIM during a facility's lifecycle to achieve one or more specific objectives [7]. A survey was conducted in 2009 to help determine the frequency by which organizations use each BIM use and the benefit to the project of each use. While the BIM uses of 3D coordination an design reviews were both the most frequently used and most beneficial based on the survey results, all of the Uses in the survey are being used to a degree on projects and are perceived beneficial [8].

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Based on phases of project development, 25 BIM uses were identified through a number of interviews with the industry experts [14]. Penn State argued that the majority of the survey focused on one two-part question [15]. First, how frequently does your organization use each BIM uses defined in the BIM Project Execution Planning Guide? Second, what is your organization's perceived level of benefit to the project for each use? The first portion of the question gave the response options of 0%, 5%, 25%, 50%, 75%, 95%, and 100%, while the second portion of the question gave the response options of very negative, negative, neutral, positive, and very positive.

G. BIM benefits and challenges

BIM plays a significant role in the construction industry and its benefits are not limited to the actual building, infrastructure, and their construction simulation, project management as well, but also to sustainable attributes and processes such as faster and more effective processes (Information is more easily shared and can be value-added and reused, better design (building proposals can be rigorously analyzed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions), controlled whole-life costs and environmental data: environmental performance is more predictable, and lifecycle costs are better understood, better production quality (documentation output is flexible and exploits automation) , automated assembly (digital product data can be exploited in downstream processes and used for manufacturing and assembly of structural systems), better customer service (proposals are better understood through accurate visualization, lifecycle data (requirements, design, construction, and operational information can be used in facilities management), an so many others [19]. Goubau argued that in a case study of 32 major projects, Stanford University's Center for Integrated Facilities Engineering reported the following benefits in statistical data (CRC Construction Innovation, 2007), up to 40% elimination of unbudgeted change, cost estimation accuracy within 3% as compared to traditional estimates, up to 80% reduction in time taken to generate a cost estimate, a savings of up to 10% of the contract value through clash detections, up to 7% reduction in project time [5].

Findings of Howard & Björk revealed that companies that are using BIM technology are finding difficulties like, for example, the lack of communication between those involved in the design and in the construction, the need for new professionals in the application of BIM context should be recognized by the industry [17]. There must be a special role in the project team: the BIM Manager and the cost of hiring of that professional is a small investment if compared to the potential benefits of using BIM [18], in addition the BIM Manager, depending on their main functions, also have been named as Information Manager, Virtual Construction Manager, Virtual Architect/Engineer, Digital Contractor, Digital Project Coordinator, BIM Champion, IDS Champion Administrator, 4D Specialist, Building Modeler, Model Integrator, BIM Integrator, BIM Coordinator, BIM Leader, Modelling Manager, among others [20].

H. BIM Risks

Azhar addressed the risks involved in BIM implementation that can be divided into two categories comprising legal (or contractual) and technical. Legal risk is when there is a lack of determination of ownership of BIM data and the need to protect. The technical risk is when the cost and schedule are added as additional dimensions onto the building information model to ensure responsibility for proper technological interface among different programs that becomes an issue as well [20].

I. Opportunities in BIM

BIM is a promising future wherein buildings, design and construction will be cheaper, safer, more efficient, and more responsive to end-users that presents several opportunities in its adoption such as automating design optimization, where computers will be able to automatically sort through thousands of possible design permutations and select the top designs that meet a project's requirements; thus, computers are going to be able to design things so much more efficiently than humans can. BIM can provide the industry with important opportunities to raise the quality of the industry to a much higher and sophisticated level [11].

J. BIM Policies

Sometimes, even those who want to embrace BIM-friendly processes can't because of company policies where legal departments are a common obstacle and contracts in many instances fail to keep up with emerging technologies [25] [9] [26]. Mostly, BIM works best when all parties working on a project can share information freely, contracts, however, often forbid such information sharing due to liability and litigation concerns, for example, if a contractor acts on information an architect supplied and something goes wrong, the contractor or project owner could then sue the architect, it is therefore obvious that solutions must simultaneously protect companies while encouraging them to collaborate, all parties can agree upon definitions, processes, policies, and parameters at the start of every project; doing so will reduce risk while streamlining the workflows BIM relies on [26] [27].

K. BIM in Climate Change Mitigation and Adaptation

Climate Change and the resultant need to drastically reduce carbon emissions across the Globe (while adaptation measures are also vital), had long been acknowledged as key challenges to industries before the unprecedented global economic crisis started to overwhelm major economies in 2008. It was reportedly argued by Skanska and Statsbygg, and Nyári that buildings contribute 40% of global carbon emissions, adequate processes are required to cut-off these emissions since it is used to calculate and evaluate the footprint of these emissions [28]. Therefore, we can't hesitate to state that BIM is a vital mechanism through which targets to lessen emissions can be achieved up to 50% of reduction in greenhouse gas emissions in the built environment [12], every industry has been forced to re-think its processes and practices to deliver efficiently. BIM has numerous uses that are effective to climate change, hence, adopting BIM could further contribute to climate resilience through optimized designs and green building development.

The technology offers improved visualization & productivity due to easy retrieval of information, increased coordination of construction documents, embedding & linking of vital information such as vendors for specific materials, location of details and quantities required for estimation and tendering, increased speed of delivery and reduced costs. With the development of modern computer technology, a large number of building energy simulation tools are available, when choosing which simulation tool to use, the user must consider the tool's accuracy and reliability, there was developed an artificial intelligence approach towards assessing building performance simulation results and found that more detailed simulation tools have the best simulation performance in terms of heating and cooling electricity consumption within 3% of mean absolute error [32].

L. Influence of BIM on Big Data

A higher demand for data will emerge within the construction industry and more effective managing of big data will change the way many of the professionals within construction (example: contractors, engineers etc.) are working [14]. Therefore, BIM will offer remarkable help in handling vast amounts of data and shall be integral with block chain or smart contracts systems.

IV. RESEARCH METHODOLOGY

Questionnaires was the main tool to undertake the data collection process for this research and was designed based on a status quo of BIM level of use and awareness in the construction industry in Rwanda especially in the city of Kigali and particularly intended to acquire the main objective of the study by answering the questions derived from it. The questionnaire was divided into various sections that focuses on fundamentals for BIM awareness and its adoption in Rwanda. It was designed to target knowledgeable, experienced, and suitably qualified individuals who were currently engaged in implementation of construction projects in Rwanda. Hence, the information that had been evaluated was reliable since it had been extracted from a reliable source of knowledgeable respondents.

Respondents included registered professionals involved in planning, design, construction and operation of country's infrastructure such as construction project managers, engineers, architects, quantity surveyors, and urban planners in different public, private, contracting and consulting companies or institutions. According to the list of registered and compliant professionals from Institution of Engineers Rwanda (IER) (2019) and Rwanda Institute of Architects (RIA) (2019) were 270 and 67 respectively. Construction project managers were few and recognized by IER while quantity surveyors and urban planners were recognized by RIA. The Sample size was estimated based on a proportion where it was calculated with an approximate 95% confidence level, the following formula was used:

$$n_{ir}=(z^2\ p*q)/d^2 \quad [15]$$

Where z=1.96 at 95% of confidence, nir = initial required sample size, q = 1-p, p = proportion of the population having the characteristic, and d = the degree of precision. The proportion of the population (p) is unknown from prior research or other sources; we used p = 0.5 which assumes maximum heterogeneity. The degree of precision (d) is the margin of error that is acceptable. Setting d = 0.08, for example, would give a margin of error of plus or minus 8%. Thus, it was found 150 respondents needed. Since the sample size (need respondents) is smaller than the population, the sample size as increased by 10% for compensation to the missed values due to non-responded questions. Therefore, nir, the number of needed respondents became 165. Considering N, the total distributed sample size, the sample size was distributed as 5 construction project managers, 127 engineers,17architects, 10 quantity surveyors, and 6 urban planners.

Data analysis consisted of examining and summarizing data with aim of extracting useful information and develop conclusions. Data analysis comprised of preparation of preliminary plan of data analysis as checking questionnaires; a questionnaire returned from the field may be unacceptable for several reasons. Editing and treating of unsatisfactory results (returning to the field or assigning missing values or discarding unsatisfactory respondents). A code was assigned, usually a number, to each possible response to each question. The code included an indication of the column position (field) and data record it occupied. Recording and data transcription involved transferring the coded data from the questionnaires or coded sheets directly into Microsoft Office Excel. Data cleaning consistency checks -data that were out of range, logically inconsistent, or had extreme values were identified and treatment of missing responses.

V. RESEARCH RESULTS AND FINDINGS

Results revealed the lack of awareness of BIM existence and insufficient use of BIM in the construction industry in Rwanda. The study validated the current shortage of building design professionals trained in collaborative design and construction practices. The study also revealed the need of BIM full adoption on construction projects in Rwanda. To support the research objectives, the study brought together ideas of different key players, their concerns and recommendations on how BIM do impact the construction industry as well as barriers were recorded. Furthermore, the research addressed the following:

(i) The extent which BIM is used on construction projects in Rwanda was explored. Results showed that only 29% of the total respondents were aware of BIM while 71% were not (see figure 1), and 82.9% of these who are aware have been using it while 17.1% of them have not.

(ii) Benefits and barriers due to use of BIM in Rwanda was examined. Based on the statistics of the respondents who were qualified to reach and answer this section, different benefits and barriers were listed. The fact that BIM allows accurate site logistics plans, easier quantity take-off and time scheduling and greater productivity due to easy retrieval of information were chosen as the most probable benefits while lack BIM training, the need for suitable data sharing standards, unawareness of benefits BIM can bring to organization and insufficient skilled personnel was ranked as the most barriers to implement BIM in Rwanda.

(iii) The experts' views regarding enhancement of BIM adoption in Rwanda were recorded as highlighted, comprising BIM dissemination and training, include BIM uses in the tender document as a requirement in order to win a public contract, make BIM mandatory to all professionals involved such as engineers and architects, development of BIM usage related policies: The Ministry of Infrastructure and other institutions involved in construction rules and regulation implementation should introduce a policy that strongly support the use BIM in Rwanda, and so many others.

(iv) A process that could be followed to ensure BIM is fully used on every construction project in country was elaborated as shown in figure 2. The outlined process consists of encouraging design and construction professionals to use BIM, BIM courses and training, ICT infrastructure, BIM authoring software and process, advocacy to policy & decision makers to include the usage of BIM in tenders, ToRs & Contracts, establishment of policy and legal framework (laws, regulations, & standards), dissemination, enforcement (Government, Industry, private sector), strategic implementation, sustainability (evolving, customization, upgrading as per users comments, modification, …), and scaling-up.

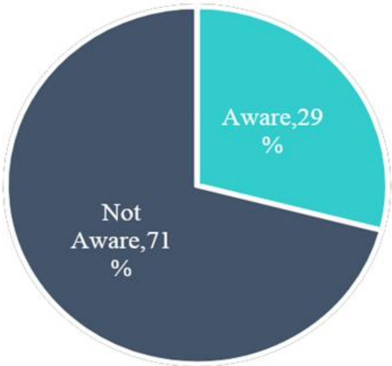

Figure 1: BIM awareness in Rwanda
Source: Field Survey, 2019

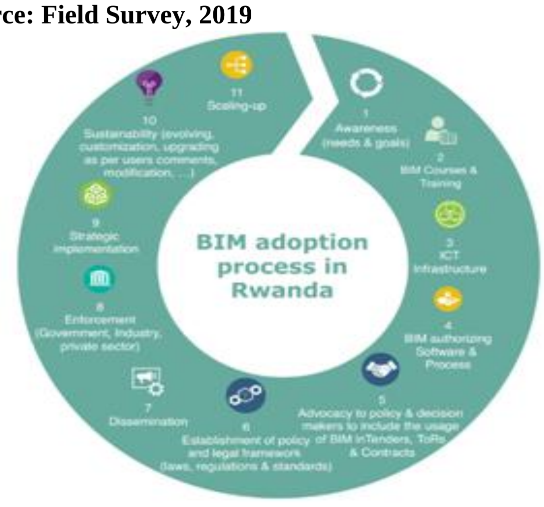

Figure 2: BIM adoption process in Rwanda
Source: Author, 2019

VI. CONCLUSION

This research had brought together awareness on BIM need in Rwanda with aim of exploring the level of use, addresses related benefits and barriers in country, and a process of adoption which the industry can opt to increase its sustainable development and for the country as well. It was agreed that there is need of raising BIM awareness and provide trainings to construction and design professionals in Rwanda. As the best technology that emerges, BIM is used on most of construction activities in both developed and developing countries, this research explored impacts and challenges that the industry experiences due to BIM implication on construction projects life-cycle in Rwanda. Implementing BIM on country's infrastructure planning, design, execution, operation, and facilities management is vital to boom the Rwanda's construction industry in Rwanda. It was recommended to the Ministry of Infrastructure, Institution of Engineers Rwanda, Rwanda Institute of Architects, and other institutions involved in developing infrastructure in Rwanda to substantially intervene in mandating the use of BIM on country's infrastructure life cycle. Mandating BIM involves elaboration of new rules and regulations regarding BIM implementation on country's infrastructure considering existing BIM related policies from software authoring companies such as Autodesk, Graphisoft, Tekla and others. Involved stakeholders should also stress on preparing tenders or Terms of References (ToRs) that focus on using BIM during setting consulting and contracting works. Contracts should also contain articles that highlight the obligations of contractors or/and consultant to fully BIM for a specific assigned construction or consulting work. It was also recommended to infrastructure development stakeholders to value and refer to the suggested BIM implementation process as highlighted in this study. Furthermore, we recommend the use of BIM during the procurement and logistics (supply chain management) processes in Rwanda.

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