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Quantity Surveying and its Association with Building Information Modeling (BIM) and Digital Twin (DT)

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Abstract:
Quantity surveyors (QS) have many roles in the construction industry, and one of such roles is preparing bills of quantities that mainly entails taking measurements and costing construction work. They also develop project schedule, engage in construction project management, arbitration as well as dispute resolution. Quantity take-off was their original role during 1820s when QS profession first came into existence. Critical observation brought criticisms that the profession would not survive if a tool could be developed that substituted QS roles in construction. Contingent to that criticism has seen the emergence of Building Information Modeling (BIM) that has specific attributes where the BIM technology can be used to quantify building works and produce schedule of work including cost loaded schedule in a 4D and 5D model interface respectively. Thus far, has the BIM technological innovation posed threats to the QS roles and/or to the profession? What of digital twin (DT)? The aim of this research was to investigate the QS and its association with BIM and DT innovation in the construction industry and to evaluate their future in the industry. Are they a bane or boon to the QS profession? Specific objectives were to determine the extent of BIM usage by QS, the level of the current usage and the future of QS considering BIM growth in the construction field. Strength, Weakness, Opportunity and Threat (SWOT) analysis was conducted about BIM usage. Survey questionnaire was administered to investigate the use of BIM and DT, current usage and future standing in construction. The results showed that BIM and DT were opportunities that added to the progress of QS. It was concluded that QS needed to embrace BIM technology more with integration of digital twins for full benefits in the construction industry.

Keywords: building information modeling (BIM), construction industry, digital twin (DT), quantity surveying**.**

1. Introduction

Quantity surveyors as professionals in the construction industry are involved in various aspects of project costs, cost control and overall project management duties. Their specific roles are required right from the project design phase, construction phase to maintenance and operation phases of the project; even to the demolition or deconstruction stage in the overall life cycle of a project (Wao, 2023). Alhasan et al. (2019) reported that the quantity surveyor is a professional who on behalf of the project owner, herein referred as owner's representative, is professionally trained, qualified and experienced in many aspects or project cost, construction project management detailing, and streamlining communication in project. The QS has different names in the global hemisphere whereupon they are construction estimators or cost engineers in the United States of America (USA), building economists and construction managers in some parts of Africa, Asia and United Kingdom (UK), and their roles in construction projects have been developing and increasing changing over the years (Wao & Flood, 2016; Wao, 2023).

Considering when it was first conceived in 1820s, the QS profession has evolved steadily from when the main roles were taking measurements of work to now where they are needed in almost every phase of the project life cycle (Wao, 2015). At those beginning times, most of their work used to be manual and relied on two dimensional (2D) drawings to calculate quantities of work (quantity take-off), and to prepare bills of quantities (BOQ) as part of project contract documents. At some point along the timeline, it was thought that

any tool that would be developed to better calculate and measure work would be a threat to the QS profession and possibly make it out-of-date in the construction industry, but it seemed to have remained firm in the construction field despite the odds (Wao, 2015).

As the demands of the project owners increase and its position in the construction industry becomes more significant, QS has taken many roles such as cost planning, measurement and quantification of construction work, cost control and has been throughout the whole project life cycle, and also offering financial advice and management, procurement advice to clients, among other more significant roles in projects, (Gilchrist et al., 2021). According to Fung et al. (2014), the services offered by the QS can be tedious, and ineffective especially if they involve a lot of information as characterized in large projects. Therefore, the QS had to find ways to keep up with the increasing needs, improvements, developments and to maintain importance and relevance in the construction industry.

The advent of information technology (IT) and effective communication processes have provided clear opportunities for the QS. Their role in representing project owners of construction and also acting as a link among professionals in projects and acting as a manager of all aspects of a project required them to improve significantly so that they are better placed to serve the field in a more improved fashion. Various areas or phases of a project might require principles of Value Engineering (VE), Lean Management, Sustainable Construction, Building Information Modelling (BIM), Internet of Things (IOT), Digital Twins (DT), Artificial Intelligence (AI) or ChatGPT. These concepts have been prevalent lately especially in industry 6.0 and they could have potential applications in the construction industry where the QS can possibly use them as opportunities to improve and in marketing themselves as key professionals to handle them when needed in construction for the benefit of project owner. For example, research on BIM has shown that BIM has presented challenges and opportunities for the QS especially in the design stage of construction (Gilchrist 2021). Also, Smith (2014) showed that BIM is not a threat but rather an opportunity for QS to provide better value services and improved efficiency in projects for the benefit of project owners.

Despite the idea favouring the use of BIM in construction projects, the application has been quite slow with some QS professionals preferring to employ traditional methods to accomplish project work in place of the state of the art approaches developed currently. Some have not embraced BIM because of its high cost which is hindering everyone from its full execution in projects (Gilchrist et al., 2021). Even more in question is the application of digital twins in construction since it depends on BIM platform or interface.

Therefore, this research examined the quantity surveying profession and its association with BIM and digital twins in the current construction industry. There is research already in the area but the IT area is ever fast changing and this can significantly impact the construction field within a small time frame, and so this research informed prior research by assessing the QS field taking into consideration the current IT uses mainly focusing on BIM and DT. Literature review section assessed the QS profession in relation to integrating BIM and DT in construction projects.

2. Literature Review

2.1 Quantity surveyor as a professional in construction project

Quantity surveyor has strategic roles in projects in the construction industry. They oversee everything in the project life cycle. That is, they are involved in every aspect of the project from preconstruction, construction, closeout, and during operation, maintenance to demolition or deconstruction especially if the focus in a project is on sustainable construction. Their roles revolve around quantity take-off, preparing bills of materials, scheduling of construction project work, dispute resolution arising in project, project waste management, preparing bidding or tender documents, and also act as project owner's representative (Wao & Flood, 2016).

The profession is popular in the UK, Africa, Asia and Australia where they have various project responsibilities which typically go beyond cost estimating as in the USA where they may be referred to as cost engineers, project estimators, cost manager or construction project accountant. Noteworthy is that the Royal Institution of Chartered Surveyors (RICS) has popularized the QS profession with various chapters all over the world which are signified by distinct professional certifications and memberships (Wao & Flood, 2016; RICS, 2024).

In providing the various roles, the QS has experienced many challenges and these include competition from other construction professionals such as civil engineers, building engineers especially in the professional fees and the terms of services offered, project owners increasing demands which results in excess pressure to them, general misconception that QS lack awareness for project value addition, and the current trends in construction such as sustainable construction and rapid technological advances which threaten to reduce QS roles (Gilchrist et al., 2021). Studies on the challenges faced by QS and avenues for them to improve on project deliveries to remain relevant and competitive has shown that BIM is top in the opportunities in the construction industry (Alhasan et al., 2019; Wao, 2023). Professional organizations such as RICS have put in place the various competency requirements of QS to improve on the value addition in projects. RICS (2024) provide basic competencies which QS must meet before engaging in projects and these including having good understanding of professional practice and procedure, information and business skills, measurements and law. Core competencies requirements such as quantifying and costing of building works by preparing BQ, contracting and construction economics and preparing accurate financial accounts for improved project budget, are competencies specific to improving QS skills and roles in projects. Optional competencies such as value engineering, risk management, BIM, research methods, arbitration and dispute resolution are considered specialty areas and provide avenues for future career development and opportunities for QS to improve further.

The influx of IT in construction has seen BIM as an area for continuous professional development (CPD) for the QS, similar to digital twins in the current wave of developments in the construction industry. These may provide strengths and opportunities for value addition services for the QS (Wao, 2023).

2.2 Quantity surveying profession and building information modeling (BIM)

The QS provides information about the project whether on procurement, cost, time, safety, and beyond the 'triad' to include sustainability and lean. These require providing information quickly for project success. This success depends on the QS meeting the project goals efficiently. As noted by Alhasan et al. (2019), the success criteria in projects could be linked to the time, cost, safety, performance or quality requirements which are the key parameters for measuring project success over its life cycle.

The use of BIM by the QS has been investigated as potential avenue to improve productivity and efficiency of service delivery of QS. Wao (2015) study on predicting the future of QS in the construction industry noted that BIM had potential for being used largely by the QS for successful project deliveries.

With BIM in focus, it is envisioned to be a collaborating process among construction teams where they can exchange digital data of a project for eventual coordination and project success. That is, BIM is a technology and a set of processes to create, communicate and analyze building models or data in a way that is replicating (in digital format) what is to be constructed (Eastman et al., 2012). Those involved could be QS, engineers, architects, contractors, project owner, among others. BIM provides them with three dimensional (3D) modelling of the project and they could input time in the model, hence called 4D, which also imply a 3D model with scheduling component added to the project model to estimate time to construct each element. A 5D model, which is a cost loaded BIM 3D model is where cost component has been added which means that the model does not only show the geometry of the building consisting of length, width and height (3D) but also shows the cost estimates of each building element which can lead to accurate cost control, budgeting and overall project management processes and procedures. Others from 6D to 9D BIM could incorporate sustainability, facility management, safety and lean management (for project process optimization and waste management) in that order respectively. These can be integrated in 3D BIM. Therefore, BIM can greatly improve project quality by providing an overview of a project in a way that project data interchange is effectively communicated among construction project teams.

With the IT BIM skills, the QS skills is expected to be improved in areas such as cost estimation, team communication, VE, lean management, project management, etc. In this case, using BIM by QS has been investigated especially in areas of estimation, quantity take off and planning where it has been found that it can be a good value addition in projects where it provides accurate cost information through application of the most effective quantity take off tools over the life cycle of a project (Alhasan et al., 2019). Even though this is an opportunity for QS, BIM presents challenges especially in the early stages of a

project, i.e., in its design stage. Noteworthy is that many QSes are still behind in understanding BIM application in projects, and therefore, they are strongly encouraged to embrace the technology if they would like to get the most benefits in construction. As noted by Alhasan et al. (2019), it is important that the project designs be detailed to replicate the actual project. With this, it is obvious that BIM would not get accepted by project owners and representatives if the designers do not provide detailed digital information that is useful to the project team over the project life cycle. As noted by Fung et al. (2014), there are several benefits of using BIM from preconstruction to post-construction during operation and maintenance periods, and these include speedy preparation of cost information at conceptual stage, providing initial or conceptual cost data by extracting quantities from BIM models, generating cost information for different design alternatives for value engineering studies, reducing design errors and cost revisions through clash detections, better 3D project visualization for improved design understanding, removing manual measurements and quantity take-offs, acting as project information management, among others. These benefits can be avenues for marketing the QS with other professionals that maybe in competition with them (Wao and Flood, 2016).

Noteworthy is that BIM is a multi-dimensional construction tool that is promising to the QS since it can provide value addition to project owners. This promise could be construed to be farfetched because of lack of skilled personnel that understand BIM workflow, high cost of implementing BIM considering the high cost of the hardware/software and related training, and most importantly, lack of higher management or leadership support that are usually reluctant to embrace or support the technology (Gilchrist et al., 2021).

2.3 Building information modeling (BIM) and digital twin (DT)

Another area of IT that has been on the rise recently is the Digital Twins (DT) technology. BIM is utilized in the design and construction stage of projects while DT, which can be applied in the operation and maintenance phase of a project, has the potential to shape a DT-enhanced BIM framework to fully enable whole life cycle digital/virtual construction (Honghong et al., 2023). Essentially, it can be construed that DT is a living version of projects that BIM create from conceptual designs. Figure 1 shows the distinction of the two terms, i.e., BIM and DT.

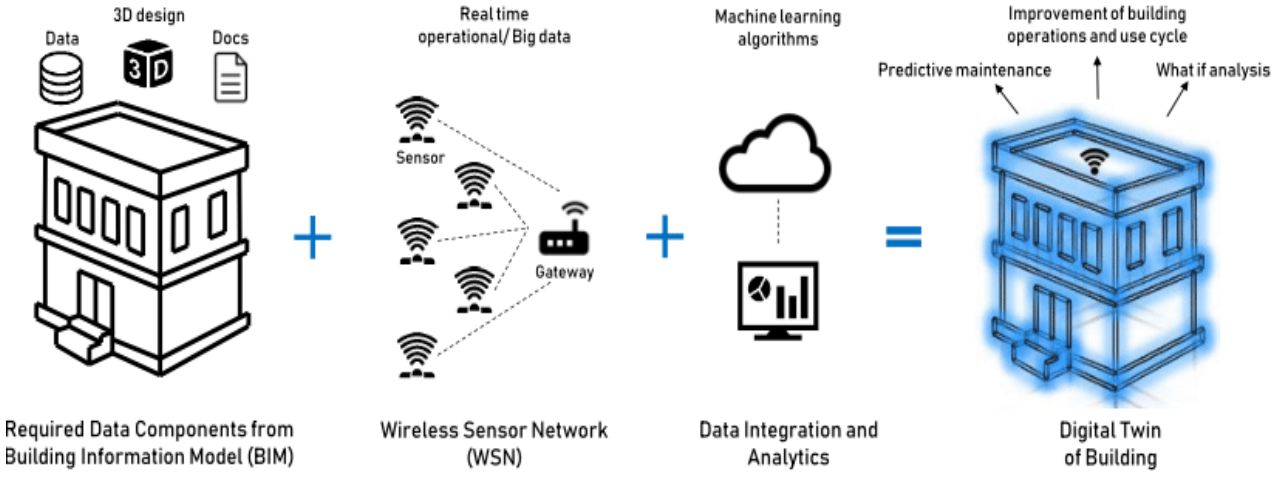

Figure 1: Creation of digital twin of a building and the difference with BIM (Khajavi et al., 2019).

Digital twins (DT) refer to replication or digital mirror of the actual project which can mimic all aspects of the physical processes under the integration of the physical project details, virtual details as well as connection data between the physical and virtual project (Pan and Zhang, 2021). Khan (2020) states that a digital twin, which links digital models and simulations with real-world data, can establish avenues for improved creativity, competitive leverage, and human-centered designs. Khajavi et al. (2019) states that the concept of a digital twin has been used in some areas to develop accurate digital model of the equipment for the purpose of predictive maintenance. As stated by Pan and Zhang (2021), DT can combine BIM, Internet of Things (IoT) and data mining techniques whereby IoT connects the physical world and the internet/cyber world to capture real time data or information for building modelling and related analysis, and data mining

methods incorporated in virtual building model is focused on discovering hidden knowledge in the collected data or information (see figure 1). This process can be done in the whole building life cycle, and so BIM based digital twins is a possible inclusion in the operation and maintenance of the construction world because it would be useful to see how the building operates in a virtual world, and the construction team is able to identify errors and correct them before damages occur. See figure 2 for details of the whole life cycle process involving the use of BIM and DT.

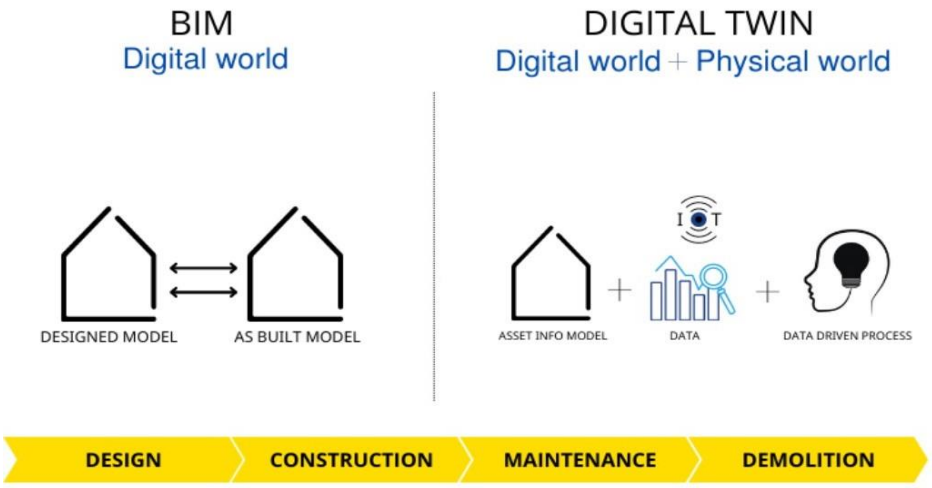

Figure 2: BIM vs Digital Twin (Biblus, 2024).

This is why DT (initially proposed in 2003) was used by National Aeronautics and Space Administration (NASA) to simulate, forecast and evaluate spacecraft state with the aim of stopping potential dilapidation or failure of aircrafts. Just like lean management, VE and sustainable development, the concept of digital twins can be integrated in the construction industry to improve processes and hence project success and value addition is realized for the benefits of the project owner.

Pan and Zhang (2021) researched about building a data driven DT framework with BIM for advanced project management. Honghong et al. (2023) discovered that the adoption of DT in bridge engineering caused confusion which hindered the DT fusion to achieve its full capability and so their study focused on a DT enhanced BIM framework to shape full life cycle digital transformation for bridge engineering. And there could be other various ways by which BIM can be integrated with IoT and Artificial intelligence (AI); even with the current ChatGPT based on bot. Noteworthy, these studies show the value in integrated BIM-DT in projects but there is still lack of relationship between them. BIM has operational standards but not DT. This is an area for QS to venture into for full use of BIM-DT enhanced interface for improved project operations and maintenance. Therefore, this research focused on examining BIM and DT innovations and the association with the QS profession. The following was the research methodology employed.

3. Research Methodology

This research set to investigate the association between the quantity surveying profession and BIM and digital twin innovations in the construction industry. Are they a bane or boon to the QS profession? The specific objectives were to determine the extent of BIM and DT usage by QS, the relationship between the current BIM and DT usage and the future of QS considering their possible growth in the construction industry. Strength, Weakness, Opportunity and Threat (SWOT) analysis were conducted about BIM and DT through literature reviews. Survey questionnaire was administered to quantity surveyors to explore the current BIM and DT usage and their future standing in the construction industry.

3.1 Survey questionnaire and administration

Survey questionnaire was used to gather the views of the respondents about QS involvement in the construction industry and their ideas about BIM and DT technologies. Emphasis was placed on their knowledge and use of these technologies in projects.

Before the administration of the survey questionnaire, five (n = 5) quantity surveyors were requested to be a part of a pilot study that focused on testing the validity and reliability of the questionnaire question items. Cronbach's alpha statistical test tested the reliability of the question items, and the result showed an alpha estimate of 0.95 which meant that that the survey questionnaire items were well written and were well understood, and so they were going to get the required feedback which adds into the research validity. Also, consent to conduct research with human subjects was sought and granted by the Institutional Review Board (IRB). This is a requirement for any research involving human subjects where researchers must seek informed consent of the participants before taking part in the research.

The questionnaire consisted of multiple-choice and open-ended questions. A section of the questionnaire focused on demographic information such as work title, number of years in the field, being a project owner representative, role in projects, knowledge about BIM and DT and possible uses of these tools in projects, and their level of utilization in projects in terms of project budget. The other part required the respondents to rate their current level of satisfaction with using BIM in their projects/company on a five (5) point Likert scale (1 = not rewarding, 2 = neutral, 3 = somewhat rewarding, 4 = rewarding, 5 = very rewarding). In addition, they were asked their opinion about the overall growth in the usage of BIM in the next 10-15 years on a similar scale (1 = not improve, 2 = neutral, 3 = somewhat improve, 4 = improve, 5 = improve highly). Finally, they were to give reasons for the growth (or not) in the given future time range.

3.2 Sample size and data synthesis

The study utilized 128 quantity surveyors who completed the survey. This sample size (n = 128) was considered adequate for statistical analyses and tests for adequate statistical power. SAS on Demand (2024) was used for quantitative data analysis which was mainly descriptive statistics. The descriptive statistical analysis utilized the measures of central tendency that mainly comprising of mean/average values. The main purpose of the analysis was to determine the level of satisfaction with the current state of BIM and DT use and to provide ideas for growth in future. Qualitative data were gleaned and assessed by content analysis.

4. Results and Discussion

4.1 Demographics and level of experience in the construction industry

Majority of the respondents were directors, senior quantity surveyors, senior cost managers, and professors. This shows that the sample was from a population that held leadership and managerial roles in construction. Out of the sample, 93% were males, 3% were females and 3% preferred not to say their gender. This outcome leads to a deduction that the QS field is male dominated and so it is important to encourage other genders to get into QS. Table 1 shows their levels of experience in years.

Table 1: Level of experience in the construction industry (N = 128).

Years	*2-10 years*	*11-20 years*	*21-30 years*	*Over 30 years*
Frequencies(*f*)	10	30	40	48
Percent (%)	8	23	31	38

The results showed that about 92% of the respondents had over 10 years of experience where about 70% had over 20years of experience with about 40% having over 30 years of experience, and so it was prudent to conclude that the majority would provide invaluable ideas in regard to the BIM, DT and the construction industry since they were rooted in the field with many years of experience.

They were mainly involved in commercial construction projects (32%) and residential construction projects (38%) with industrial and heavy civil projects accounting for 18% and 12% respectively. About 60% of the respondents had been project owner's representatives. Their roles included cost planning and control, contract administration, construction management, project management and integrative delivery partnerships, and consultancy. These roles aligned with those in the study by Wao and Flood (2016). About 95% of the respondents were registered with professional organizations and they mentioned that the benefits

tied to their registrations and memberships were for idea/information sharing and networking, CPD, and being recognized as professionals by their peers and the institutions they are in as part of their profession.

4.2 Knowledge and familiarity with BIM and DT, and respective uses in projects

Regarding knowledge and familiarity with BIM, about 85% of respondents stated that they were familiar with the term with about 50% having first heard of BIM from reading while about 30% got to know BIM first from taking courses and about 20% hearing it first from their routine job training as part of their continuous professional developments (CPD). It can be concluded that avenues such as CPD and academics need to be used more to disseminate BIM knowledge to construction professionals especially QSes.

Noteworthy is that this familiarity and knowledge was not for long term use in projects. About 40% of the respondents had used BIM in their construction projects, and from those who had used it in their projects, 75% of them had used BIM for about 2-5years with about 20% having used it for 6-10years and the rest (5%) having used it for less than 1 year. This states that BIM usage by QS was still in its infancy and needed to be embraced more for increased use in the construction field. For those who had used BIM in projects, about 55% had used it in 2-5 projects, 30% for 6-10 projects while 15% had it in over 20 projects. Again, this shows that a few embraced BIM for use in many projects.

Of those who had used BIM in projects, about 42% had used it in the design phase, 30% in the construction phase, 15% in facilities management and 4% in the deconstruction phase. Others (10%) used it in university training course. This implied that a few people got involved with BIM training in the academia. Noteworthy is that it was used in the facilities management and deconstruction phase which is an opportunity to integrate DT with BIM since DT is used more in the operation and maintenance phase.
When asked about the various aspects of project they used BIM in, Table 2 summarized the details.

Table 2: Usage of BIM (N = 128).

Item	*Frequency (f)*	*Percent (%)*
Quantity Take off	29	23
Estimating	22	17
3D building simulation	19	15
Clash detection	23	18
Scheduling	13	10
Project presentation	10	8
Waste management	4	3
Sustainability	8	6

Table 2 shows that majority used BIM-5D for QTO and estimating (and costing) but also for the other extended versions like 4D for scheduling, 6D for sustainability to 9D for lean construction, and these opened up various applications and opportunities for QS. Also, about 15% of the respondents had used BIM in projects worth $2millions-10 millions, 20% in $11-50millions, 30% in $51-100millions worth of projects with about 35% in projects over $100 million. Table 3 showed the summary.

Table 3: Usage of BIM in projects (N =128).

Project Value on Average ($)	*2 -10 millions*	*11-50 millions*	*51-100 millions*	*Over 100 million*
Frequency (f)	19	26	38	45
Percent (%)	15	20	30	35

It can be deduced from Table 3 that BIM was used mainly in large projects to drive the return on

investment (ROI). In these projects, about 85% of the respondents mentioned benefiting from using BIM with some experiencing difficulties in using it. Some stated that BIM software were expensive with deep learning curve. This aligned with the study in the literature review which stated some of the hindrances to the BIM adoption by the QS. Also, some respondents cited getting 'buy in' from all the supply chain, information overload for some of the parties and too many revisions to drawings as some of the problems in BIM usage which also aligned with other viewpoints from the literature review. Also, some stated that there were few BIM operators which called for more training of BIM professionals in the industry. A notable one stated that some design consultants fell behind with regular uploads of their developing models making them not able to be clash managed prior to tendering, and this resulted in change management and additional costs in the post contract phase. This posed serious problems which needed to be addressed for efficient adoption and further integration with DT.

On the topic of digital twins, only 28% were familiar with DT. Of those familiar with it, 35% had heard about it from taking a course and from reading respectively while 10% from colleagues and from job training. When asked if they had used DT in their projects, only 15% reported to have used it. When asked if DT and BIM could be related, about 70% thought that they were related. This provided opportunity for training on BIM and DT integration in construction. Majority of the QSes were not familiar with it, and so training and CPD, possibly by RICS, could have these put in the core competencies for the QS so that it is one of those skills that they must equip themselves with while providing their routine value addition services to the project owners.

4.3 The current status and future of BIM and DT for QS

When asked about rating the current use of BIM in their companies, about 62% of the respondents thought that it was rewarding with about 30% being neutral and about 6% on the somewhat rewarding range while about 2% stated that it is not rewarding. A reported average score of 4.2 meant it was rewarding on a 5-point Likert scale. The same percent scores were seen when asked for the level of satisfaction with the current use of BIM in their companies with a mean score of 4.3 was reported implying being satisfied on a 5-point Likert scale.

For the growth in usage of BIM in projects in the next 10-15years, 75% believed that it would greatly improve, 8% were neutral while 17% thought it would somewhat improve. So about 92% of the respondents believed that BIM would be improved in future and this could provide a greater opportunity for QS to grow or flourish. This aligned with Wao (2015) that also noted BIM for greater use in future. Some viewpoints of the respondents for the future of BIM alluded to the BIM technology evolving with great potential for improvement, more contracts requiring BIM uses, and the fact that BIM was increasingly getting adopted in projects with more innovations and applications expected in years to come. These also showed positive development of BIM which could also align with DT as well as opportunities for QS to diversify their skills and roles in construction projects in future.

5. Conclusion

This research used survey questionnaire to investigate the association the QS has with BIM and DT technologies, and to determine the breadth of current usage and future standing of these technologies in construction especially for the QS. Strength, Weakness, Opportunity and Threat (SWOT) analysis was conducted on BIM. It was found that BIM had not been fully embraced within the QS profession and the few who had embraced it had not employed full potential of BIM in construction projects. DT as integrated with BIM was also not popular in the QS field and was not applied fully in projects. As such, the QS field needed to recognize these as opportunity and to integrate full use of these two increasingly developing technologies to enhance value addition in projects, and also to develop professionally so they can provide needed services in the construction field.

The contribution of this research is closely aligned to the body of knowledge that focuses on the application of IT in the construction industry with special emphasis on BIM and DT. The use of BIM had shown that it was rewarding to the QS, and BIM was expected to improve in the next 10-15 years with integration of DT as a part of it.

6. Future Research

Future research could focus on DT and its application in the construction industry especially in the operation, maintenance and deconstruction stage which focuses on closed loop system or circular economy under sustainable construction.

References

1. Alhasan, S., Omar, A., Michael, T., & Bimal, K., (2019). Effectiveness of adopting BIM on quantity surveying profession during the project life cycle, In THIRTY-FIFTH ANNUAL CONFERENCE, p. 273-282.
2. Biblus: What is a digital twin? Examples and tips in construction. Accessed from https://biblus.accasoftware.com/en/digital-twin-what-is-it/ on December 15 2024.
3. Eastman, C., Teicholz, P & Sacks, R. (2012). BIM Hand Book, 2nd Edition. Chichester: J Wiley.
4. Fung, W., Salleh, H. & Mohd ,F. (2014). Capability of Building Information Modeling Application in Quantity Surveying Practice. Journal of Surveying, Construction and Property, 5 (1)1–13, doi: 10.22452/jscp/vol5no1.4.
5. Gilchrist, C., Cumberlege,R. & Allen,C (2021). Lack of implementing Building Information Modelling in the quantity surveying profession. IOP Conference Series: Earth and Environmental Science, doi: 10.1088/1755-1315/654/1/012025
6. Honghong, S., Gang, Y., Haijiang, L., Tian, Z. & J. Annan, J. (2023). Digital twin enhanced BIM to shape full life cycle digital transformation for bridge engineering. Automation in Construction, 147. doi: 10.1016/j.autcon.2022.104736
7. Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmström, J. (2019). Digital twin: vision, benefits, boundaries, and creation for buildings. IEEE access, 7, 147406-147419.
8. Khan, R. A. (2020). Using Sensor Data from Building Automation Systems in Digital Twins Nutzung von Sensordaten der Gebäudeautomation in Digitalen Zwillingen (Doctoral dissertation, Faculty of Civil Engineering, Institute of Construction Informatics, University of Technology).
9. Pan, Y. & Zhang, L. (2021). A BIM-data mining integrated digital twin framework for advanced project management. Automation in Construction. doi: 10.1016/j.autcon.2021.103564
10. Royal Institution of Chartered Surveyors (RICS, 2024). https://www.rics.org/profession-standards (Access date: 12.11.2024)
11. SAS® On Demand for Academics (SAS, 2024). Retrieved on December 13, 2024 from https://welcome.oda.sas.com/
12. Smith, P. (2014). BIM and the 5D Project Cost Manager. Procedia - Social and Behavioral Sciences, 119, 475–484. doi: 10.1016/j.sbspro.2014.03.053.
13. Wao, J.O & Flood, I. (2016). The role of quantity surveyors in the international construction arena. International Journal of Construction Management, 16, 2, 126–137 doi: 10.1080/15623599.2016.1142251.
14. Wao, J. (2015). Predicting the future of quantity surveying profession in the construction industry. Journal of Construction Project Management and Innovation, 5 (2),1211-1223: https://hdl.handle.net/10520/EJC183324
15. Wao, J.O. (2023). Effect of building information modeling(bim) innovation on quantity surveying. Proceedings of the Creative Construction Conference 2023. https://doi.org/10.3311/CCC2023-035