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DOI:
10.1088/1755-1315/1196/1/012111

Adopting BIM to Enhance Sustainability. The Saudi Arabia Construction Projects case study

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Abstract. Building information modelling (BIM) has become an efficient tool to contribute more effectively to achieving sustainability development goals. BIM utilities have progressively revealed efficient environments to share data amongst stakeholders. The present paper aims to evaluate levels of awareness around BIM capabilities amongst engineers and project managers, focusing on the Saudi Arabia construction industry. The study targeted individuals registered with the Saudi Council of Engineers until the year 2020, who were invited to engage with a questionnaire survey. The study targeted individuals registered with the Saudi Council of Engineers, who were invited to engage with a questionnaire survey. A sample of 940 participants was taken by the survey out of a total population of the study of 55776 engineers whose responses materialised in a robust statistical analysis. According to the survey, 61% (circa 572) have developed awareness of BIM, whereas 39% (368) confirmed that they had never heard of it. A descriptive Statistics framework with the aid of SPSS has been developed to complete the statistical study. Analyses of data indicated that the benefit of using BIM is significant in the broad sustainability realm, Life Cycle Cost (LCC), operations and maintenance, efficient use of energy, daylight analysis, thermal design, and transparency in cost.

Keywords: Sustainability, BIM, Adopting of BIM, Awareness of BIM.

1. Introduction
During the past few years, the construction industry has experienced rapid growth, and the trend is expected to continue. This growth requires infrastructure to cover the needs of all sectors of society, which has inevitably had a significant environmental impact. Current statistics show that approximately 40% of the primary energy is used in the construction sector, and 80% of the energy is used in building operation [1] which identifies the construction industry as a major source of greenhouse gas emissions reaching approximately 36-38% globally [2].

On the other hand, the Saudi Arabian economy growth recorded during the first decade of the twentieth century has encouraged investments in construction. As reported by [3], Saudi Arabia's government has increased the productivity of the construction industry trough housing and infrastructure development, while sustainability of buildings is highly dependent on material's efficiency, as reported by [4]. There is therefore an increasing pressure on building owners to ensure their buildings are sustainable and compliant with building standards. Standardisation of procedures for ensuring sustainability is challenging due to the unique design and nature of each building. This has required the adoption of BIM for integrating aspects of sustainability in economics, the environment, and society.

Building Information Modelling (BIM) has contributed to shape modern construction. It allows architects and engineers to digitally blueprint buildings and effectively allocate resources. In BIM, the entire project life cycle can be visualised from the planning and construction stages to demolition and renovation, which enables integrating quantity estimation and quantity take-offs, modelling, budgeting, time planning, programming, and site analysis. BIM can thus assist with the planning, coordination, and design, and inform further documentation for procurement and tendering [6,7,8]. This holistic approach stimulates safe construction activities by enabling identifying possible errors before works on-site begin. This minimises costs, increases productivity, and enables managing financial and legal risks [9,10,11]. These attributes have been highlighted by researchers [12] who state that BIM's virtual environment allows implementing geometric and spatial and geometric information from various sources, including properties of building components, that inform costs estimation inventory and schedules required for in-depth planning and executing of construction. Its core functionalities enrich with 3D rendering, fabrication, collision detection, and forensic analysis through graphical illustration.

This study aims at evaluating BIM adoption and acceptance levels in Saudi Arabia, based on a questionnaire survey that captures opinions of Saudi engineers. The study extends to quantify knowledge and awareness contractors on those benefits and importance of BIM with regards to enhanced sustainability required to tackle global challenges nowadays.

2. Literature Review
The construction industry, as other productive sectors have benefitted from technological advancement that have led to development in terms of automation and digitalisation, which has increased productivity. It is thus intended to analyse the literature on the adoption of BIM in the construction industry as well as highlight advantages and challenges that project managers face when implementing BIM technologies in Saudi Arabia.

2.1. Concept of building information modelling (BIM)
BIM enables virtual modelling in the digital construction of buildings through graphical tools and utilities. It is nowadays considered one of the major contributors in architecture and engineering as it allows producing digital blueprints of buildings and allocate resources through various configurations, until optimisation is achieved. This is the narrative established by researchers such as [13] that states that digitalised building construction method serves different purposes, such as planning, designing, operations, and construction activities. Furthermore [12] indicated that the virtual environment created with BIM characterises the spatial information, properties of the building elements, cost estimation,

geometric and geographical information, inventory, and schedule that are used in an in-depth understanding of construction from the planning stage. According to the systems theory, there are different characteristics associated with a complex system, such as interrelation among the functionalities that create dedicated outputs [14], which effectively utilises all building components to direct the outputs which maximises the possibility of achieving sustainability targets. [12] connoted that cost estimation is a significant functionality of BIM that allow project managers to put together appropriate budget estimations, which in turn help to avoid budget overruns. For example, Revit is a tool to support BIM in construction that helps in the successful execution of projects in different geographical positions and situations. According to the systems theory, Revit is used to analyse project requirements of complex projects to identify the required resources. In Saudi Arabia, BIM software in construction activities is adopted due to its capabilities for smart development that permeate the construction sector worldwide. Accordingly, BIM integrates several dimensions which can be used to quantify the extent of its adoption in projects. Those dimensions are shown in Table 1 [15,16].

Table 1. The data sharing environment for Dimensions BIM.

BIM	Key properties	Model characteristics
2D	2D basic documentation	Initial construction models containing simple images
3D	3D dimension models	The project can be visualised in 3D
4D	Programming time	The execution plans Simulate the project phases
5D	Cost estimation	The expense budgets The operating cost
6D	Energy efficiency and sustainability	Analysis of the energy consumption Sustainability analysis
7D	Management of the facility	The maintenance and operation The life cycle analysis of the project
nD	The life cycle phase	Future work and development

2.2. Adoption of BIM in the construction industry

According to [5], traditional construction activities is affected by recurrent issues like human errors, time-taking secondary activities, and inaccurate or missing cost estimations due to the improper illustration of the activities to be executed. In this context, digital illustration of the construction is beneficial. According to [17], the use of BIM in construction projects in Saudi Arabia has been stimulated due to its capability for illustration of the site map, architecture, plot number, location, a position through software and proper estimation of the geometric conditions, as well as for proper visualisation of road maps needed to develop evacuation of wastewater and the establishment of transportation links. It stimulates architects to further develop creativity, for example by being able to revisit designs to improve the compatibility and standards of living. The counterbalance of those improvement, according to [12], is that the emergence of technologies in different industries increases steps in construction processes due to quality assurance and health and safety requirements that must be observed.

A global survey to try and establish the impact of emerging technologies in construction yielded the following. Approximately 40% of Icelandic engineers use BIM [18]; by 2007, the Norwegian and Danish governments had requested the adoption of BIM in all projects [19]; three McGraw-Hill reports indicate that the use of BIM increased significantly between 2007 and 2009 in the United States, with 75 per cent of projects altogether [18]; similarly, Singapore adopted BIM in public projects since 2015 [19]. In addition, the Australian government adopted BIM in 2016 without interfering with industry procedures or technical details [18]. [20] states that the official use of BIM to manage projects has boosted its use through the world. For example, by 2050 the UN report predicts that the world population will reach 7.9 billion, and therefore the construction sector must transfer information and data to digital formats. Figure 1 illustrates BIM's global rate of expansion.

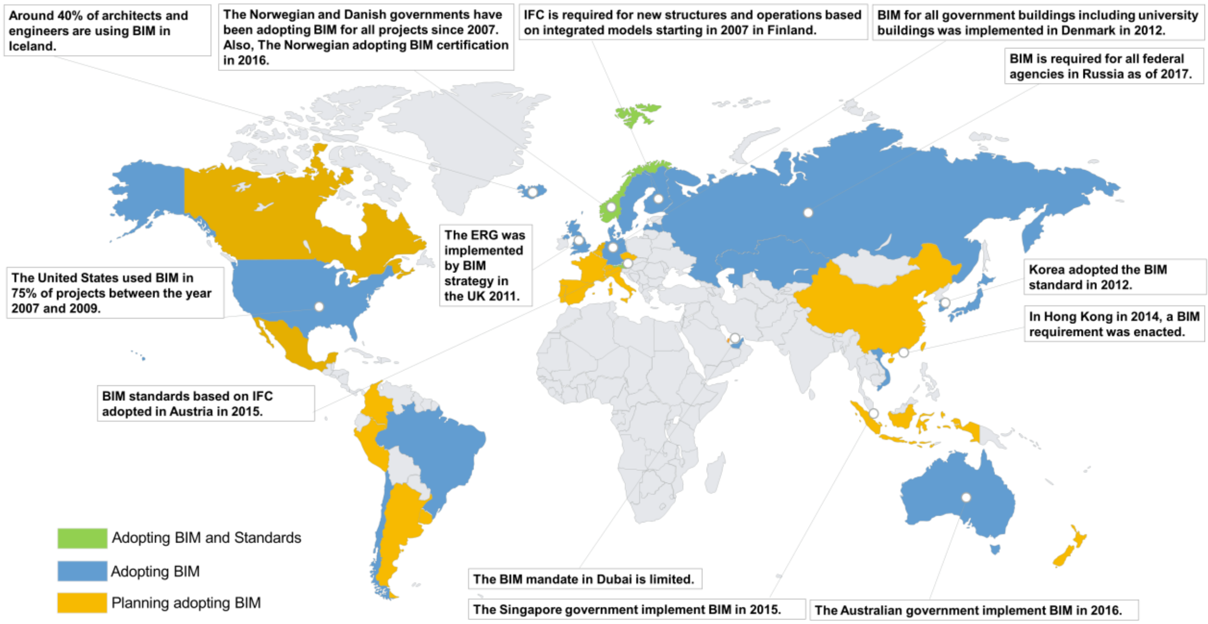

Figure 1. A global overview of BIM adoption. [20]

2.3. Benefits and challenges associated with BIM

According to [5], the improvement of on-site collaboration using BIM tools allows workers to access detailed information of the project and the activities assigned to individuals. For example, the BIM 360 tool of Autodesk is a cloud-based BIM tool that helps to integrate collaboration among all the disciplines of the project [21]. Furthermore, [13] identifies model-based cost estimation as an additional benefit as it allows project managers to eliminate the chances of budget overrun. The benefits add visualisation tools for preconstruction, where 3D projection and the space-use simulation allow the clients to make changes as required before starting the project. The virtual modelling capabilities also help to decrease production costs by identifying possible errors during planning stages therefore increasing productivity through proper forecasting that informs the decision-making.

The identified benefits of BIM [4,22-29,39]. [30] includes the gathering of information for the preparation of demolition pre-audits and the alignment of coordinates generated by separate components of design (including those considerations by subcontractors), which helps to import quality materials for improving the strength of the building. Prefabrication is considered another significant benefit of using BIM in construction, where the production drawings along with the databases are easily generated to maintain detailing, remove wastage, and reduce costs. It appears that sustainability enhancements are generating additional economic and environmental developments [31]. It was found in [32] that integrating BIM and value engineering can optimise the building envelope from the perspective of energy efficiency. Furthermore, BIM visualisation features can be used to engaging clients in the whole lifecycle of the building [33]. Specifically, [4] advocates for ensuring that sustainable building plans reduce total lifecycle costs.

The counter side of adopting BIM points towards the contrast between large and small projects in large projects technology is considered cost-effective investment as it helps to save money due to optimised resource allocation and inventory costs. However, in the context of small projects, the costs of hiring BIM experts and other implementations increase the overall budget, which might cause a challenge of budget overrun. Therefore, these challenges are required to be acknowledged by the project managers of different small and large projects to successfully utilise the functionalities of BIM and sustain operational efficiency. It is also important to note that although BIM has demonstrated potential in the construction sector, it has limited applicability in the demolition and refurbishment of buildings. As it stands, the overlap and sharing of information across several experts, the concept of BIM presented numerous challenges. Even so, this challenge led to the discovery of critical problems, faults and overlaps between the different engineering disciplines during the design process.

3. Methodology

A quantitative research approach involves generating numerical or statistical data to support a hypothesis deductively [34]. Several methods are used to administer the questionnaires, including mail, one-on-one, and online, to ensure that the data collected is relevant to the research question Similarly, questionnaires are labelled as closed-ended, open-ended, and mixed [35]. The speed at which questionnaires in addition to being inexpensive can be collected is regarded as one of the major advantages of using them, [36]. Some argue that the larger the sample, the better, as it not only facilitates more complex statistical analyses, but also improves reliability [37].

3.1. Questionnaire survey description

Saudi Arabian engineers have been surveyed to determine their level of awareness of BIM. To this end we developed a questionnaire to be taken by a random sample extracted from the local engineering community. This complemented with a field survey among Saudi engineers registered with the Saudi Council of Engineers. To estimate the size of the referred sample we followed the criteria suggested by Yamane (1967:886):

- **Calculating the sample size:**

$$\boldsymbol{n} = \frac{N}{1+N\times(e)^{2}}$$

$\boldsymbol{n}$ = The sample size.
N = The population size
e = Confidence level (1- percent confident)

The Saudi Council of Engineers has registered approximately (55776) Saudi engineers by 2020, which represents the total size of the population in the engineering sector. The sample is equal to 55776 while we establish a margin of error of 5% to reach a confidence level 99%, so (656) respondents are required. For some questions, the relative importance index (RII) will be used to determine an order of effectiveness using the following equation [38]:

- **Relative importance index** $\boldsymbol{RII} = (\sum \boldsymbol{W}) / (\boldsymbol{A} * \boldsymbol{N})$

W = The weighting given to each element by the respondents (from 1 to 5).
A = The highest weight.
N = The total number of respondents.

A team of experts validated the content of the survey questions to ensure these questions did cover the topics that define the scope of our study. The actual survey was thus preceded by several stages including its development, validation and pilot testing.

3.2. Survey campaign

Participants received a link sent by email to their individual address or via the Saudi Council of Engineers, which helped to promote and distribute the survey information amongst Saudi engineers. To ensure clarity in the terminology, we create a separate questionnaire using a Google Form to map English to and from Arabic. In compliance with the University of Birmingham policy, the questionnaire went through standard procedures for ethical approval, holding the registration number ERN-20-0402. The survey results were statistically analysed using SPSS software. This enabled to determine the level of awareness of the BIM dimensions listed in Table 1, as well as the enablers and constraints associated with the use of BIM technology in government projects. The study also attempted to quantify the extent to which BIM technology has been adopted in the region. The information returned through the survey also allowed to learn what other software is currently used during the design and construction phase of major projects, as well as its compatibility with BIM.

4. Results and discussion

The questionnaire remained open three months. We received 996 replies to the initial survey request out of which 94% per cent (940) agreed to engage and 6% declined. In the actual survey, the Saudi engineers were asked whether they knew about BIM; 61% (n=572) responded they were familiar with the system, while 39% (n=368) were unfamiliar, see Figure 2. Figure 3 shows the histogram of the participants' occupations, so we confirmed that civil engineers made up the majority of the participants with 286 (30.4%), followed by architects 194 (20.6%), electrical engineers 135 (14.4%), mechanical engineers 118 (12.6%), project managers (heads) 61 (6.5%), facilities managers 12 (1.3%), quantity surveyors 4 (0.4%), and some other occupation 111 (11.8%).

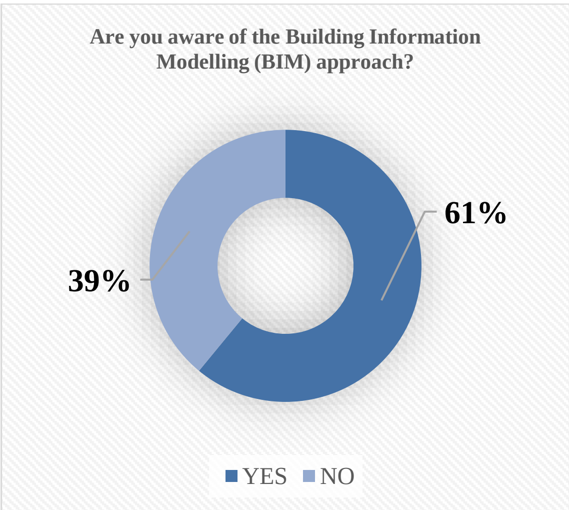

Figure 2. The percentage of KSA respondents who are aware of BIM.

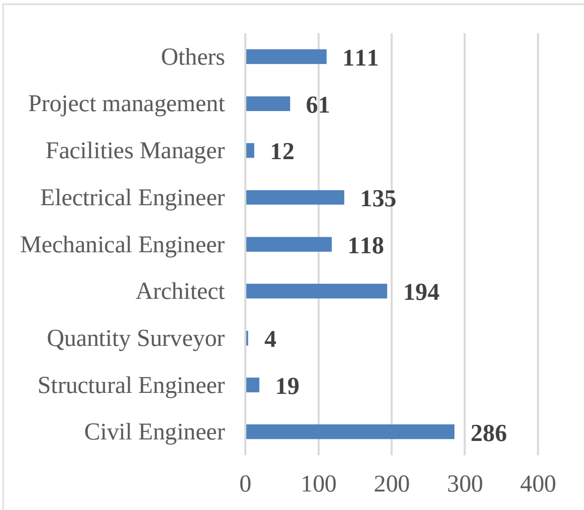

Figure 3. A description of the professions of respondents.

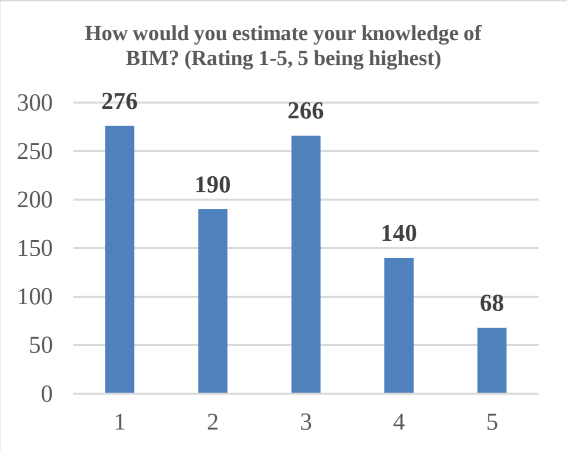

Figure 4. Level of estimating the knowledge of BIM.

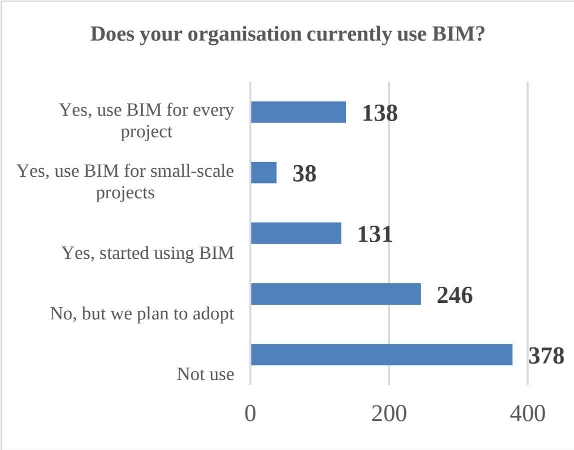

Figure 5. The use of BIM in the organisation.

Figure 4 shows, in a scale of 1 to 5, how much survey population estimate their BIM knowledge. This yielded as that a minority rated high (level 5) n = 68 (7.2%), whereas at the other side of the scale we recorded n=276 (29.3%). Figure 5, shows that 246 engineers (26.2%) reported that their organisation does not use BIM but plans to adopt it, whereas 386 (41.1%) responded that their organisation does not utilise BIM. Additionally, 138 (14.7%) indicated that their organisation used BIM for all projects, 131 (13.9%) indicated their organisation began utilising BIM, and 38 (4%) indicated their organization implemented BIM only for smaller projects.

Figure 6 depicts the level at which organisations have adopted BIM. The most common BIM level in the KSA is CAD, with 403 (42.8%), followed by 3D in second place with 315 (33.5%). Despite its capabilities, 6D remains relatively weak, reaching only n=19 (2%). Figure 7 provides more details on preferences. It is estimated that most engineers (n = 613, 65.2%) like BIM and plan to continue using it. Meanwhile, 209 (22.2%) are hesitant, 54 (5.7%) are unhappy with BIM and consider not using it, and 6.8% are unsure.

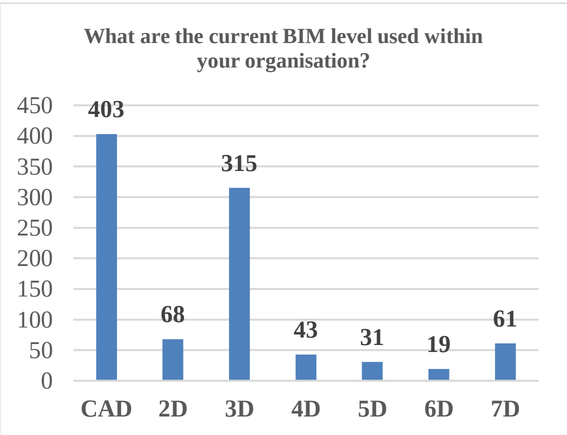

Figure 6. Level of BIM adoption in the organisation.

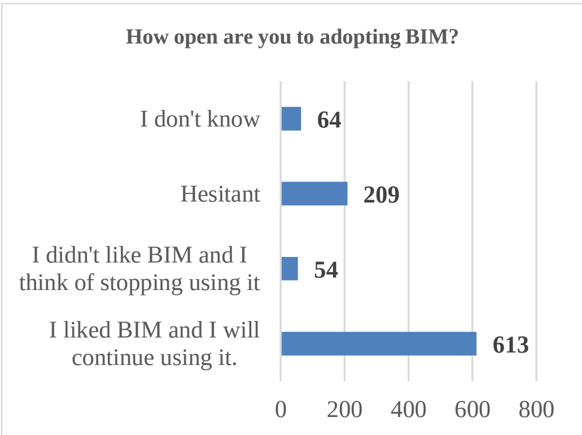

Figure 7. The opinion of respondents about the adoption of BIM.

Cronbach's alpha is utilised in Table 2 to determine the dependability of the various BIM features. The alpha value of Cronbach's coefficient falls between 0 and 1; values closer to 1 indicate more internal consistencyhence an alpha value higher or equal to 0.70 reflects a high degree of internal consistency. The Cronbach's alpha value for the 15 variables listed below is 0.97, suggesting a good level of internal consistency amongst these.

Table 2. Reliability.

Cronbach's Alpha	N of Items
.970	15

Table 3 lists first and second order statistics for capturing any additional information (the last column lists two standard deviations These figures further reflect the consistency across BIM features established above.

Table 3. Benefits and advantages of adopting BIM.

	Mean	Std. Deviation
Minimising changes	3.5340	1.21488
Sustainability analyses	3.5436	1.22592
Remove any omission	3.4957	1.21272
Quality management	3.7691	1.21969
Logistics management	3.3936	1.21069
Established life cycle	3.3904	1.21480
Life cycle cost	3.4596	1.25012
Operations and maintenance	3.6702	1.23654
Efficient use of energy	3.5351	1.22706
Facility management	3.6426	1.21137
Daylight analysis	3.4255	1.28553
Thermal design	3.5128	1.21967
Transparency cost	3.4862	1.22922

Table 4 shows the frequency and percentage distribution of the various engineering software applications utilised by the participant organisations.

Table 4. The many engineering software applications utilised by an organisation.

	Frequency	Percentage
Auto CAD	859	91.4
Autodesk Revit (Architecture Structure and MEP)	378	40.2
DDS-CAD	52	5.5
ArchiCAD	107	11.4

VICO Constructor	31	3.3
Bentley Systems Architecture	62	6.6
Autodesk Robot Structural Analysis	96	10.2
Tekla Structures	45	4.8
SAP	224	23.8
STAAD	101	10.7
Allplan	49	5.2

Finally, Table 5 shows the ranking results for each of the identified BIM benefits. The relative significance index enable to map comments by the engineers. For example, BIM high level (H) (0.8 ≤ RII ≤ 1), (H–M) (0.6 ≤ RII ≤ 0.8), medium (M) (0.4 ≤ RII ≤ 0.6), medium-low (M-L) (0.2 ≤ RII ≤ 0.4), and low (L) (0 ≤ RII ≤ 0.2).

There were 15 benefits assessed on a 5-point Likert scale, which the 940 respondents evaluated. All these carry a high-to-medium level of relevance. The result, however, indicates that most factors are significant, as none of them fall between medium and low relevance, see Table 3.

Table 5. Relative importance index (RII) for BIM advantages.

	RII Value	Importance	Importance Level
Time saving	0.743	2	H-M
Cost estimation	0.738	3	H-M
Minimising changes	0.707	7	H-M
Sustainability analyses	0.709	6	H-M
Remove any omission	0.699	10	H-M
Quality management	0.754	1	H-M
Logistics management	0.679	14	H-M
Established life cycle	0.678	15	H-M
Life cycle cost	0.692	12	H-M
Operations and maintenance	0.734	4	H-M
Efficient use of energy	0.707	8	H-M
Facility management	0.729	5	H-M
Daylight analysis	0.685	13	H-M
Thermal design	0.703	9	H-M
Transparency cost	0.697	11	H-M

5. Conclusion

This study aimed to assess knowledge, awareness, and adoption of BIM across the construction sector in Saudi Arabia. The study was conducted based on expert opinions captured through an online survey. The data was analysed with a descriptive and inferential methodology. Its results indicate that CAD and 3D in the KSA are the most widely adopted nowadays. This suggests that further awareness and training on the use of these technologies is required to fully implement all BIM dimensions. In fact, several respondents of the survey stated that they prefer to use BIM and would like to continue using it.

In raising levels of awareness and training, architects and engineers in the region could operate BIM in three dimensions which would be a step forward in coparison with the current two-dimensional modelling approaches they currently know. It is thus possible to give technical individuals step-by-step instructions and 3D illustrations of the necessary tasks with the use of visualisation, augmented reality, and simulations. In addition to identifying and correcting design flaws early in the construction process. BIM could also improve schedules throughout the entire building process. It is an innovative method of planning and managing construction projects. By communicating with experts and customers, better project choices can be made.

Finally, the benefit of using BIM is that Building orientation, energy consumption, and sunlight can now be considered in an improved environmental study. Water conservation, waste management, and energy efficiency may also be enhanced with BIM. BIM can also create more aesthetics and resilient buildings. As a result of BIM, design decisions can be analysed in virtual reality, and natural lighting can be simulated to optimize. By adopting reality capture technology during construction, accuracy can be improved, thereby promoting sustainability. Convincing developers, decision-makers, and engineering and manufacturing departments of the importance and benefits of employing BIM thus remains as an immediate challenge.

Acknowledgements
In acknowledgement of the generous financial support provided by the Saudi Arabian Ministry of Education, the first author is grateful for the opportunity to study for his PhD at the University of Birmingham.

References

[1] Huang L., Krigsvoll, G., Johansen, F., Liu, Y. and Zhang, X. 2018. Carbon emission of global construction sector. Renewable and Sustainable Energy Reviews, **81**, pp.1906-1916.
[2] Santos, R., Costa, A., Silvestre, J. and Pyl, L. 2019. Informetric analysis and review of literature on the role of BIM in sustainable construction. *Automation in Construction*, **103**, pp.221-234.
[3] Naim, A. (2019). *An investigation of building information modelling implementation in KSA*. [online] Ethos.bl.uk. Available at: https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.767228 [Accessed 4 Dec. 2019].
[4] Marzouk, M., Azab, S. and Metawie, M. 2018. "BIM-based approach for optimizing life cycle costs of sustainable buildings". *Journal of cleaner production*, ***188***, pp.217-226.
[5] Liu, Z., Chi, Z., Osmani, M., and Demian, P. 2021. Blockchain and building information management (BIM) for sustainable building development within the context of smart cities. *Sustainability*, ***13***(4), 2090; DOI: 10.3390/su13042090.
[6] Badran, D., AlZubaidi, R. and Venkatachalam, S. 2020. BIM based risk management for design bid build (DBB) design process in the United Arab Emirates: a conceptual framework. *International Journal of System Assurance Engineering and Management*, ***11***(6), pp.1339-1361.
[7] Tomek, A., and Matějk, P. 2014. The impact of BIM on risk management as an argument for its implementation in a construction company. *Procedia Engineering*, ***85***, pp.501-509.
[8] Wetzel, E.M. and Thabet, W.Y., 2015. The use of a BIM-based framework to support safe facility management processes. *Automation in Construction*, ***60***, pp.12-24.
[9] Mering, M.M., Aminudin, E., Chai, C.S., Zakaria, R., Tan, C.S., Lee, Y.Y. and Redzuan, A.A. 2017. Adoption of Building Information Modelling in project planning risk management. In *IOP Conference Series: Materials Science and Engineering* (Vol. **271**, No. 1, p. 012043). IOP Publishing.

[10] Sarhan, J.G., Xia, B., Fawzia, S., Karim, A., Olanipekun, A.O. and Coffey, V. 2019. Framework for the implementation of lean construction strategies using the interpretive structural modelling (ISM) technique: A case of the Saudi construction industry. *Engineering, Construction and Architectural Management.*

[11] Alotaibi, N.O., Sutrisna, M. and Chong, H.Y. 2016. Guidelines of using project management tools and techniques to mitigate factors causing delays in public construction projects in kingdom of Saudi Arabia. *Journal of Engineering, Project, and Production Management,* ***6***(2), pp.90-103.

[12] Kocakaya, M. (2019). Building information management (BIM), a new approach to project management. *Journal of sustainable construction materials and technologies*, *4*(1), 323-332.

[13] Olawumi, T., and Chan, D. 2019. Building information modelling and project information management framework for construction projects. *Journal of Civil Engineering and Management,* ***25***(1), 53-75; DOI: 10.3846/jcem.2019.7841.

[14] Sahingoz, O., Buber, E., Demir, O., and Diri, B. 2019. Machine learning based phishing detection from URLs. *Expert Systems with Applications,* ***117***(1), 345-357;DOI: 10.1016/j.eswa.2018.09.029.

[15] Mesároš, P., Smetanková, J. and Mandičák, T. 2019. The Fifth Dimension of BIM – Implementation Survey. *IOP Conference Series: Earth and Environmental Science,* **222**, 012003.

[16] GhaffarianHoseini, A., Zhang, T., Nwadigo, O., GhaffarianHoseini, A., Naismith, N., Tookey, J. and Raahemifar, K. 2017. Application of nD BIM Integrated Knowledge-based Building Management System (BIM-IKBMS) for inspecting post-construction energy efficiency. *Renewable and Sustainable Energy Reviews*, **72**, pp.935-949.

[17] Cha, H., and Lee, D. 2018. Framework based on building information modelling for information management by linking construction documents to design objects. *Journal of Asian Architecture and Building Engineering,* ***17***(2), 329-336; DOI: 10.5961/hcgt49274.

[18] Eadie, R., Browne, M., Odeyinka, H., McKeown, C. and McNiff, S. 2015. A survey of current status of and perceived changes required for BIM adoption in the UK. Built Environment Project and Asset Management.

[19] Smith, P. 2014. BIM & the 5D Project Cost Manager. Procedia - Social and Behavioral Sciences, 119, pp.475-484.

[20] Autodesk.com. 2020. Benefits of BIM | Building Information Modeling | Autodesk. [online] Available at: <https://www.autodesk.com/solutions/bim/benefits-of-bim> [Accessed 10 May 2020].

[21] Autodesk. 2022. Construction Management Software | Autodesk BIM 360. Retrieved July 8, 2022, from https://www.autodesk.com/bim-360/

[22] Azhar, S. 2011. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. Leadership and Management in Engineering, 11(3), pp.241-252.

[23] Diao, P. and Shih, N. 2019. BIM-Based AR Maintenance System (BARMS) as an Intelligent Instruction Platform for Complex Plumbing Facilities. Applied Sciences, 9(8), p.1592.

[24] GhaffarianHoseini, A., Zhang, T., Nwadigo, O., GhaffarianHoseini, A., Naismith, N., Tookey, J. and Raahemifar, K. 2017. Application of nD BIM Integrated Knowledge-based Building Management System (BIM-IKBMS) for inspecting post-construction energy efficiency. Renewable and Sustainable Energy Reviews, 72, pp.935-949.

[25] Harding, J., Suresh, S., Renukappa, S. and Mushatat, S., 2014. Do building information modelling applications benefit design teams in achieving BREEAM accreditation. Journal of Construction Engineering, 2014, pp.1-8.

[26] Jiang, X. 2011. Developments in cost estimating and scheduling in BIM technology (Doctoral dissertation, Northeastern University).

[27] Kehily, D. 2016. Leveraging building information modelling to address the barriers that prevent the widespread adoption of life cycle costing by quantity surveyors (Doctoral dissertation, University of Salford).

IOP Conf. Series: Earth and Environmental Science 1196 (2023) 012111 doi:10.1088/1755-1315/1196/1/012111

[28] Zou, Y., Kiviniemi, A. and Jones, S.W. 2017. A review of risk management through BIM and BIM-related technologies. *Safety science*, ***97***, pp.88-98.
[29] Alasmari, E., Martinez Vazquez, P. and Baniotopoulos, C. 2022. "Building Information Modeling (BIM) towards a Sustainable Building Design: A Survey". Proceedings of *CESARE22, 3rd Coordinating Engineering for Sustainability and Resilience, Irbid, 8-10.05.22,* ISNN 2788-6204, 11.
[30] Elshafey, A., Saar, C., Aminudin, E., Gheisari, M., and Usmani, A. 2020. Technology acceptance model for Augmented Reality and Building Information Modeling integration in the construction industry. *J. Inf. Technol. Constr*, ***25***(1), 161-172.
[31] Biolek, V. and Hanák, T. 2019. LCC estimation model: A construction material perspective. *Buildings*, ***9***(8), p.182.
[32] Yuan, Z., Zhou, J., Qiao, Y., Zhang, Y., Liu, D. and Zhu, H. 2020. BIM-VE-Based Optimization of Green Building Envelope from the Perspective of both Energy Saving and Life Cycle Cost. *Sustainability*, ***12***(19), p.7862.construction waste management. *Sustainability*, *12*(6), 2483.
[33] Johansson, M., Roupé, M., & Bosch-Sijtsema, P. 2015. "Real-time visualization of building information models" (BIM). *Automation in construction*, ***54***, 69-82.
[34] Hansen, M., O'Brien, K., Meckler, G., Chang, A.M. and Guise, J.M. 2016. Understanding the value of mixed methods research: the Children's Safety Initiative-Emergency Medical Services. *Emergency Medicine Journal*, ***33***(7), pp.489-494.
[35] Zohrabi, M. 2013. Mixed Method Research: Instruments, Validity, Reliability and Reporting Findings. *Theory & practice in language studies*, ***3***(2).
[36] Dalati, S. and Gómez, J.M. 2018. Surveys and Questionnaires. In *Modernizing the Academic Teaching and Research Environment* (pp. 175-186). Springer, Cham.
[37] Cohen, L., Manion, L., and Morrison, K. 2017. Research Methods in Education. 8th edn. London and New Yourk: Routledge.
[38] Chan, D.W. and Kumaraswamy, M.M. 1997. A comparative study of causes of time overruns in Hong Kong construction projects. International Journal of project management, 15(1), pp.55-63.
[39] Alasmari, E., Martinez-Vazquez, P. and Baniotopoulos, C. 2022. A Systematic Literature Review of the Adoption of Building Information Modelling (BIM) on Life Cycle Cost (LCC). Buildings, 12(11), p.1829.