Investigation and Comparative Study between Research Methods used in the Five Categories of BIM-Based Built Environment Sustainability Studies

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Abstract

Using Building Information Modelling (BIM) helped enhance the environmental performances of building and civil infrastructure projects throughout their life cycle. However, the construction industry continues to be one of the most impactful industries on the environment, hence the imminent need for further research in this area. The choice of the right Research Method and Design (RMD) was always important to ensure relevant results for the Five Categories (Cs) of BIM-based Built Environment Sustainability (BIMBES) studies: BIM-based studies discussing either sustainability in general 'C1'; carbon emissions 'C2'; construction and demolition wastes 'C3'; water supply or use 'C4'; or energy 'C5', but the availability of a wide array of research methods and the absence of a clear mapping of the best methods to be used for each category remain significant challenges. The purpose of this study is to thoughtfully investigate the RMDs used for BIMBES studies. Thus, based on scoping review of 458 relevant papers, the study showed that BIMBES topics are contemporary and C1 and C5 are the most discussed. Similarly, the paper disclosed the evolution of BIMBES studies including categories' overlap, identified and mapped the RMDs used for BIMBES studies and highlighted 9 mixed research designs, 1 paradigm, 12 research instruments, and 4 data analysis approaches. This research paper could be the starting point for any study related to the BIMBES as it allows scholars to have a clear and well understanding of the used and useful RMDs to be adopted according to the topic they are exploring.

Keywords: BIM; Sustainability; Mixed method; Qualitative method; Quantitative method

1 Introduction

The Construction Industry (CI) is one of the most impactful industries on the environment (Bouhmoud *et al.*, 2022a). Scholars and practitioners joined forces to help reduce this impact towards green buildings by developing structured guidelines and/or standards such as LEED, BEAM+, and BREEAM (Awadh, 2017); providing innovative conceptual methods such as Lean Construction (Mellado & Lou, 2020) and Life Cycle Assessment (LCA) (Jalaei *et al.*, 2019); and implementing green construction alternatives such as recycling

(Guerra *et al.*, 2020), prefabrication (Liu *et al.*, 2019), and renewal resources (Chudikova *et al.*, 2019). Krygiel & Nies (2008) underlined that adopting green buildings could averagely save 30% of energy consumption, 35% of Carbon Emissions (CEs), 30–50% of potable water use, and 50–97% of Construction and Demolition Wastes (CDW).

1.1 Environmental Impact of the CI and Related BIM benefits

The CI environmental impact is a significant concern all over the world. Indeed, Bouhmoud et al. (Bouhmoud *et al.*, 2022a) emphasized that, globally, construction work and buildings are responsible for 39% of CEs, 40% of raw materials' consumption, 30% of energy-related CEs, and 20-50% of wastes deposited in landfills. This critical impact is basically due to operational, technological, and managerial issues related to currently used practices in the CI. Yet, these can significantly be lessened using the innovative technology of Building Information Modelling (BIM) including issues related to the fragmented nature of the CI (Haruna *et al.*, 2021), the poor coordination and communication, and the tasks synchronization between different construction disciplines (architecture, structure, topographical surveys…) within the same project (Bouhmoud & Loudyi, 2021).

BIM has a great potential to reduce construction impacts on the environment in the different phases of a building lifecycle as it enables the incorporation of multi-disciplinary data into one 3D model, then simulates and analyses different sustainability parameters during the same design process to find the most optimized eco-friendly scenario (Bouhmoud & Loudyi, 2021). Jen and Vernatha (Tu and Vernatha, 2016) conceptualized a BIM-based energy management support system to monitor and track the real-time energy performance of different zones in a building and optimize energy consumption. Similarly, adopting a BIM-based approach to lifecycle data management, helped the Shanghai Center, the tallest building in China, to achieve a material waste rate of 4% instead of 10% that is considered the common rate in China (Bouhmoud & Loudyi, 2021).

BIM provides the opportunity to considerably reduce time, cost and effort required to manage building information and life cycle assessment (LCA) data and remarkably accelerates the establishment of the LCA model (Bouhmoud & Loudyi, 2021). This technology helps to quantify, anticipate and optimize materials' production and transportation, onsite construction workflow, building operational consumption (equipment use, lighting, heating, ventilation and air conditioning), and demolition process and wastes; and considerably reduces the CEs at all buildings' stages (Bouhmoud *et al.*, 2022b).

1.2 Research Methods and Designs

Scholars (Creswell & Clark, 2017; Ellis & Levy, 2009; Rahi, 2017) distinguish between method types and development instruments. Method types are differentiated into quantitative, qualitative, and mixed according to the nature of the research questions. Mainly, quantitative methodologies are applied to research questions about causality, generalizability, or magnitude of effects whereas qualitative methodologies are used to investigate research questions aiming to develop a theory, explore why or how a phenomenon occurs, or describe the nature of individuals' experience (Fetters *et al.*, 2013). Mixed methods research studies combine the strengths of both quantitative and qualitative methods (Creswell & Clark, 2017) and provide an inventive approach to examine contemporary and/or complex research topics in the Architecture, Engineering and Construction (AEC) fields including the use of BIM for Buildings and Infrastructure (B&I) Environmental Sustainability (ES).

In the meantime, method development instruments, called also approaches (Ellis & Levy, 2009) or strategies (Rahi, 2017), refer to the adopted process to collect and interpret data with clear objectives. The choice of the method instrument depends on the stage of studying the addressed problem: exploration, description, evaluation, development, validation or applied exploitation (Ellis & Levy, 2009). The method instrument could be quantitative, qualitative or mixed. Interviews and focus groups are mostly qualitative whereas case studies and pre-test/post-test are commonly quantitative. However, some instruments could be either quantitative or qualitative according to the data analysis approach such as Literature Review (LR) which could be quantitative

such as scientometric LR or qualitative such as narrative or systematic ones.

Both quantitative and qualitative research methods follow three key steps: data collection, data analysis, and results. Though, mixed methods consist of the following three steps: (1) collect and analyse both qualitative and quantitative data separately, (2) integrate the findings either concurrently or sequentially by comparing, correlating, contrasting, validating, and/or interrelating both data types, and then (3) get the results by interpreting the findings to address the research question (Creswell & Clark, 2017).

1.3 Research Objectives

Considering both BIM considerable ecological potential and the current environmental harm caused by the CI, it is necessary to endorse research and development to permit more BIM-based studies enabling efficient solutions toward greener B&Is with less environmental impact in their different life cycle stages. In this vein, this study aims to provide both scholars and practitioners with the key tools and data needed to develop further studies helping to create innovative approaches, strategies, or technological tools serving this purpose. Hence, based on an exploratory mixed method design (Section 2), the study aim is achieved through the following research objectives:

i. to present the different categories of B&Is environmental sustainability (§2.1),
ii. to explore the publication evolution of topic-related studies (§3),
iii. to investigate the used method-development instruments in each defined studies' category (§4),
iv. and to examine the used method types and designs (§5).

2 Methodology

To meet the study objectives, the authors adopted a two-phase exploratory mixed method design where the qualitative results of the first phase were used as fundamentals to develop both quantitative (metrics) and qualitative results of the second phase.

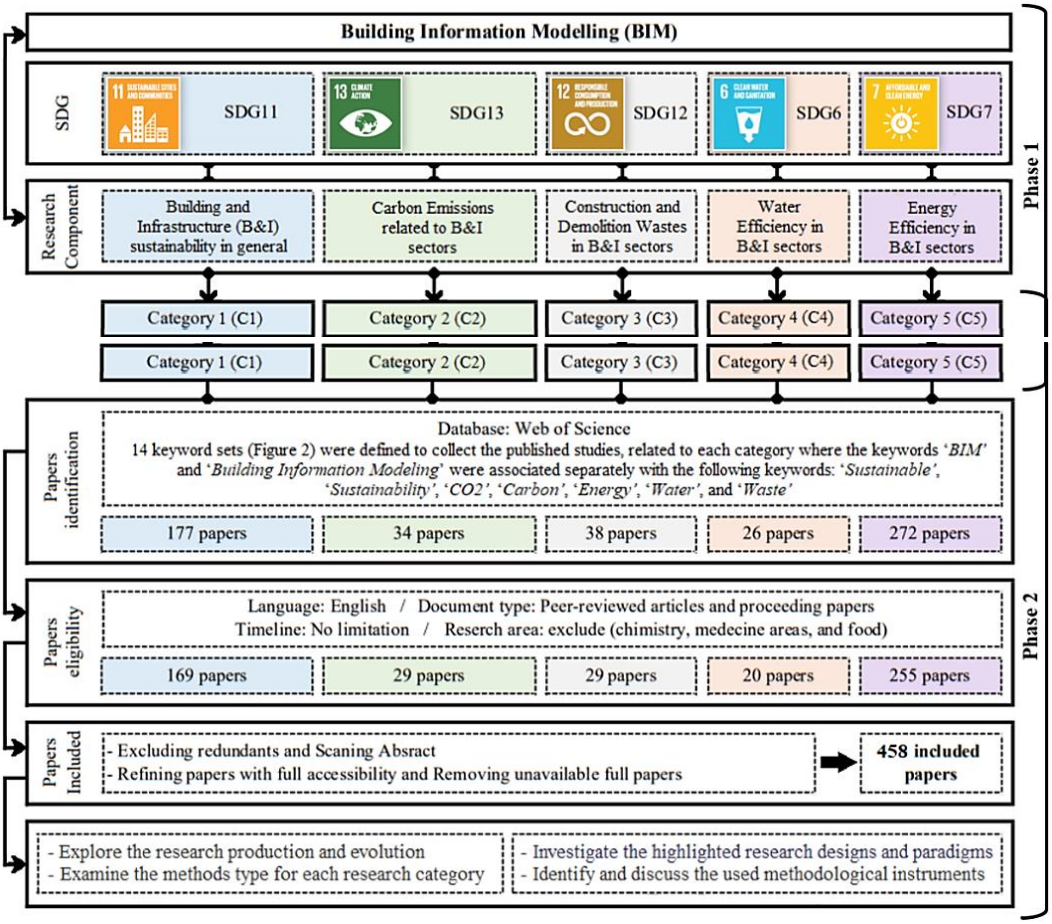

Fig. 1: Methodology flow – (a) Phase 1: preparatory study / (b) Phase 2: scoping review

2.1 Phase 1: Preparatory Study

The first phase consisted of a qualitative preparatory study to define the environmental aspects related to B&I in the CI that should be considered for the investigation. For this purpose, the authors reviewed the global main environmental strategies adopted by most countries, namely the Sustainable Development Goals (SDG) defined by the United Nations Development Programme (UNPD) (United Nations Development Programme (UNPD), n.d.) and reports of Conferences of the Parties (COP) administrated by the United Nations of Climate Change (UNCC) (n.d.). The investigation showed that the SDGs are strongly interconnected but five SDGs are considered closely connected to the ES in the CI:

- SDG6 "Clean Water and Sanitation" intends to endorse actions helping '*ensure availability and sustainable management of water and sanitation for all*.' For the CI, B&Is are responsible for 16% of the global water consumption (Ou *et al.*, 2017).
- SDG7 "Affordable and Clean Energy" focuses on '*ensuring access to affordable, reliable, sustainable and modern energy for all.*' Most undertaken actions, to reduce the environmental impact, concern substituting fossil energy with renewable ones and decreasing their consumption (UNCC, n.d.). Yet, the CI is responsible for 45% of global energy consumption (Ou *et al.*, 2017).
- SDG11 "Sustainable Cities and Communities" consists of actions to '*make cities and human settlements inclusive, safe, resilient and sustainable.*' The CI concerns the urban dimension as well where community management, green area versus built area, disasters risk management, and transportation/connectivity management represent big part of the AEC studies and projects. Several standards have been released to manage the sustainability of these aspects including environmental ones (Awadh, 2017).
- SDG12 "Responsible Consumption and Production" consists of '*Ensuring sustainable consumption and production patterns*' where '*achieve the environmentally sound management of chemicals and all wastes throughout their life cycle*' and '*substantially reduce waste generation through prevention, reduction, recycling and reuse*' are two of the main fixed targets. Construction work and buildings consume 40% of global raw materials and produce 20-50% of wastes deposited in landfills (Bouhmoud *et al.*, 2022a).
- SDG13 "Climate Actions" supports actions to '*take urgent action to combat climate change and its impacts.*' While, the total CEs per year is one of the most considered indicators for this purpose, construction materials and building operations are responsible for 28% and 11% of the global CEs, respectively (Bouhmoud *et al.*, 2022a).

As shown in Fig. 1, the study of the BIM-based Built Environment Sustainability (BIMBES) involves five categories of studies: C1, C2, C3, C4 and C5 that refer to BIM-based studies related to B&I sustainability in general, B&I CEs, CDWs, water and energy components, respectively.

2.2 Phase 2: Scoping Review – Metrics and Thematic Analysis

Considering the pre-defined category in phase 1, 14 keyword sets (Fig. 1) were defined to collect the published studies, related to each category where the keywords '*BIM'* and '*Building Information Modelling*' were associated separately with the following keywords: '*Sustainable'*, '*Sustainability'*, '*CO2'*, '*Carbon'*, '*Energy'*, '*Water'*, and '*Waste'*. The papers were collected from the largest scientific databases Web of Science. The paper-identification step led to the collection of 547 indexed papers, which were shortlisted to 458 included papers after applying eligibility criteria, excluding redundant, and refined available and accessible papers. The last three objectives of this study were investigated by using scoping LR as a method development instrument (Fig. 1).

3 Research Evolution in Bim-Based Built Environment Sustainability

The BIMBES research production experiences an upward trend with a significant disparity between the 5 studies categories. Energy and general sustainability represent the most discussed CI environmental aspects as

they represented 55.7% and 36.9% of the included papers respectively (Fig. 2). Similarly, since 2013, the energy and general sustainability-related research using BIM had the highest production rates, with 23.4 and 15.8 papers per year respectively, compared to other categories whose production rates did not exceed 2.8 papers per year. CDW-related research was the first to consider BIM use in 2005, followed by energy-related research in 2007 whereas water-related research started evoking BIM only in 2013 (Fig. 2).

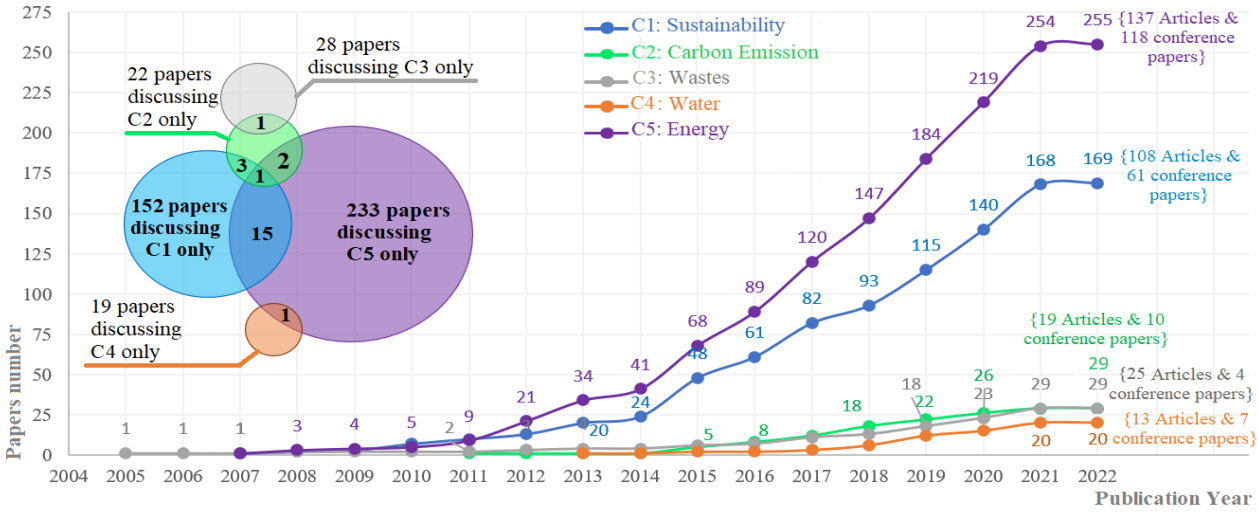

Fig. 2: Evolution of Research Production in BIM-Based Built Environment Sustainability: Dispatching by Research Category and Overlaps

4 Research Method Types and Research Designs and Paradigms

In the BIMBES research, scholars mainly use either quantitative or mixed methods which are adopted in 43.7% and 34.7% of the published studies, respectively (Fig. 3). However, the distribution of the used method types is dissimilar for each study category. Quantitative methods are mostly adopted for BIM-based research addressing water and energy efficiencies (C4 and C5), as they represent more than half the used methods with 55.6% and 53%, respectively, whereas they correspond to only one-third for the other ES aspects in BIMBES research (Fig. 3). On the other hand, qualitative methods are less considered for BIM-based studies addressing CEs (C2), CDW (C3), and energy efficiency (C5) as this type represented for these three categories less than one-fifth (21.4%) which corresponds to the rate of qualitative methods used for BIMBES research in total. However, qualitative methods are significantly adopted in BIM-based research tackling either B&I sustainability in general or water efficiency where it was considered for 30.1% and 27.8% of the related research respectively (Fig. 3).

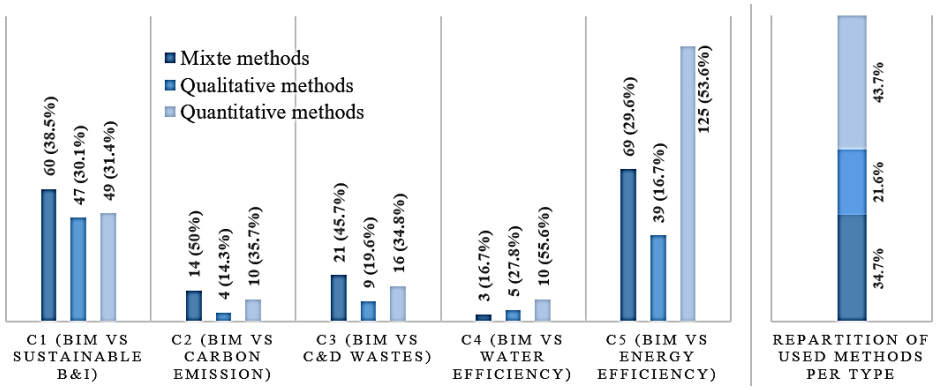

Fig. 3: Breakdown of the used Research Methods by Type and Per Research Category

The mixed method is the dominant method type in research associating BIM with CEs (C2), CDW (C3) and/or B&I sustainability in general (C1) with respective shares of 50%, 45.7% and 38.5%, whereas it

represents 29.6% for C5 studies and only 16.7% for C3 research (Fig. 3). Nine mixed research designs were explicitly highlighted in the reviewed work: Development Strategy Formulation and Evaluation Methodology (DSFEM) (Kim *et al.*, 2015), Design Science Research Methodology (DSRM) (Kang *et al.*, 2022), Sensitivity Analysis Method (Li *et al.*, 2020), Triangulation Design (Afaifia *et al.*, 2021), Axiomatic Design (GhaffarianHoseini *et al.*, 2019), Integrated Design (Schlueter & Geyer, 2018), Exploratory Design (Akinade *et al.*, 2016), Collaborative Science Research Design (CSRD) (Michaud *et al.*, 2021), Multi-Objective Optimization Approach (MOOA) (Abbasi & Noorzai, 2021). Among the four research paradigms (Rahi, 2017), one was explicitly mentioned: Constructivist (Akinade *et al.*, 2016).

5 Research Method Development Instruments and Data Analysis

The review study revealed that BIMBES research mostly utilizes literature review, modelling and case study instruments (Fig. 4). Scholars employed the LR instrument to either collect data to be used as input to develop the research delivery or to explore or describe research problems, the modelling instrument to develop a new framework, approach, or algorithm or upgrade existing ones to handle pre-defined research questions and the case study instrument to either evaluate a research problem or validate/refute research outcomes mainly the modelled elements or the findings of a previous study. As a result, most papers are studying research problems at mature stages namely evaluation, development, validation, or applied exploitation stages (§1.2).

The LR instrument, including all forms, is highly used in BIM-based research related to CEs (C2) and CDW (C3); with 66% and 97% of the related papers, respectively; and moderately used in studies addressing B&I general sustainability (C1), water and energy efficiencies (C4 and C5) with 42%, 40% and 31% of the related papers, respectively (Fig. 4). Scholars in topic-related research use five forms of the LR: Systematic, Scientometric, Scoping, Narrative, and General LR, which were used completely in C1 and C5 of BIMBES research and partially in the other categories. Systematic is the most used form followed by scientometric ones (Fig. 5).

Fig. 4: Used Research Instruments for Each of the Five Topic-Related Research Categories

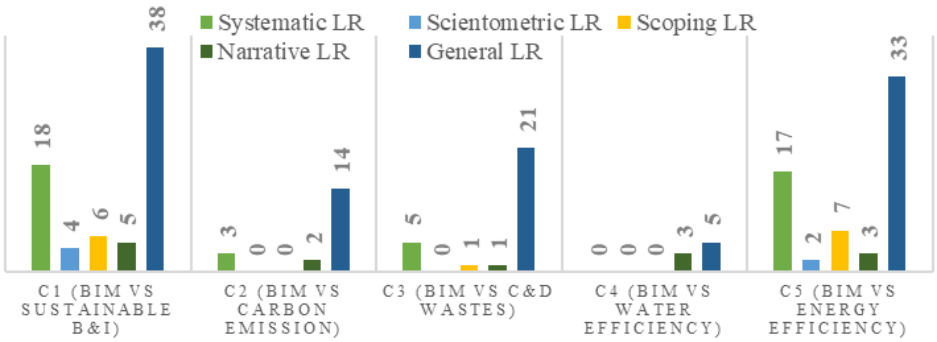

Fig. 5: The LR Breakdown into the Five Used LR Forms for Each Topic-Related Research Category

The modeling and case study instruments are commonly applied among CDW, CEs, and water efficiency studies using BIM (C3, C2, and C4) with respective percentages of 79%, 55%, and 50% for modeling and 62%, 52%, and 40% for case study. Likewise, the simulation instrument is frequently adopted for energy efficiency topics (C5), moderately used for B&I general sustainability (C1) and CEs (C2) topics, and lightly applied for CDW (C3) and water efficiency (C4) (Fig. 4).

In total, twelve method instruments are employed in BIMBES research: Ethnography, Survey, Interview, Focus Group, Modelling, Case study, Archival data, Document scan, Pre-test | Post-test, Simulation, Experiment, and Literature review. In the same vein, four data analysis approaches were emphasized: regression analysis (Afaifia *et al.*, 2021), statistical analysis (Schlueter & Geyer, 2018), Tukey's method (Alshibani & Alshamrani, 2017) , and hierarchical cluster analysis (Afaifia *et al.*, 2021).

6 Conclusion

The review study revealed that, referring to the SDGs, BIM could be used to enhance the B&Is ES by acting on five environmental aspects: B&I sustainability in general (C1), CEs (C2), CDW (C3), water efficiency (C4) and energy efficiency (C5). The topics within the BIMBES research are contemporary as the first paper was published in 2005 in C3 category followed by a 1st paper in C5 category in 2007 whereas C4 category was the last category to involve the BIM use with a 1st paper in 2013. Moreover, the study showed that C5 and C1 are the most discussed ES categories and have the highest production rates, with 23.4 and 15.8 papers per year respectively, whereas the remaining categories are still very limited.

The scoping review showed that most presented BIMBES research address mature stages of research problems study; namely evaluation, development, validation, or applied exploitation stages; and primarily apply quantitative and mixed methods with 43.7% and 34.7%, respectively. In the same vein, the study demonstrated that the LR, Modelling and Case study are topping the used development instruments for BIMBES research especially C3 category, with 62 to 97% of the used methods, followed by C2, with 52 to 66% of the used methods, and then C4, with 40 to 50% of the used methods. In terms of research methods metrics, this paper disclosed that the BIMBES research employs twelve method-development instruments: Ethnography, Survey, Interview, Focus Group, Modelling, Case Study, Archival Data, Document Scan, Pre-test | Post-test, Simulation, Experiment, and Literature Review. Similarly, four data analysis approaches were emphasized: Tukey's Method, Hierarchical Cluster Analysis, Regression Analysis and Statistical Analysis; and nine mixed research designs were explicitly highlighted in the reviewed work: DSFEM, DSRM, Sensitivity Analysis Method, Triangulation Design, Axiomatic Design, Integrated Design, Exploratory Design, CSRD, MOOA. Among the four research paradigms, one was explicitly mentioned: Constructivist.

By presenting a thoughtful investigation of the BIMBES research production and used research methods and designs for each category of the B&Is ES, this study endorses research and development to permit more studies using the considerable BIM abilities to enable efficient solutions toward greener B&Is in

different life cycle stages. Hence, this study would provide both scholars and practitioners with the key tools and data needed to develop and create innovative approaches. Although, this study is still limited since it used one scientific database which enabled omitting several published studies in the BIMBES research. In the meantime, this paper represents a first study discussing this topic hence further studies are needed to confirm this study findings and cover more scientific databases.

References

Abbasi, S. & Noorzai, E. (2021). "The BIM-Based Multi-optimization Approach in Order to Determine the Trade-off between Embodied and Operation Energy Focused on Renewable Energy Use", *Journal Of Cleaner Production*, Vol. 281, doi: 10.1016/j.jclepro.2020.125359.

Afaifia, M. et al. (2021). "An Energy Consumption Model for the Algerian Residential Building's Stock, Based on a Triangular Approach: Geographic Information System (GIS), regression analysis and hierarchical cluster analysis", *SUSTAINABLE CITIES AND SOCIETY*, Vol. 74, doi: 10.1016/j.scs.2021.103191.

Akinade et al. (2016). "Evaluation Criteria for Construction Waste Management Tools: Towards a Holistic BIM Framework", *International Journal of Sustainable Building Technology and Urban Development*, Vol. 7 No. 1, pp. 3–21, doi: 10.1080/2093761X.2016.1152203.

Alshibani, A. & Alshamrani, O. (2017). "ANN/BIM-based Model for Predicting the Energy Cost of Residential Buildings in Saudi Arabia", *Journal of Taibah University for Science*, Vol. 11 No. 6, pp. 1317–1329, doi: 10.1016/j.jtusci.2017.06.003.

Awadh, O. (2017), "Sustainability and Green Building Rating Systems: LEED, BREEAM, GSAS and Estidama critical analysis", *Journal of Building Engineering*, Vol. 11, pp. 25–29, doi: 10.1016/j.jobe.2017.03.010.

Bouhmoud, H. & Loudyi, D. (2021). "Building Information Modeling (BIM) Framework, Potential and Challenges", *International Journal of Information Science and Technology*, Vol. 5 No. 3, pp. 24–35, doi: 10.57675/IMIST.PRSM/ijist-v5i3.173.

Bouhmoud, H., Loudyi, D. & Azhar, S. (2022a). "Building Information Modelling (BIM) for Lifecycle Carbon Emission: Scientometric and Scoping Literature Reviews", *Smart and Sustainable Built Environment*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/SASBE-05-2022-0086.

Bouhmoud, H., Loudyi, D. & Azhar, S. (2022b). "Evaluation of Building's Life Cycle Carbon Emissions Based on BIM and LCA: A Case Study of Affordable Housing in Morocco", presented at the CITC-12. The Twelfth International Conference on Construction in the 21st Century, Amman, Jordan, pp. 378–386.

Chudikova, B., Faltejsek, M., & IOP. (2019). "Advantages of Using Virtual Reality and Building Information Modelling When Assessing Suitability of Various Heat Sources, Including Renewable Energy Sources", Vol. 542, presented at the 2018 The 6th International Conference on Mechanical Engineering, Materials Science and Civil Engineering, doi: 10.1088/1757-899X/542/1/012022.

Creswell, J.W. & Clark, V.L.P. (2017). "Chapter 4: Choosing a Mixed Methods Design", *Designing and Conducting Mixed Methods Research*, 3rd ed., SAGE Publications, Inc., pp. 58–88.

Ellis, T. & Levy, Y. (2009). "Towards a Guide for Novice Researchers on Research Methodology: Review and Proposed Methods", *Issues in Informing Science and Information Technology*, Vol. 6, pp. 323–337, doi: 10.28945/1062.

Fetters, M.D., Curry, L.A. & Creswell, J.W. (2013). "Achieving Integration in Mixed Methods Designs—Principles and Practices", *Health Services Research*, Vol. 48 No. 6 Pt 2, pp. 2134–2156, doi: 10.1111/1475-6773.12117.

Ghaffarian Hoseini et al. (2019). "ND BIM-integrated Knowledge-Based Building Management: Inspecting Post-Construction Energy Efficiency", *Automation in Construction*, Vol. 97, pp. 13–28, doi: 10.1016/j.autcon.2018.10.003.

Guerra, B.C., Leite, F. & Faust, K.M. (2020). "4D-BIM to Enhance Construction Waste Reuse and Recycle Planning: Case Studies on Concrete and Drywall Waste Streams", *Waste Management*, Vol. 116, pp. 79–90, doi: 10.1016/j.wasman.2020.07.035.

Haruna, A., Shafiq, N. & Montasir, O. (2021). "Building Information Modelling Application for Developing Sustainable

Building (Multi Criteria Decision Making Approach)", *Ain Shams Engineering Journal*, Vol. 12 No. 1, pp. 293–302, doi: 10.1016/j.asej.2020.06.006.

Jalaei, F., Zoghi, M. & Khoshand, A. (2019), "Life Cycle Environmental Impact Assessment to Manage and Optimize Construction Waste Using Building Information Modelling (BIM)", *International Journal Of Construction Management*, Vol. 21 No. 8, pp. 784–801, doi: 10.1080/15623599.2019.1583850.

Kang, K. et al. (2022). "Building Demolition Waste Management Through Smart BIM: A Case Study in Hong Kong", *Waste Management*, Vol. 143, pp. 69–83, doi: 10.1016/j.wasman.2022.02.027.

Kim, J. et al. (2015). "BIM-based Decision-Support Method For Master Planning of Sustainable Large-Scale Developments", *Automation in Construction*, Vol. 58, pp. 95–108, doi: 10.1016/j.autcon.2015.07.003.

Krygiel, E. & Nies, B. (2008). *Green BIM : Successful Sustainable Design with Building Information Modeling*, Wiley Pub.

Li, H. et al. (2020). "Exploring and Verifying BIM-Based Energy Simulation for Building Operations", *Engineering Construction and Architectural Management*, Vol. 27 No. 8, pp. 1679–1702, doi: 10.1108/ECAM-06-2019-0314.

Liu, H. et al. (2019). "Towards Sustainable Construction: BIM-Enabled Design and Planning of Roof Sheathing Installation for Prefabricated Buildings", *Journal of Cleaner Production*, Vol. 235, pp. 1189–1201, doi: 10.1016/j.jclepro.2019.07.055.

Mellado, F. & Lou, E. (2020), "Building Information Modelling, Lean and Sustainability: An Integration Framework to Promote Performance Improvements in the Construction Industry", *Sustainable Cities and Society*, Vol. 61, doi: 10.1016/j.scs.2020.102355.

Michaud, M. et al. (2021). "A Taxonomy of Sources of Waste in BIM Information Flows", *Buildings*, Vol. 11 No. 7, doi: 10.3390/buildings11070291.

Ou, X., Li, Q. and Li, D. (2017). "Low-Carbon Architectural Design and Data Analysis Based on BIM", in Fei, M et al. (Eds.), *Advanced Computational Methods in Life System Modeling and Simulation, Lsms 2017, Pt I*, Vol. 761, Springer-Verlag Berlin, Berlin, pp. 390–399, doi: 10.1007/978-981-10-6370-1_39.

Rahi, S. (2017), "Research Design and Methods: A Systematic Review of Research Paradigms, Sampling Issues and Instruments Development", *International Journal of Economics & Management Sciences*, Vol. 6, doi: 10.4172/2162-6359.1000403.

Schlueter, A. & Geyer, P. (2018). "Linking BIM and Design of Experiments to Balance Architectural and Technical Design Factors for Energy Performance", *Automation in Construction*, Vol. 86, pp. 33–43, doi: 10.1016/j.autcon.2017.10.021.

Tu, K. J. & Vernatha, D. (2016). "Application of Building Information Modeling in Energy Management of Individual Departments Occupying University Facilities", *International Journal of Architectural and Environmental Engineering*, Vol. 10 No. 2, pp. 225–231, doi: doi.org/10.5281/zenodo.1112113.

United Nations Development Programme (UNPD). (n.d.). "The 17 Goals | Sustainable Development", available at: https://sdgs.un.org/fr/goals (accessed 18 December 2022).

United Nations of Climate Change (UNCC). (n.d.). "UNsFCCC: Session at COP | Documents, decisions and resources", available at: https://unfccc.int/ (accessed 18 December 2022).

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