RESILIENCE
IN RESEARCH AND PRACTICE

Proceedings of the International Postgraduate Research Conference 2022

Edited by
Tanja Poppelreuter

Resilience in Research and Practice

Proceedings of the International Postgraduate Research Conference (IPGRC 2022)

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University of Salford MANCHESTER

Resilience in Research and Practice
University of Salford, 2023
The Crescent
Salford, M5 4WT

ISBN: 978-1-912337-64-4

Publisher: The University of Salford
Editor: Tanja Poppelreuter
Copyediting and design: Ayesha Chari
Production assistance: Hanneke van Dijk
Cover page design: Daniela Atzori and Laura Janicka

https://www.salford.ac.uk

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FOREWORD

'Resilience in Research and Practice' are the proceedings of the International Postgraduate Research Conference (IPGRC) that was organized by the School of Science, Engineering and Environment (SEE) at the University of Salford, United Kingdom, from 4th to 6th April 2022.

As an international conference, it brought together postgraduate researchers from universities in South Africa, Lithuania, Sri Lanka, Czechia, and Brazil, among others. Researchers presented findings concerning sustainable technologies, cross-disciplinary methodologies, and contemporary urban challenges.

The title of the conference 'Resilience in Research and Practice' alluded to research themes that we wished to attract; themes addressing, for example, resilient bacterial strains, resilient materials used in construction, resilient urban planning in the face of climate change, and so on. The title also applauded young researchers who had experienced the challenges brought about by the COVID-19 pandemic and who had prevailed in pursuing their research despite laboratory closures, the inability to undertake fieldwork, and the unavailability of resources and individuals for interviews or questionnaire surveys. Their contributions to the conference are testament to their resilience in the face of unprecedented circumstances and to their ability to succeed.

Each conference session was chaired by a University of Salford postgraduate research (PGR) candidate with their supervisor. This not only allowed students to gain experience with organizing and chairing a conference session but also supported the forming of synergies and networks between young researchers. We were proud to have had as our keynote speakers Prof. Hope Magidimisha-Chipungu from the College of Humanities at the University of KwaZulu-Natal, Durban, South Africa and Prof. Marie-Christine Therrien, Professeure titulaire et Directrice de Cité-ID Living Lab Gouvernance de la résilience urbaine, Montréal, Canada. Their research addresses urban green activism, resilience governance, and crisis management, which supported the themes of most of the sessions in this conference.

We thank all speakers at the conference and our SEE session chairs (PGRs and academic supervisors), and give special thanks to our colleagues who acted as peer reviewers for the proceedings and whose expertise and knowledge was paramount: Omar Alani, Belqais Allali, Zeeshan Aziz, Teslim Balogun, Andrew Clark, Paul Coates, Hisham Elkadi, Terrence Fernando, Kwasi Gyau Baffour Awuah, Anthony Higham, Bingu Ingirige, Yingchun Ji, Kaushal Keraminiyage, Amanda Marshall-Ponting, Brodie McAdam, Athena Moustaka, Mustapha Munir, Jason Underwood, Greg Watts, and Mike Wood.

Thanks also to our copyeditor, Ayesha Chari, who enhanced papers with diligence and exactitude; Hanneke van Dijk, for administrative support; Daniela Atzori and Laura Janicka, for designing the splendid front cover; and the School of Science, Engineering and Environment for supporting the conference and its proceedings.

Without all of you, academic conferences, synergies, and networks across countries and publications such as this one would not be possible.

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Applications of Digital Technologies

A building information modelling framework for the scheduled maintenance of public university buildings in Nigeria

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Abstract: Poor maintenance management systems have always led to preventable increase in maintenance costs, inadequate user satisfaction, and low productivity. Maintenance professionals use sheets of paper and field notes to handle various types of information, including two-dimensional drawings for inspection and maintenance, and this process could be very tiring. The building information modelling (BIM) approach can be applied and developed as three-dimensional models to improve maintenance works. This study aims to develop a building maintenance management framework for public university hostels using BIM as a benchmark. The specific objectives are to assess the maintenance management framework used by the Works Department of public universities in the study area and to develop the BIM framework. A triangular approach of design was used in carrying out data collection: questionnaire, review of relevant literature, and eventual development of the BIM scheduled maintenance framework. The Professor Peter Olufemi Adeniyi Men's Hostel in the Federal University of Technology Akure, Nigeria, was taken as a case study. The study found that the major maintenance management framework used in the study area is routine maintenance and concluded that the newly developed BIM scheduled maintenance framework will reduce the downtime of facilities and provide swift response to maintenance requests. BIM is still at its developmental stage in the Nigerian construction industry and it is hoped that digital twin (DT) technology will also be adopted to enhance the use of BIM. Further research should be carried out on DT and early warning systems for building maintenance management.

Keywords: BIM, facility management, Industry 4.0, information technology, maintenance management

Acknowledgements: The authors are grateful to the management of the Federal University of Technology, Akure, Nigeria, for the enabling environment to carry out this research.

1 Introduction

There is no doubt that the maintenance management of buildings is critical to prolonging a building's life cycle and reducing an organization's loss. When buildings are not properly managed defects can arise, which most times result in widespread and inevitable damage to the buildings (Yuseni & Abd Samad, 2013). Lateef et al. (2010) explained in a study that tertiary institutional buildings need maintenance in order to create and aid favourable learning, teaching, innovation and research environments. Over the years, university halls of residence have been subjected to intense use as a result of the upsurge in the number of students admitted into the school for various programmes. To cope with this reality, universities have embarked on various construction projects that include the construction of new halls of residence, lecture halls, and laboratories. Constructing new buildings is critical to the improvement of educational facilities and provides an enhanced quality of education; however, it is also essential to maintain the existing buildings to a satisfactory level of performance, to ensure that the buildings are adequate to ease the transmission of knowledge and other academic intentions (Lateef et al., 2010). Several drawbacks have surfaced over the years including maintenance schedules that are not properly developed, deficiency of study and predictive systems to overcome building failures, and unstructured plan to reduce failure time of building components or decreasing the cost of inspection and maintenance. All these call for a more structured approach to handling the maintenance of these facilities.

Khalil and Husin (2009) explained that the educational system and learning activities of higher institutions is usually at risk when buildings experience poor performance conditions. There have been a lot of criticisms in the media and in literature that tertiary institutional buildings are not performing as expected because of poor management ideas; this expresses the absence of value added services by maintenance stakeholders. Buys et al. (2009) and Zulkarnain et al. (2011) asserted that the performance of tertiary institutions in developing countries, in relation to maintenance management, is far below best practice. There is no doubt that there could be a problem of insufficient funds; but the foremost issue is attributed to poor management philosophy and principles. It was thus noted by Lateef et al. (2010) that poor maintenance management systems have always led to preventable increase in maintenance costs, inadequate user satisfaction, and low productivity. The foregoing poses questions such as 'what could the management of maintenance organizations in tertiary institutions do to improve their services?' 'What are the innovative ideas in line with Industry 4.0 that can be inculcated for effective management of maintenance activities?' Generally, maintenance professionals are expected to access building locations to handle inspection and maintenance work. This has always been carried out using manual processes that could be very tiring. Su et al. (2011) agreed to this assertion that the staff of maintenance units use sheets of paper and field notes when carrying out their works; and they also manage diverse information forms, including two-dimensional (2D) drawings, ancillary components, and fixtures manuals for inspection and maintenance. Conversely, as buildings become more complex, it is not easy to make use of the regular 2D computer-aided design (CAD) information for efficient maintenance of buildings. It has become a challenge to achieve an efficient maintenance of university buildings. Hence, the need for a more efficient approach in the maintenance management of tertiary institutional buildings cannot be overemphasized. The fourth industrial revolution (4IR) technologies could be used for efficient management of buildings.

Industry 4.0, which can also be regarded as 4IR, is one of the most recent developmental phases that incorporates information technology/techniques into production routes. A number of terms have also been used to describe the 4IR, including internet of services, industrial internet, advanced manufacturing, and smart factory. Other climes have also described the phase as the industrial age or second machine age (Hermann et al., 2016). Davies (2015) noted that the European Commissioner's seminar, which was made public in September 2015, asserted that the expression originated from Germany's manufacturing industry and the federal government bred the phenomenon in 2011. It was with the aim to project its high-tech approach that the German federal government came up with 4IR in 2011. The 4IR technology incorporates a widespread array of interdisciplinary perceptions with no palpable difference (Lasi et al., 2014; Oesterreich and Teuteberg, 2016), which shows that the adoption of Industry 4.0 tools, like building information modelling (BIM) in the maintenance management of university buildings, will lead to a more efficient and robust framework causing competitiveness in the university system. Industry 4.0 or 4IR was viewed by then German Chancellor Angela Merkel as the merging of digitalization concepts with a traditional industrial system in order to transit the whole system of manufacturing industries to an upgraded level (Davies, 2015). The chancellor's statement implied that the total make-up of industries (designers, manufacturers, products, and end-users) should be digitalized. 4IR permits a better inclusive, coordinated, and cohesive manufacturing method. Moreover, 4IR has the capacity to link the physical and digital environments of products, countenancing an improved collaboration and communication between sectors, purveyors, goods, and employees (Taher, 2021); it can also be said that these are some of the salient features of BIM. Xu et al. (2018) posited that 4IR improves various industries, business set-ups, and their practices. Hence, there is need to take advantage of Industry 4.0 tools for efficient maintenance management of tertiary institutional buildings.

BIM has been recognized as a recent and useful system for the maintenance management of buildings. Motawa and Almarshad (2013) presented the case-based reasoning-integrated BIM system for maintenance of constructed facilities to improve the decision-making efficiency and communication among professionals and a list of other stakeholders. Hu et al. (2018) also justified the relevance of BIM in the maintenance management of buildings. The BIM approach can be applied and used to develop three-dimensional (3D) information models for improved maintenance of university hostels. With the integration of building information models and related information of building maintenance work, the activities of maintenance professionals will be made more efficient. Using this approach, building maintenance management information can be spread and shared in the 3D environment. Hence, this research proposes an innovative and practical method to capture and represent building maintenance management information in Nigerian universities through the application of BIM. The proposed framework was tested on the Professor Peter Olufemi Adeniyi Men's Hostel in the Federal University of Technology Akure (FUTA), Nigeria, using the Autodesk Revit software package to prepare the maintenance schedule. This study aims to develop a building maintenance management framework for public university hostels using BIM as a benchmark. The specific objectives are to assess the maintenance management framework used by the Works Department of public universities in the study area and develop a framework for maintenance management of hostels using BIM.

2 Literature review

2.1 Review of various maintenance management frameworks

Olanrewaju (2009) proposed the improvement of the worth of buildings through a proactive maintenance management structure with particular emphasis on the concept of value. The author explained that such a management approach offers a distinct goal definition of the maintenance programmes and policies and establishes the maintenance problems that require solutions. The concept of value as proposed by the study is that buildings are to be maintained to continually serve the purpose of their construction; for example, a lecture hall is built to deliver a favourable atmosphere for teaching and learning. The drawback of this study is that it failed to consider other services or use that a building is subjected to. Adequate maintenance of faculty buildings to continually fulfil the purpose of their construction (e.g. office spaces and lecture rooms) without taking note of other services such as restrooms or mini stores will not make these buildings outlive their lifespan because all components of the building are not paid attention to.

A life-cycle cost for multi-storey housing was developed by the collaboration of researchers at the University of Technology Malaysia and the Ministry of Housing and Local Government (Tapsir et al., 2005). The model presented an ability to measure and estimate the life-cycle cost of a building, with the prediction of its functional life. It was not void of setbacks as it required an overwhelming amount of data to estimate a building's life-cycle cost. Moreover, the difficulty in estimating future costs specifically for maintenance of constructed facilities was noted. The use of the model was very expensive, predominantly for private owners of buildings.

Lateef et al. (2011), in their research on the maintenance management structure of a tertiary institution in Malaysia, noted that the maintenance management structure used by the government's Property and Maintenance Management Department was mainly corrective and cyclical. Corrective maintenance was usually carried out to remedy a building to its original state after a failure. The works are performed based on the results of the building survey or inspection indicating the defects or as requested by occupants. The criticisms on these approaches for maintenance activities make them inadequate for use; a continuous use of these approaches mostly end in maintenance backlogs and poor user satisfaction. These and other maintenance management approaches (like deferred maintenance, which is based on budget rather than apparent needs) have been used in constructed facilities.

From the review of various frameworks that have been suggested and recommended for the maintenance management of buildings, this study identified a gap in the use of a BIM-enabled platform for the scheduled maintenance of public university buildings. Building maintenance management framework using BIM as proposed by this study will provide a better platform to maintain facilities in the university. This framework will utilize a type of maintenance planning system that includes the scheduled system. The adoption of BIM will allow scheduling work and inspections to be carried out at predetermined times and intervals; this will predict when specific works will be needed and the extent of work to be done. BIM use can reduce downtimes in the facilities and also eliminate further deterioration of building components by providing a rapid response system. There is no doubt that the newly developed framework will improve decision making and collaboration among stakeholders and increased information technology maturity in the maintenance management of public university buildings in Nigeria.

2.2 Building information modelling

In a work by Savage (2014), an integrated body made up of the Royal Institute of British Architects, Construction Project Information Committee, and BuildingSMART defined BIM as the 'digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition'. BIM can also be defined as 'a set policy, process and technology approach for managing the collaboration and integration of building projects through the building's lifecycle' (Succar et al., 2007). Yan and Damian (2008) explained that BIM serves as a design management tool for analysing the building life cycle – the design, construction, and facility management stages. BIM evolved as a tool with advantages such as decrease in contract sum, increased productivity, increased project delivery time, and improved quality (Azhar, 2011). Costly errors, clashes that may arise on site, and rework can be avoided by using BIM for detections; this results in safe, effective, and quality constructed facilities. Arayici et al. (2009) also reiterated that the arrival of BIM has led to improvement in the design, management, operations, and maintenance of buildings. BIM technology has created a building virtual model called 'building information model' (Azhar, 2011). Dim et al. (2015) explained that BIM recently emerged as a dominant tool for the design, construction, and maintenance of building projects to promote collaboration and to integrate the design team with all other professionals and stakeholders.

BIM enables the building industry to increase productivity by an efficient and effective communication and collaboration process between the stakeholders of a project from its inception to completion (Becerik-Gerber & Rice, 2010). Building information models have the ability to store up-to-date information and can be accessed in an integrated digital environment, giving the building professionals and other stakeholders (e.g. clients) a clear and overall view of projects. It is a better and faster decision-making process leading to an increase in profitability and quality of projects (Nisbet & Dinesen, 2010). The use of BIM in the construction industry aids in ensuring that information is communicated among project stakeholders on time, which allows for the early production of data needed for design and detailing (Ashcraft, 2008). The emergence of BIM has made project teams operate in multi-sensory collaboration and with a better communication structure (Ugochukwu et al., 2015). Fox and Hietanen (2007) asserted that BIM is a powerful tool for analysis and decision making among construction disciplines, which will help to identify and simulate existing or virtual building structures. Eastman et al. (2011) agreed that the use of BIM creates a more effective building process. Succar et al. (2012) also affirmed that BIM can aid in solving problems of inefficiencies in the architecture, engineering, and construction industry.

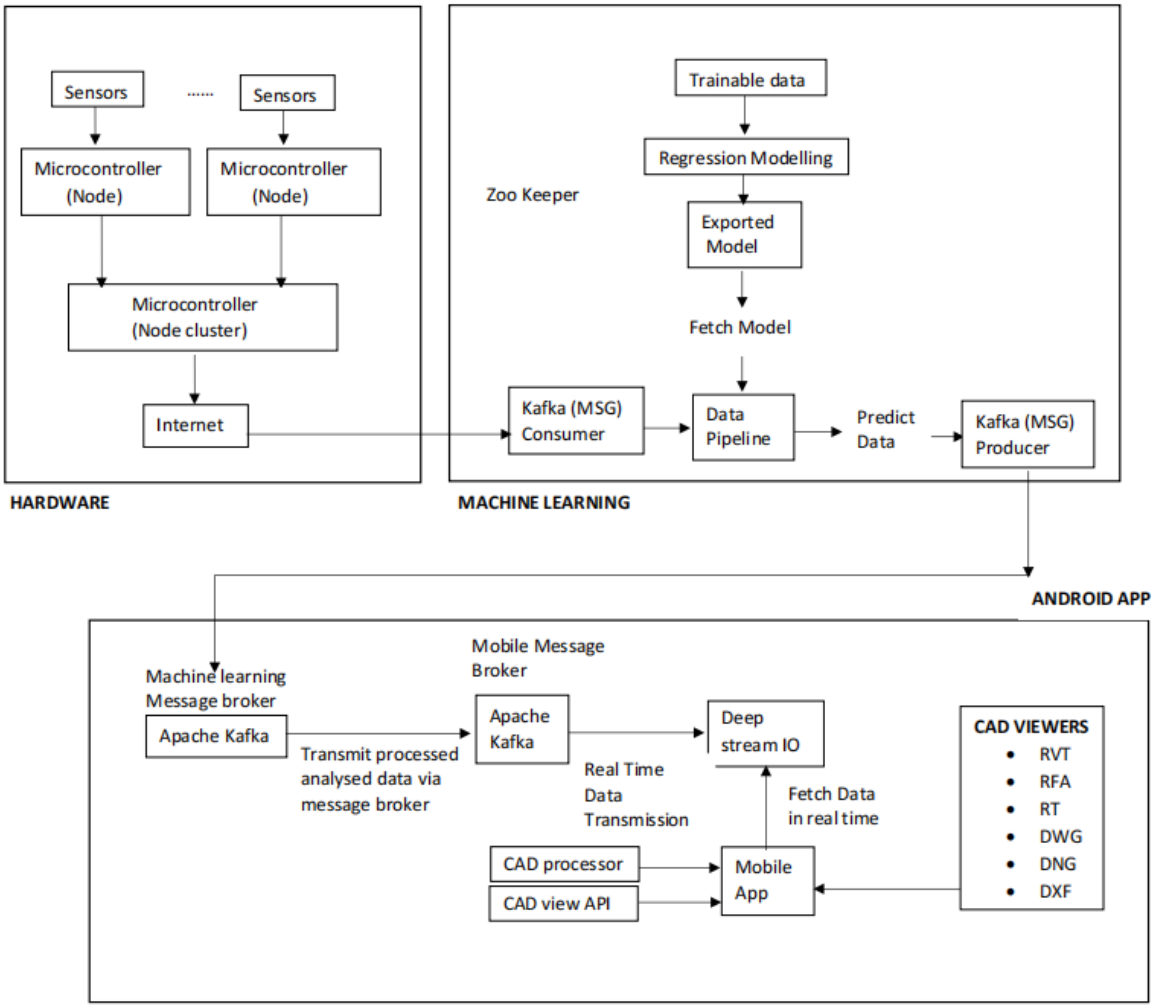
Azhar et al. (2008) explained the important difference between BIM and 2D CAD. Their study argued that the 2D CAD only gives views like plans, elevations, and sections that do not depend on each other. When changes are made on a project view (e.g. elevations), if other views are not properly corrected, it makes way for error and makes documentation incomplete. Sacks et al. (2010) asserted that BIM is a generic term that explains the use of advanced 3D (or 4D or 5D) CAD technology to model and manage buildings with their related information.

Yusuf et al. (2015) proposed an interrelationship of BIM and three components: (i) people, (ii) process, and (iii) digital technology; for a complete cycle of BIM, none of these components should be absent. Their study concluded that BIM is a system developed from the interrelationship of these three elements.

The present study is part of ongoing and planned research on the use of Industry 4.0 tools for efficient maintenance management of constructed facilities. This is an experimental and applied study that can be improved through the use of more robust and innovative systems. A support system to produce efficient maintenance management, on the rise in other industries, is the digital

twin (DT) technology. DT technology can be used to improve the newly developed BIM framework of this study through its capacity to bring about better scheduled and predictive maintenance of building facilities. The diagrammatic model in Figure 1 is a path to the implementation of DT in the maintenance management of public university buildings in Nigeria.

Figure 1: Flow diagram of DT for buildings



Source: Authors' own.

3 Methodology

3.1 Overview

This study evaluates various building maintenance management frameworks and aims to develop a new maintenance management framework, which is the BIM scheduled maintenance. For the aim of this study to be accomplished, a triangular design approach was used to carry out the data collection using a questionnaire, review of relevant literature, and eventual design and development of the BIM scheduled maintenance. The research was carried out in Ondo State, Nigeria, where there are four public universities. The Professor Peter Olufemi Adeniyi Men's Hostel in FUTA was taken as a case study (Plate 1).

Plate 1: Different views of the case study building

(a) Side view of the building

(b) Front view of the building

(c) Rear view of the building

(d) Side view of the building

(e) Side view of the building

(f) Interior view of the building

Source: Photographs by Ayokunle Onadiji, co-author of this study.

3.2 Research methods

The case study design was chosen for this study because it is the framework governing the research being conducted, serving as a guide in the successful pursuit of the aims of the study (Churchill, 2001) and influencing the research instrument for collecting data (Sarantakos, 2005). According to Yin (1984), the case study research technique is an empirical investigation that examines a current phenomenon in its actual setting; when the distinctions between phenomenon and setting are not immediately apparent and when several kinds of evidence are utilized. Yin (1984) emphasized that a research project using a case study approach might use a variety of methodologies and sources to look into a topic. Hence, the survey part of the present study used the quantitative method of research for collection of relevant data to aid the case study.

Professionals actively engaged in the maintenance management of public university facilities were the targeted population for the quantitative component of the study. Professionals working in the Works Department of public universities in the study region include architects, builders, engineers, quantity surveyors, estate surveyors and valuers, and project managers. After identifying the target group, it is crucial to choose a sampling technique that will work for the population being sampled. Convenience sampling was chosen for this study because the professionals who were accessible and willing to participate in the study were taken as the respondents. Convenience sampling, also

referred to as haphazard sampling or accidental sampling, is a type of non-probability or non-random sampling in which members of the target population who meet specific practical criteria, such as easy accessibility, geographic proximity, availability at a specific time, or a willingness to participate, are included for the study's purposes (Dörnyei, 2007). Therefore, a sample size of 75 professionals was selected for the questionnaire survey.

The primary data were gathered through a questionnaire study and the secondary data came from a review of the literature from earlier research. The primary data collected through the survey questionnaire were derived based on the factors found in previously published maintenance management literature. For participants who are actively involved in building maintenance, a structured questionnaire was given. The questionnaire was divided into two sections: Section A contained respondents' personal information, such as their organizational affiliations, job titles, educational backgrounds, and years of work experience, whereas Section B focused on the specific goals of this study. The collected data were displayed in tables and analysed using frequency and percentages in the statistical program for social sciences (SPSS 21). The BIM scheduled maintenance was developed for the case study building using AutoCAD 2010 and Revit Autodesk 2016 design software packages.

4 Results and discussion

4.1 Demographic information of the respondents

Table 1 reveals that 75 copies of the questionnaire were administered; a total of 64 usable responses were retrieved, which represents an 85.3% effective rate of response, and 11 responses were not retrieved, which indicates a 14.7% rate of failure to respond. Thus, 85.3% of the questionnaires administered were retrieved and valid for this research.

Table 1: Demographic information of respondents

Respondents characteristics	Frequency	Percentage
Number of questionnaires distributed	75	100
Number of questionnaires retrieved	64	85.3
Number of questionnaires not collected	11	14.7
Gender of respondent		
Male	46	71.9
Female	18	28.1
Total	64	100
Position in organization		
Facilities manager	25	39.1
Foreman of works/supervisor	14	21.9
Finance officer	12	18.8
Maintenance engineer	12	18.8
Others	1	1.6
Total	64	100
Years of experience		
3–5 years	35	54.7
1–2 years	16	25.0
More than 5 years	9	14.1
Total	64	100
Qualification of respondent		
BSc	41	64.0

MSc	14	21.9
HND	6	9.4
OND	2	3.1
PhD	1	1.6
Total	64	100
Professional affiliation		
NIESV	15	23.4
Others (NIM, IPMA)	15	23.4
NIOB	14	21.9
NSE	11	17.2
NIA	6	9.4
NIQS	3	4.7
Total	64	100

Notes: HND, higher national diploma; OND, ordinary national diploma; NIESV, Nigerian Institution of Estate Surveyors and Valuers; NIM, Nigerian Institute of Management; IPMA, Institute of Professional Managers and Administrators; NIOB, Nigerian Institute of Building; NSE, Nigerian Society of Engineers; NIA, Nigerian Institute of Architects; NIQS, Nigerian Institute of Quantity Surveyors.

Source: Authors' own.

As shown in Table 1, 71.9% of respondents are male and 28.1% are female, which means that, on average, both genders are represented in the questionnaire administered. However, the low representation of the female gender presents the true state of low participation of women in the construction industry.

For position in organization, 39.1% of respondents are facility managers, 21.9% foremen of works/supervisors, 18.8% finance officers, 18.8% maintenance engineers, and 1.6% other. This means that majority of the respondents are facility managers.

For years of experience, 54.7% of the respondents have between 3 and 5 years of experience, 25% between 1 and 2 years, 14.1% more than 5 years, and 6.2% less than 1 year. This shows that majority of the respondents have a satisfactory level of experience.

As shown in Table 1, the highest qualification of the majority of respondents is a BSc, with 64% of them holding a BSc degree; 21.9% have an MSc degree, 9.4% a higher national diploma (HND), 3.1% an ordinary national diploma (OND), and 1.6% a PhD, which implies that all respondents are educated.

From the 75 questionnaires administered to the construction professionals, 64 copies were retrieved. As shown in Table 1, 23.4% of the respondents are affiliated to NIESV, 23.4% to other professional institutes such as NIM and IPMA, 21.9% to NIOB, 17.2% to NSE, 9.4% to NIA, and 4.7% to NIQS. This indicates that all the respondents are professionally registered and qualified statutorily.

4.2 Maintenance management frameworks used in the study area

Table 2 presents the results of the mode of maintenance used by the respondents. A larger percentage of the respondents (42.2%) use reactive maintenance, 26.6% use routine maintenance, 12.5% use preventive maintenance, 9.4% use proactive maintenance, 6.2% use BIM scheduled maintenance, and 3.1% use deferred inspection. This shows that awareness of the benefits and relevance of BIM for improved management of building facilities is low in the study area.

Table 2: Mode of maintenance used

Framework	Frequency	Percentage
Reactive maintenance	27	42.2
Routine maintenance	17	26.6
Preventive maintenance	8	12.5
Proactive maintenance	6	9.4
BIM scheduled maintenance	4	6.2
Deferred inspection	2	3.1
Total	64	100

Source: Authors' own.

Table 3 shows the factors that necessitate the carrying out of maintenance on buildings in the study area by the respondents. Of the respondents, 43.8% go with maintenance upon request, 31.2% with maintenance upon inspection, and 25% with maintenance before the occupancy of new tenant. Thus, a larger percentage of the respondents agreed with maintenance upon request as the best option. This reflects the need for a more innovative approach through the use of a BIM-enabled framework.

Table 3: Factors for carrying out of maintenance

Factors	Frequency	Percentage
Upon request	28	43.8
Upon inspection	20	31.2
Before occupancy of new tenant	16	25.0
Total	64	100

Source: Authors' own.

4.3 Development of BIM scheduled maintenance

To achieve the study objective and validate the conceptual framework developed in this study – that is, to develop a framework for maintenance management of hostels using BIM – the following processes were followed.

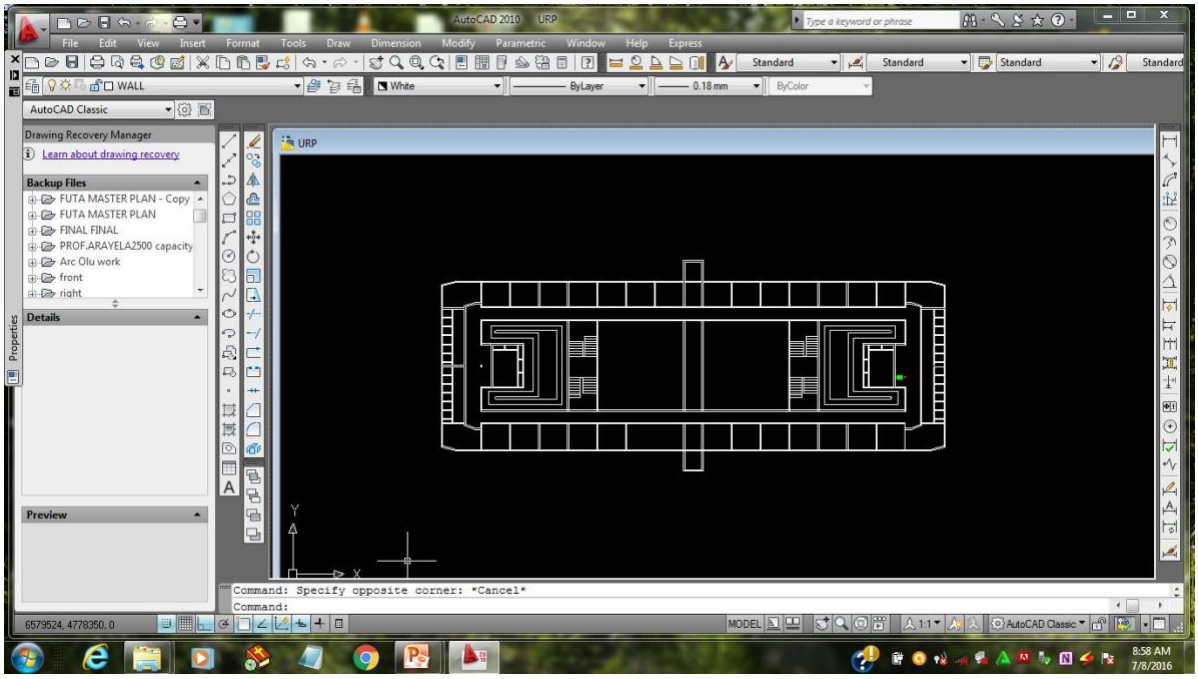
4.3.1 Taking as-built measurement of the building

The first step was to take the as-built measurement of all the components and sub-assemblies of the case study building: the Professor Peter Olufemi Adeniyi Men's Hostel in FUTA. Pictures were taken to ensure precision and accuracy during design. Details of various components were also noted.

4.3.2 Design on AutoCAD

After taking the as-built measurement, the next step taken was its design on AutoCAD (2010 version; Plate 2).

Plate 2: Screenshot of the floor plan design on AutoCAD

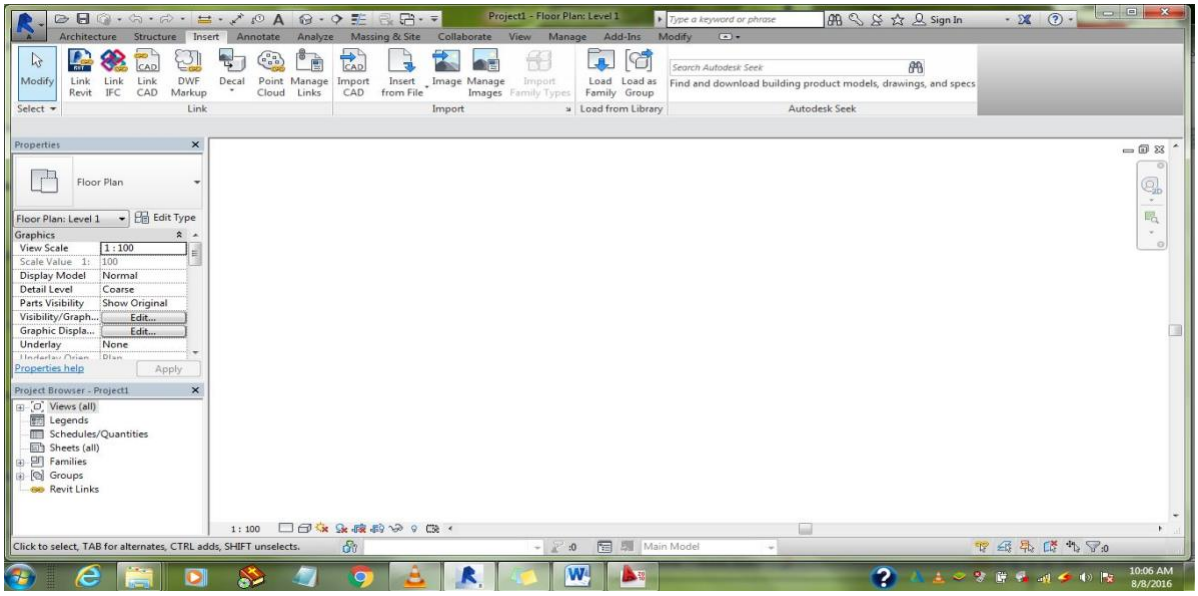


Source: Authors' own.

4.3.3 Import into Revit Autodesk environment

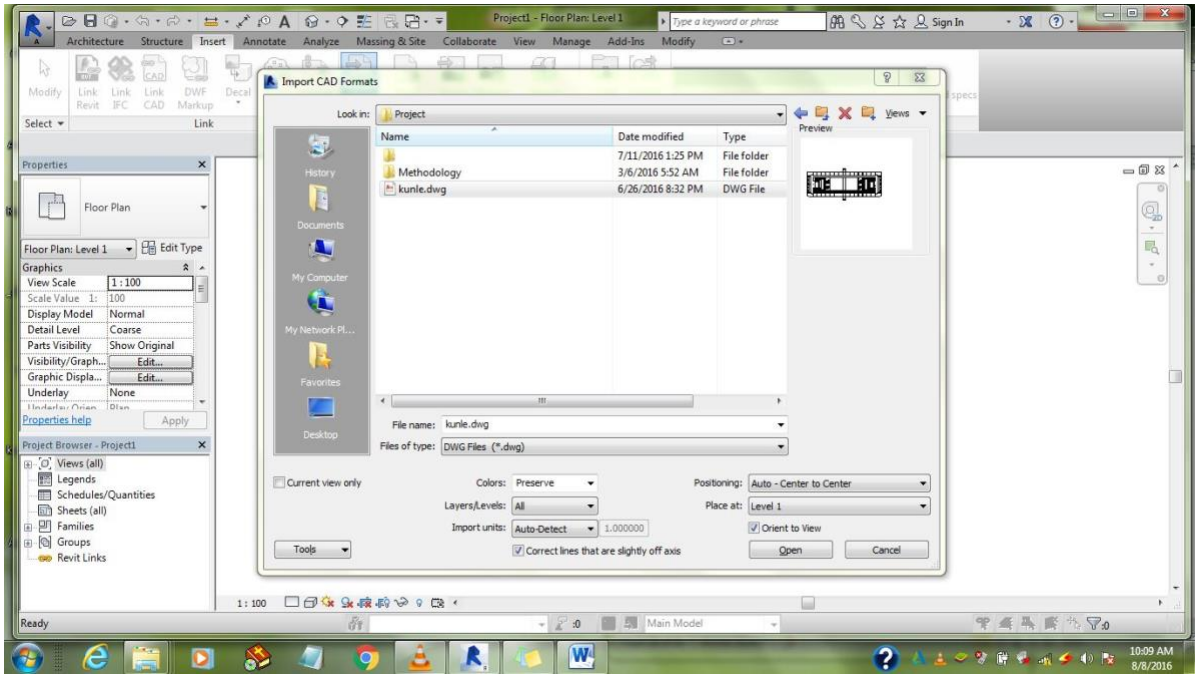
After design on AutoCAD, the plan was imported into the Revit Autodesk architecture software package for 3D modelling. Various components and sub-assemblies of the building were modelled. Interoperability of the two design software made it easy for the import and export of the plan. The first step was to open a new board on AutoCAD, and the previously saved plan was copied. Note that the file was first saved as URP.dwg and then saved on the new board with a new name; this enabled the file to be accessible using Revit Autodesk (Plates 3 and 4).

Plate 3: Screenshot of Revit board showing where to access the Import tab



Source: Authors' own.

Plate 4: Screenshot of Revit board showing how to import AutoCAD file

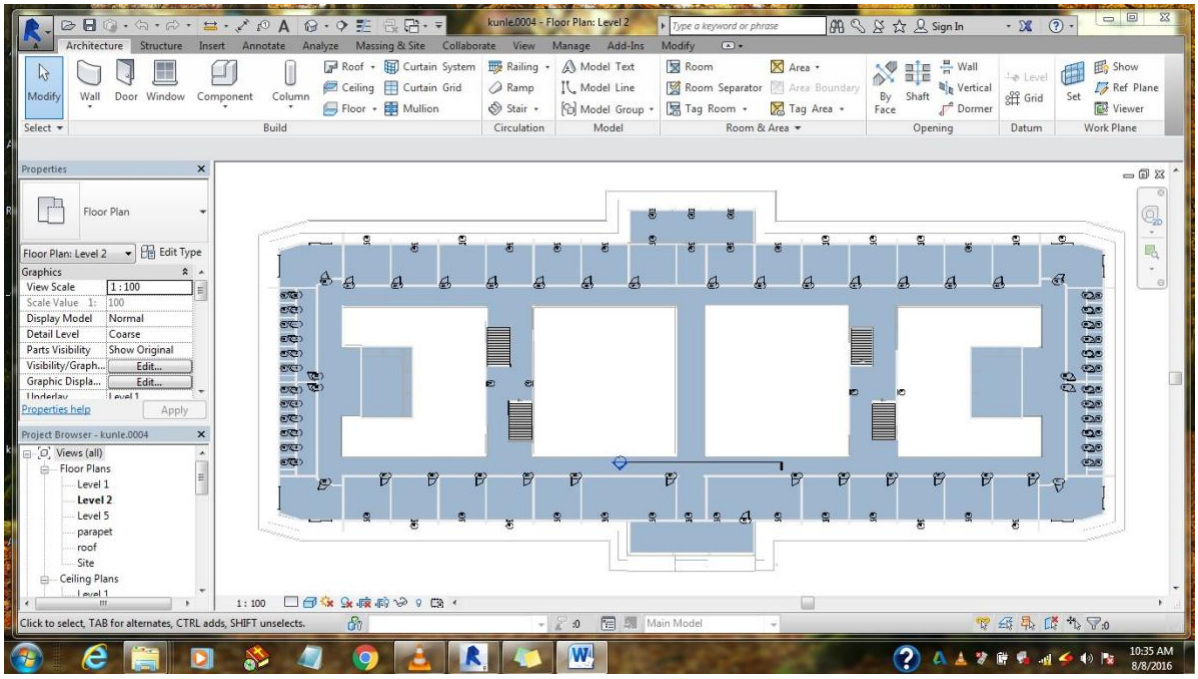


Source: Authors' own.

4.3.4 Design using Revit software

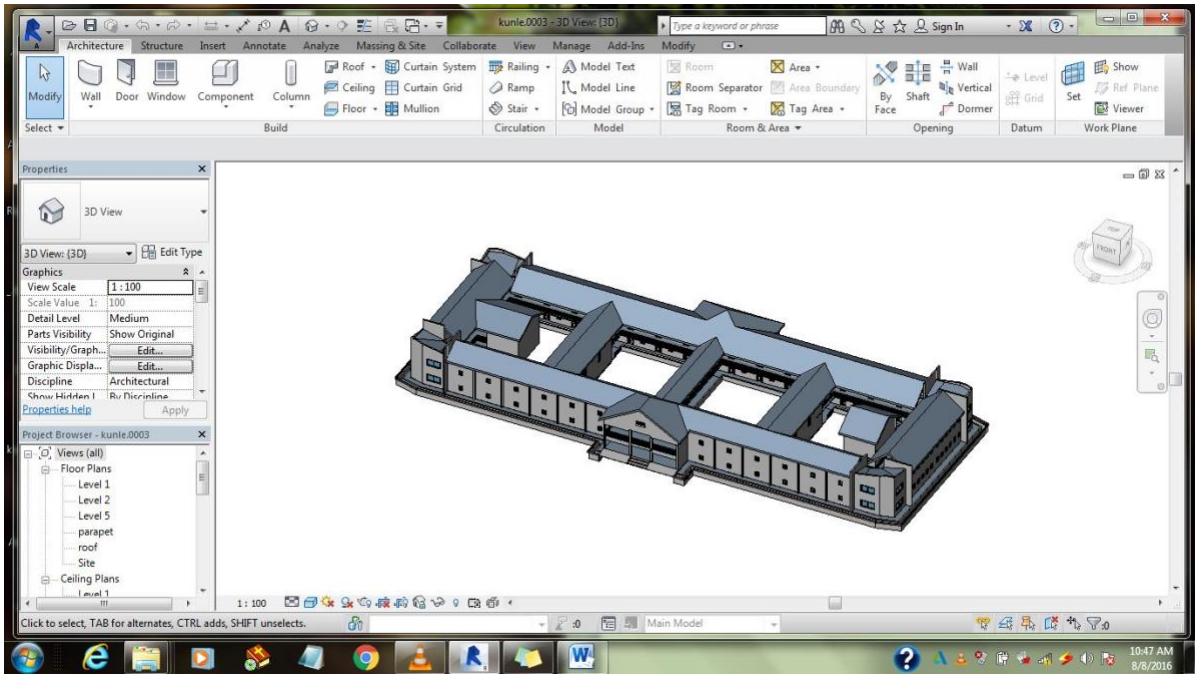
The 3D model of the building was made using Revit Autodesk. The modelling started with the floor and then components such as doors, windows, and sub-assemblies (walls and roof) were added (Plates 5 and 6).

Plate 5: Screenshot of the floor plan design on Revit



Source: Authors' own.

Plate 6: Screenshot of the ongoing design using Revit



Source: Authors' own.

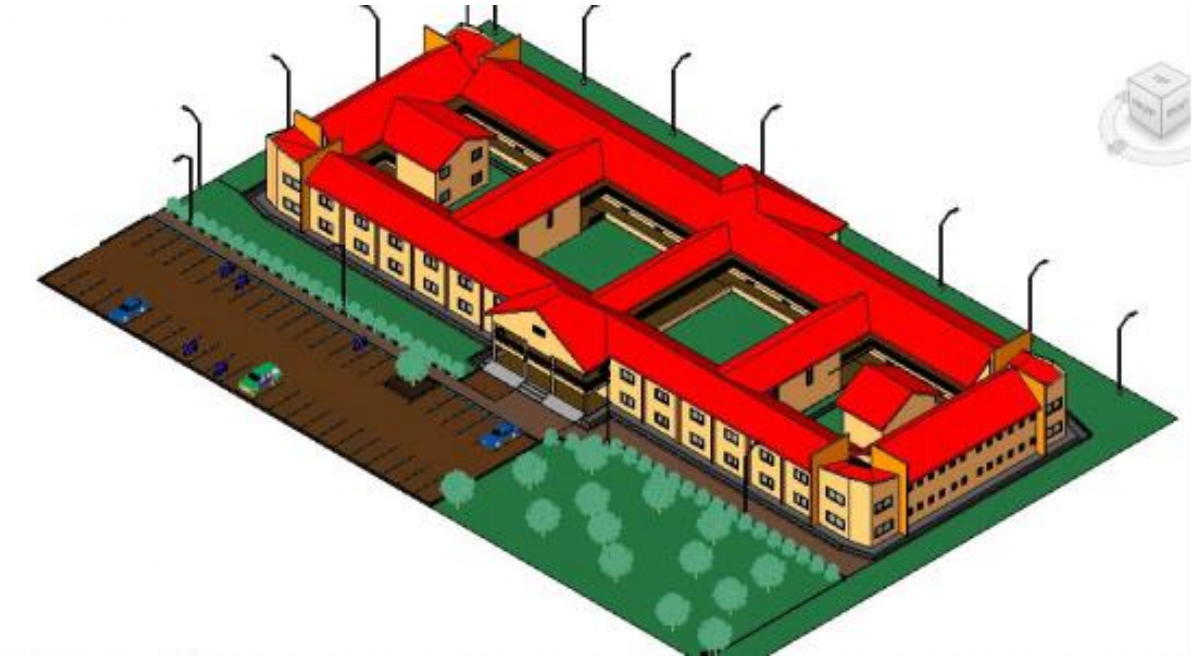
4.3.5 Rendering of the building

After completion of the 3D modelling, the building was rendered for aesthetic appreciation and to make the building as realistic as possible (Plates 7–10).

Plate 7: Screenshot of the front view of the Professor Peter Olufemi Adeniyi Men's Hostel, FUTA, Nigeria, as developed from Revit Autodesk design software

Source: Authors' own.

Plate 8: Screenshot of the aerial view of the Professor Peter Olufemi Adeniyi Men's Hostel, FUTA, Nigeria, as developed from Revit Autodesk design software



Source: Authors' own.

Plate 9: Screenshot of the interior view of the Professor Peter Olufemi Adeniyi Men's Hostel, FUTA, Nigeria, as developed from Revit Autodesk design software

Source: Authors' own.

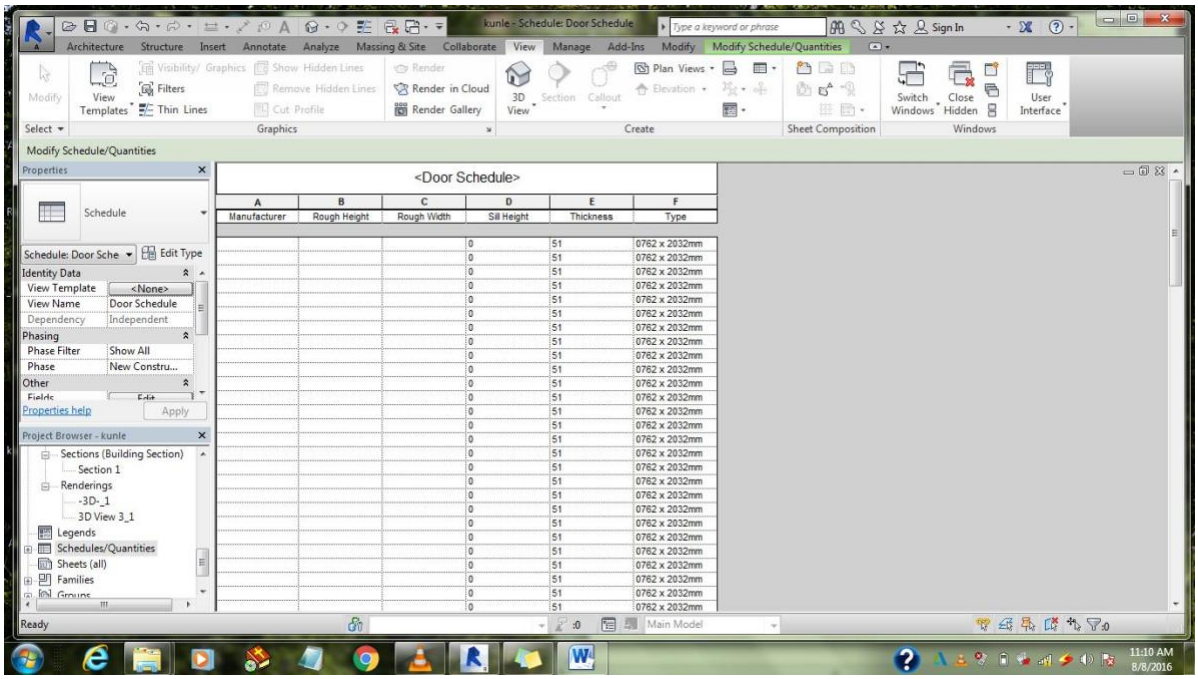
Plate 10: Screenshot of the 3D modelled view of the Professor Peter Olufemi Adeniyi Men's Hostel, FUTA, Nigeria, developed from Revit Autodesk design software

Source: Authors' own.

4.3.6 Generating the building maintenance schedule

The schedule of components for the modelled building was developed after the completion of design. Important items such as details, numbers, and location of the components was used in preparing the maintenance schedule (Plate 11).

Plate 11: Screenshot of the generation of schedule of components using Revit



Source: Authors' own.

4.4 Discussion of building maintenance results generated using BIM

The case study building of the Professor Peter Olufemi Adeniyi Men's Hostel in FUTA was constructed in 2011, indicating that the building had been in use for about 7 years at the time of carrying out this research work. The building houses a total of 48 rooms on two floors for accommodation of students. Each room is assigned to four students. Other facilities in the building include two laundry rooms on each floor, one common room, two toilet-and-bathroom wings on each floor, and two reading rooms. Each toilet-and-bathroom wing houses six bathrooms and six toilets. The building can be referred to as duplicated as the left section of the building is the same as the right section of the building when a section is taken through the middle.

Table 4 shows a section of the generated BIM maintenance schedule. It shows the components in the rooms, their quantities, sizes/dimension, average lifespan, and the date for replacement. The total number of light bulbs in all the rooms is 48, with an average lifespan of 6 months and a due date for replacement of February 2017. The total number of switches in all the rooms is also 48, with an average lifespan of 3 years and a due date for replacement of 2019. The aluminium casement windows in all the rooms totals 96 (two per room), with dimensions of 1,200 mm×1,200 mm, an average lifespan of 5 years, and a due date for replacement of August 2021. This table, through the interface of the as-built BIM model, serves as the BIM scheduled maintenance framework for the professionals and stakeholders in the university for a prompt scheduled maintenance of the facility.

Table 4: Maintenance schedule for the Professor Peter Olufemi Adeniyi Men's Hostel, FUTA, Nigeria, as generated from Revit Autodesk design software

Components	Location	Manufacturer	Quantity	Size/dimension	Average lifespan	Due for replacement
	Rooms					
Light bulbs			48		6 months	February 2017
Switches			48		3 years	August 2019
Ceiling fan		SMC	48		2 years	August 2018
Fan regulator		SMC	48		2 years	August 2018
Wall socket		Smart Royal	96		1 year	August 2017
Doors			48	900 mm×2,100 mm		
Wardrobe doors and locks			3 wardrobe doors and locks/room	600 mm×1,800 mm	2 years	August 2018
Aluminium casement window			96 (2 per room)	1200 mm×1,200×mm	5 years	August 2021

Source: Authors' own.

5 Conclusion and recommendations

This study aimed at developing a building maintenance management framework for FUTA hostels using BIM as a benchmark. The objectives of this study were achieved through the assessment of the maintenance management framework used by the Works Department of public universities in Ondo State and the development of a framework for maintenance management of hostels using BIM.

The following conclusions were drawn:

- The major maintenance management framework used by the Works Department of higher institutions in Ondo State is routine maintenance.
- The BIM scheduled maintenance framework developed will reduce downtime of facilities and provide swift response to maintenance requests.

The study makes the following recommendations to help facilitate effective maintenance management of hostel facilities:

- Higher institutions should adopt a building maintenance management framework using BIM as a benchmark.
- Institutions should invest in a building maintenance management framework using BIM as a benchmark.
- Government policies on the implementation of BIM scheduled maintenance management framework should be formulated and enforced.
- Personnel in charge of maintenance operations in higher institutions should be trained on the use of BIM scheduled maintenance.
- DT technology can be used to improve the framework of this study through its capacity to bring about an effective scheduled and predictive maintenance of building facilities.

BIM is still at its developmental stage in the Nigerian construction industry and not without limitations when it comes to the predictive maintenance of buildings. It is recommended that further research should be carried out on how to develop improved frameworks in line with Industry 4.0 and be used to address issues pertaining to building maintenance management, such as the DT technology and early warning systems. The outcome of this study can also be enhanced by application of the computerized maintenance management system, to provide a rapid response to maintenance requests. This framework provides a better platform to maintaining hostel facilities by reducing emergency maintenance cost, ensuring prompt response to maintenance requests, ensuring that components are replaced with originals, and reducing the downtime experienced in hostel facilities.

6 References

Arayici, Y. Khosrowshahi, F., Ponting, A. M., & Mihindu, S. (2009, May 20–22). *Towards implementation of BIM in the construction industry* [Paper presentation]. The 5th International Conference on Construction in the 21st Century (CITC-V), University of Salford, Manchester, United Kingdom.

Ashcraft, H. W. (2008). Building information modelling: A framework for collaboration. *Construction Lawyer*, *28*(3), 5–18.

Azhar, S. (2011). Building information modelling (BIM): Trends, benefits, risks and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Azhar, S., Nadeem, A., Mok, J. Y. N., & Leung, B. H. Y. (2008, August 4–5). Building information modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects. In *Proceedings of the First International Conference on Construction in Developing Countries (ICCIDC – I): Advancing and Integrating Construction Education, Research & Practice*, Karachi, Pakistan (pp. 435–446).

Becerik-Gerber, B., & Rice, S. (2010). The perceived value of building information modelling in the US building industry. *Journal of Information Modelling in Construction*, *15*(2), 185–201.

Buys, F., Cumberledge, R., & Crawford, G. (2009, September 10–11). Comparative analysis of the performance of tertiary institutions in managing its assets. In *Proceedings of the RICS COBRA Research Conference* (pp. 658–671), University of Cape Town.

Churchill, G. A. (2001). *Basic marketing research.* The Dryden Press.

Davies, R., (2015). *Industry 4.0. Digitalisation for productivity and growth* [Briefing]. European Parliamentary Research Service.

Dim, N. U., Ezeabasili, A. C. C., & Okoro, B. U. (2015). Managing the change process associated with BIM implementation by the public and private investors in the Nigerian building industry. *Danish Journal of Engineering and Manufacturing Technology*, *2*(1), 1–6.

Dörnyei, Z. (2007). *Research methods in applied linguistics*. Oxford University Press.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modelling for owners, managers, designers, engineers and contractors* (2nd ed.). Wiley.

Fox, S., & Hietanen, J. (2007). Inter-organisational use of building information models: Potential for automation, informational and transformational effects. *Construction Management and Economics*, *25*(3), 289–296. https://doi.org/10.1080/01446190600892995

Hermann, M., Pentek, T., & Otto, B. (2016, March). Design principles for industrie 4.0 scenarios. In *Proceedings of the 49th Annual Hawaii International Conference on System Sciences (HICSS 2016)* (pp. 3928–3937), Koloha, Hawaii. https://doi.org/10.1109/HICSS.2016.488

Hu, Z. Z., Tian, P. L., Li, S. W. and Zhang, J. P. (2018). BIM-based integrated delivery technologies for intelligent MEP management in the operation and maintenance phase. *Advances in Engineering Software*, *115*, 1–16. https://doi.org/10.1016/j.advengsoft.2017.08.007

Khalil, N., & Husin, H. N. (2009). Post occupancy evaluation towards indoor environment improvement in Malaysia's office buildings. *Journal of Sustainable Development*, *2*(1), 186–191. https://doi.org/10.5539/jsd.v2n1p186

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, *6*(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

Lateef, O. A., Khamidi, M. F., & Idrus, A. (2010). Building maintenance management in Malaysian university campuses: a case study. *Australasian Journal of Construction Economics and Building*, *10*(1/2), 76–89. https://doi.org/10.5130/ajceb.v10i1/2.1593

Lateef, O. A., Khamidi, M. F., & Idrus, A. (2011). Validation of building maintenance model for Malaysian universities. *Elixir International Journal*, 36, 3410–3414.

Motawa, I., & A. Almarshad (2013). A knowledge-based BIM system for building maintenance. *Journal of Automation in Construction*, *29*, 173–182. https://doi.org/10.1016/j.autcon.2012.09.008

Nisbet, N., & Dinesen, B. (2010). *Constructing the business case: Building information modelling*. BuildingSMART, British Standards Institute, United Kingdom. https://www.hfms.org.hu/joomla/images/stories/BIM/FreeReport-BIM.pdf

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitization and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121–139. https://doi.org/10.1016/j.compind.2016.09.006

Olanrewaju, A. (2009). Case for alternative approach to building maintenance management of public universities. *Journal of Building Appraisal*, *5*, 2–4.

Sacks, R., Koskela, L., Dave, B. A., & Owen. R. (2010). Interaction of lean and building information modelling in construction. *Journal of Construction Engineering & Management*, *136*(9), 968–980. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000203

Sarantakos, S. (2005). *Social research* (3rd ed.). Palgrave Macmillan.

Savage, D. (2014). Building information modelling: What is it and what are the legal issues arising from its use? *Mondaq*, 1 September. https://www.mondaq.com/uk/construction-planning/336106/building-information-modelling-what-is-it-and-what-are-the-legal-issues-arising-from-its-use

Su, Y. C., Lee, Y. C., & Lin, Y. C. (2011). Enhancing maintenance management using building information modeling in facilities management. In *Proceedings of the 28th International Symposium on Automation and Robotics in Construction (ISARC 2011)* (pp. 752–757), Seoul, Korea. https://doi.org/10.22260/ISARC2011/0140

Succar, B., Sher, W., Aranda-mena, G., & Williams, T. (2007, March 8–10). *A proposed framework to investigate building information modelling through knowledge elicitation and visual models* [Paper presentation]. The 31st Annual Conference Proceedings of the Australian University Building Education Association, National Institute of Standard and Technology, Melbourne, Australia.

Succar, B., Sher, W., & Williams, A. (2012). Measuring BIM performance: Five metrics. *Journal of Architectural Engineering and Design Management*, *8*(2), 120–142. https://doi.org/10.1080/17452007.2012.659506

Taher, G. (2021). Industrial revolution 4.0 in the construction industry: Challenges and opportunities. *Management Studies and Economic Systems (MSES)*, *6*(3/4), 109–127. https://doi.org/10.12816/0060000

Tapsir, S. H., Yatim, J. M., & Usman, F. (2005, August 31–September 3). Towards better housing management: Service life planning in achieving sustainability for affordable housing? In *Proceedings of the Tenth International Conference on Civil, Structural and Environmental Engineering Computing* (Paper 73), Rome, Italy.

Ugochukwu, S. C., Akabogu, S. C., & Okolie, K. C. (2015). Status and perceptions of the application of building information modelling for improved building projects delivery in Nigeria. *American Journal of Engineering Research*, *4*(11), 176–182.

Xu, L. Da., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, *56*(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

Yan, H., & Damian, P. (2008, October 16–18). *Benefits and barriers of building information modelling* [Paper presentation]. The 12th International Conference on Computing in Civil and Building Engineering, Tingshua University, Beijing, China.

Yin, R. K., (1984). *Case study research: Design and methods*. Sage Publications.

Yuseni A. W., & Abd Samad, H. B. (2013). Building maintenance management preliminary finding of a case study in ICYM. *Middle-East Journal of Scientific Research*, 17(9), 1260–1268.

Zulkarnain, S. H., Zawawi, E. M. A., Rahman M. Y. A., & Mustafa, N. K. F. (2011). A review of critical success factor in building maintenance management practice for university sector. *World Academy of Science, Engineering and Technology*, *5*(3), 195–199.

Digital technological solutions for embodied carbon estimation in the building sector

A PRISMA review

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Abstract: Embodied carbon (EC) has emerged as a pressing issue in the building sector, with a focus on achieving the 2050 net zero carbon target. Accurate estimation of EC requires extensive data inputs, policies, and standards from the global construction supply chains. Although various tools exist for computing EC in the building sector, they largely rely on secondary data from users and environmental product declarations, raising concerns about the accuracy of the estimates. Critics argue that the construction industry needs to focus on adopting emerging digital technologies (EDTs) to improve the accuracy of EC estimation. This study aims to investigate state-of-the-art current literature on the use of EDTs in embodied emission estimation of the construction industry. Using preferred reporting items for systematic reviews and meta-analyses, a systematic literature review was conducted on government reports, journal articles, and conference publications from the last five years (2017–22). The study focused on five EDTs – blockchain, machine learning, building information modelling, digital twin, and Internet of things – to analyse their potential adoption for improving the accuracy of EC estimation. The research community has attempted to address the limitations of existing tools by utilizing salient features of the EDTs, and the study highlights four key performance features – accuracy, traceability, transparency, and efficiency – that have contributed to the development of the EC tool. The study concludes that the usage of EDTs has proven to be effective in overcoming certain limitations, but more research is required to develop commercially viable tools using EDTs. The authors critically evaluate the building sector's contribution to achieving the United Nations Sustainable Development Goal 13 of 'climate action', highlighting the need for the construction industry to adopt emerging technologies to improve EC estimation accuracy and contribute to global sustainability efforts.

Keywords: building sector, embodied carbon measurement, emerging technologies, measurement tools, performance features

1 Background

The construction industry has been identified as 'one of the least digitized industries compared to other major sectors' (Dewhurst, 2017). This can be attributed to several factors such as involvement of numerous stakeholders, loose coupling of tasks and participants, lack of incentives to embrace new methods, and insufficient investments in research and development budgets (Koeleman et al., 2019). Nevertheless, with growing interest in new technologies, stakeholders are paying more attention to embracing digitalization (Chen et al., 2021).

In the meantime, the industry, scholars, and governments are increasingly focused on reducing greenhouse gas emissions, especially carbon dioxide (CO_2) emissions, in the quest for sustainability through technology (Su et al., 2021). According to WorldGBC (2019), the construction industry is 'responsible for 39% of all carbon emissions in the world, with operational emissions (from energy used to heat, cool and light buildings) accounting for 28%. The remaining 11% comes from embodied carbon emissions [. . .] associated with materials and construction processes.' Mathematical equations and models were initially developed to estimate the embodied carbon (EC) emissions of building products that included carbon content from cradle to grave. However, the usage of such manual models has been gradually replaced by open-source EC counting tools (Ekundayo et al., 2019).

Professionals often use stand-alone EC estimation tools, such as the Institution of Civil Engineers (ICE) database, the embodied carbon in construction calculator (EC3), and OneClick life-cycle assessment (LCA) tool. However, many notable inaccuracies have been identified, including the scope, usage of generic data, and data representativeness (Sinha et al., 2016). Moreover, when estimating carbon using EC estimation tools such as GaBi and SimaPro, the models have produced different results even when using the same materials, similar origins, and similar technology (Sinha et al., 2016). Methodological differences such as 'different system boundaries, different geographical locations, lack of standardisation, lack of data on new products, incomplete data, assumptions, and lack of transparency' may cause further inaccuracies in these standard tools (Rodrigo et al., 2020). Consequently, scholars have attempted to integrate various emerging digital technologies (EDTs) for EC estimation with the assumption that they could eliminate inaccuracies by utilizing the contemporary features of the EDTs. As a result, these attempts show a significant reduction of existing limitations in EC emission tools (Resch et al., 2020).

This study seeks to critically evaluate the latest research on the use of EDTs to mitigate inaccuracies in EC emission assessments. Although Khan et al. (2022) have previously conducted a similar study on the background, approaches, and advancements in LCA of EC in buildings, the present study is the first to concentrate solely on the role of EDTs in enhancing EC emission assessments. Previous research has focused on either one technology or a particular data modelling technique. The EDTs chosen for this study were based on their maturity and commercial viability, as determined by Gartner's Hype Cycle for emerging technologies, which is a graphical representation of the life-cycle stages of a technology from conception to widespread adoption (Gartner, 2021). The top five EDTs identified in this study are (i) blockchain, (ii) building information modelling (BIM), (iii) digital twin (DT), (iv) machine learning (ML), and (v) the Internet of things (IoT). To the best of the authors' knowledge, this study is the first to investigate state-of-the-art current literature focused on EDTs in EC estimation in the construction industry.

2 Research method

The study used a general deductive approach to analyse qualitative data. This approach involves an evaluation based on an existing theory and drawing conclusions from propositions or premises by collecting, analysing, collating, and interpreting data in an organized manner (Thomas, 2006). To investigate the state-of-the-art techniques for deploying EDTs to enhance the accuracy of EC estimates in the building sector, the study adopted a systematic literature review that collected secondary data and synthesized all available and relevant evidence. The literature review method was mainly selected for the detailed study and assemblage of multiple knowledge domains in the areas of EC, estimation, information technologies, and relevant models and frameworks in the building sector.

The methodological process of this review was reinforced by using preferred reporting items for systematic reviews and meta-analyses (PRISMA) to ensure an unbiased analysis by obtaining more refined information under specific selection criteria (Liberati et al., 2009). PRISMA focuses on reporting reviews evaluating the effects of interventions but can also be used to report systematic reviews with objectives other than evaluating interventions. Although initially used to report clinical decisions through medical journals, PRISMA has been applied to other cases, such as the built environment, carbon emission, and estimation-related reviews (Samarasinghe et al., 2019).

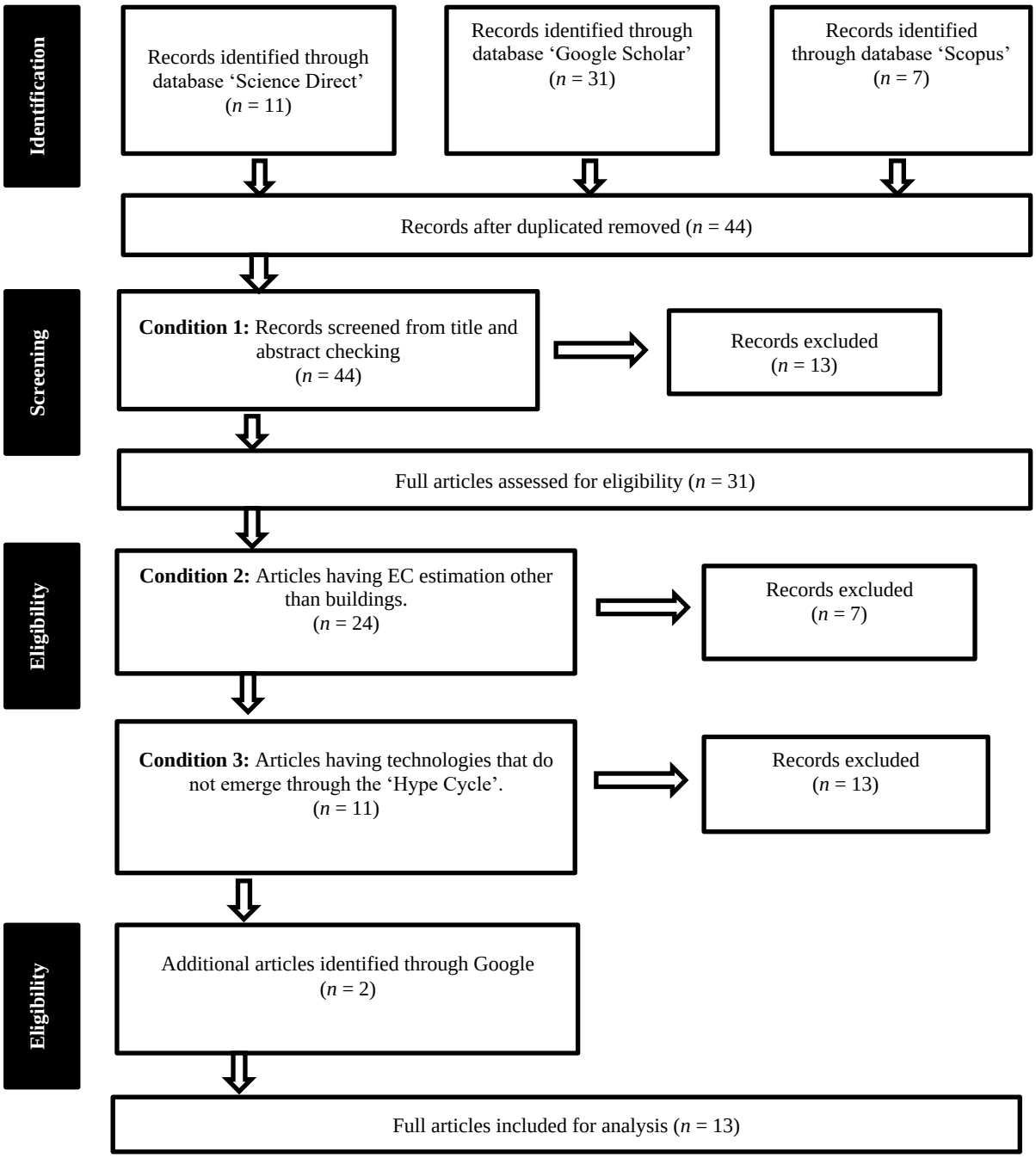
For instance, Minunno et al. (2021) used a PRISMA analysis to research the 'link between embodied energy, embodied carbon, and water consumption and how they affect buildings' running costs'. The present study aimed to fill this research gap by providing a systematic and comprehensive review of the available literature in this area.

The present study used the 'people, intervention, comparator, and outcome' (PICO) study design method to identify the search strategy for PRISMA. Besides, the PICO framework was used to perform bias-free searches and to develop literature search strategies. The PICO-structured form elicited more detail and resulted in more complex and specific search strategies, thus improving the precision of retrieval (Booth et al., 2000). The study aimed to answer the research question, 'What is the current state of the art in the building sector to adopt EDT solutions to minimize EC estimation inaccuracies in the construction industry?' To align with the PICO elements of the research question, a basic logic grid was developed, including keywords such as 'building projects', 'community', 'emerging digital technologies', and 'embodied carbon estimation'. The initial search was followed by the development of a comprehensive logic grid using alternative terms or synonyms filtered from abstracts and titles of the initial search. Synonyms suggested by the indexed databases were also considered for the extended logic-grid design. The final keyword string was developed using the Boolean statement form (('X' OR 'X2') AND ('Y' OR 'Y2')). By adopting a rigorous search strategy, the study aimed to identify and analyse all relevant literature in the field and provide a comprehensive review of state-of-the-art EDT solutions to minimize EC estimation inaccuracies in the building sector.

The study utilized Science Direct, Google Scholar, and Scopus as indexed databases for keyword search. The Boolean strings resulted in an exhaustive list of publications related to EDTs and their features adopted for accurate EC estimation during the last five years (2017–22). To distil the most useful publications from the secondary search, inclusion and exclusion conditions were defined as illustrated in Figure 1 (Conditions 1–3). In addition, the PRISMA method allows for the inclusion of other relevant papers that have a broad discussion on the subject to maintain the search's consistency (Ostadtaghizadeh et al., 2015). Therefore, the search was extended to a Google search, resulting in the identification of two additional papers with significant contributions to the study.

By using a robust search strategy and applying strict inclusion and exclusion criteria, the study aimed to ensure that the review included only the most relevant and high-quality literature.

Figure 1: PRISMA flow diagram for literature search and screening



Source: Authors' own.

3 Literature findings and analysis

The EDTs that were selected represent the adoption of their key features to address limitations of existing EC tools. Table 1 presents a summary of key literature identified through PRISMA and their significant contribution to minimizing the inaccuracies associated with current EC estimations.

Table 1: Summary of key literature identified through PRISMA

Article no.	EDT	Article description	Limitation(s) addressed
1	Blockchain	Rodrigo et al. (2020) presented a conceptual framework using the key features of blockchain technology to estimate EC in construction supply chains.	Information declaration, different geographical locations
2		Rodrigo et al. (2021) introduced a prototype of a blockchain-based embodied carbon estimator for distributed construction supply chain-based EC estimating to improve the estimation accuracy.	Use generic data, data representativeness, assumptions
3	Building information modelling	Cang et al. (2020) proposed a BIM-based calculation method that takes the building element as the basic unit.	Data representativeness
4		Nizam et al. (2018) presented a framework to develop a tool to estimate the embodied energy content within the native BIM environment. The tool was further developed to assess EC emissions in construction operations.	Lack of data on new products, incomplete data, information declaration
5		Abanda et al. (2017) proposed a system that can automate the computation of embodied energy/CO_2 of buildings and aligns the results to the UK's new rules of measurement.	Lack of standardization, tendency to use generic data
6		Alwan et al. (2021) suggested an LCA–BIM interactive user-led method of addressing energy hotspots for both EC and operational elements'.	Incomplete data, use of generic data
7	Machine learning	Thilakarathna et al. (2020) experimented with EC assessment using ML algorithms has been carried out to minimize the carbon emission of building materials.	Assumptions, lack of standardization
8		D'Amico et al. (2019) proposed an ML algorithm that can look at the visual representation of building elements to predict their EC estimates accurately and reliably.	Incomplete data, use generic data
9		Płoszaj-Mazurek et al. (2020) proposed a tool that was developed based on regenerative design guidelines for ML simulation purposes and parametric modelling, generating a training set and a testing set of building designs to calculate EC and/or operational carbon footprint.	Lack of standardization, issues associated with the scope
10		Pomponi et al. (2021) presented a tool that is a real-time decision-support system to aid building design that leverages ML methods.	Data representativeness
11	Internet of things	This tool proposed by Tao et al. (2018) is a GHG emission monitoring system based on IoT technology to monitor real-time EC emissions'.	Information declaration, incomplete data
12		Mao et al. (2018) developed a system to monitor EC emissions using an IoT-based framework that integrates a distributed sensor network to collect real-time carbon emissions data and a BIM virtual model to show the emissions status of different construction activities.	Lack of standardization, incomplete data
13	Digital twin	Chen et al. (2021) proposed a system for estimating EC based on DT technology and LCA. The method evaluates cradle-to-grave LCA and an automated data communication between LCA and BIM databases.	Data representativeness, usage of different system boundaries

Notes: EDT, emerging digital technology; EC, embodied carbon; BIM, building information modelling; LCA, life-cycle assessment; ML, machine learning; IoT, Internet of things; DT, digital twin.

Source: Authors' own.

Table 2 highlights the key performance feature(s) of selected EDTs used in each study and their objectives identified through literature analysis, which has attempted to address the above-identified limitation(s).

Table 2: Key performance feature(s) of selected EDTs to address limitations

Key performance features identified	Objective(s) identified through literature analysis	Article no.
To improve 'accuracy'	To assure the degree of conformity of results retrieved from EC tools against actual carbon emission results	7, 8, 9, 10
To enhance 'traceability'	To enhance access to the activities of extended processes of construction supply chains to maintain the inclusiveness of carbon emission data at various life-cycle stages	1, 2
To ensure 'transparency'	To maintain the consistency of carbon emission data at the various life-cycle stages and assure that the emission data is declared in original values	1, 2, 3, 4, 5, 6, 13
To assure 'efficiency'	To ensure the frequency of carbon emission data at the product level and ensure that emission data is declared at regular intervals with less human interference	11, 12

Source: Authors' own.

The next step of the literature review is to analyse and synthesize to extract the state-of-the-art previous research knowledge on (i) the adoption of EDTs for EC estimation and (ii) performance features that enable EC estimation improvements. The outcome of utilization of each EDT was analysed and is presented in the following sections.

3.1 Blockchain technology-based EC estimation

According to Gartner (2021), blockchain technology is 'one of the complex architectural designs of the broader adoption of distributed ledgers, and a set irrevocable transactional records in a network where participants are defined'. Studies 1 and 2, by Rodrigo et al. (2020, 2021), mainly focused on specifying systems boundaries to develop an EC estimation tool and attempted to showcase how a product can be escalated to develop a minimum viable product using blockchain technology. Besides, the extended version of the study by Rodrigo et al. (2021) further analysed 'a systematic methodology followed to develop the data-flow diagram (DFD), entity relationship diagram (ERD) and user flow diagram required to develop the BEC which depicts the detailed structure and the development process of the DFD, ERD and user flow diagram that forms the basis of the BEC estimator'. The study adopted a supply chain-based EC estimating method using a multi-layer Delphi-based expert forum that exemplifies how domain-specific knowledge elicitation could occur in the development of a blockchain-based system to accurately estimate the EC.

3.2 BIM technology-based EC estimation

As defined in the policy paper by HM Government (2012, p. 3), BIM is a 'collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets'. Studies 3, 4, 5, and 6 (as in Table 1) illustrate how BIM technology later adapted to estimate EC in buildings. The proposed methodology by Cang et al. (2020, p. 3) suggest that 'the total amount of EC emissions from buildings can be calculated by multiplying the amount of each of the six components (six components selected for study (i.e., foundation, walls or columns, floor, staircase, roof, doors, and windows) with the corresponding carbon emission factors' (CEFs). This method combined a newly established CEF database into the study, including the CEFs of raw materials, energy, and gas, building materials, and shifting of construction machinery.

In their study, Nizam et al. (2018) mainly focused on emissions from construction operations and the transportation of materials. The proposed tool integrated Revit software to extract material quantities and the ICE database to retrieve coefficients. Besides, vehicle types, capacities, and

distances from suppliers to sites have been used to measure the transportation emission assessments extracted from the BIM authoring tool. The proposed system by Abanda et al. (2017) aimed at streamlining the upfront CO_2 assessment using BIM and the new rules of measurement (NRM; Royal Institution of Chartered Surveyors, 2012). The present study developed an algorithmic process model that integrates the BIM framework for the automatic computation of EC added to cost. The model suggested by Nizam et al. (2018) 'mainly utilised the information modelled in Revit and quantities extracted automatically and fed into the required volume placeholders' (concepts based on NRM 1). The objective was to develop a BIM-enabled CO_2 estimation tool that is capable of automatic insertion of quantity take-off into a structured NRM 1, which has previously failed because of the disorderly nature of quantity take-off outputs from BIM authoring tools.

Alwan et al. (2021) aimed to develop 'a single parametric BIM and whole LCA-based tool that can be used to estimate both operational and embodied energy of buildings', with a unique integration created by linking the ICE and operational energy (EnergyPlus+) databases. The Bombyx plug (used for energy analysis) was adapted for the new context. In addition, based on the embodied and operational energy analysis of key energy outputs (i.e. global warming potential in megajoules and kilowatt-hours in the selected case studies), a unique framework was developed. The proposed system allows users to carry out efficient and timely analysis to use the feedback immediately for real-time design decisions.

3.3 ML technology-based EC estimation

According to IBM (2020), ML is a 'branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy'. Studies 7, 8, 9, and 10 (as in Table 1) illustrate state-of-the-art current literature using ML to produce tools to compute CO_2 emissions in buildings.

The effective use of ML algorithms by Thilakarathna et al. (2020, p. 4) is evident: they 'proposed an equation to predict the average EC value using the experimental data and ML models using some key ML algorithms, namely artificial neural network (ANN), support vector machines (SVM), and Gaussian process regression (GPR), that was experimented with [. . .] to develop the main model'. In addition, another equation was developed to analyse the sum of the EC associated with the indirect emissions (raw material, A1 in EN15978 and transport, A2 in EN15978) and production of goods and indirect services in manufacturing (A3 in EN15978). Their study further experimented with 'integrating some supporting technologies, including SimaPro V8.0.2 application to retrieve GWP [global warming potential] of materials from the Australian Life-Cycle Inventory (LCI) database, and Ecoinvent database (3.0) is also considered when the Australian LCI database is not available for inputs to enhance the accuracy of the analysis' (Thilakarathna et al., 2020, p. 4).

Moreover, D'Amico et al. (2019, p. 5) discussed 'a case where a trained and validated machine learning algorithm is able to look at visual representation of building structures to accurately and reliably predict their EC estimates'. Alternatively, it could produce 'a material efficiency index by looking at the difference between the structure fed to the algorithm and equivalent optimised structures on which the algorithm was trained' (D'Amico et al., 2019, p. 5). Their study revealed that a neural network could take very few numerical inputs related to the building structure to estimate EC or LCA to assess the circular economy potential or to produce optimized designs by looking at reuse of material at the end of the life cycle of a building.

The model suggested by Płoszaj-Mazurek et al. (2020) was inherited from three complex and consecutive studies that 'resulted in creation a working machine learning model that could aid

architects in [. . .] developing environmentally conscious design models'. The effect of their study was 'a trained neural network that could predict the total carbon footprint [i.e. embodied and operational carbon] of a design proposal based on scarce information ([. . .] – all read automatically from the building and urban shape modelled by the user)' (Ploszaj-Mazurek et al., 2020). The predicted value was compared with an actual simulation of the model that was tested on an actual concept design, modelled in Rhinoceros3D.

Finally, the tool proposed by Pomponi et al. (2021) is a 'real-time decision-support tool to aid building design that leverages machine learning (ML) methods from computer science to speed-up the computationally expensive process of finite element analysis (FEA) traditionally exploited in structural engineering'. The tool was developed by maximizing its usability and diffusion to assess EC as both standalone and plugin versions (integrating Trimble SketchUp). The results offered by the tool 'correlated with uncertainty analysis in the form of probability density functions to account for the inherent variability of input data that characterises early stages in the design process' (Pomponi et al., 2021, p. 3). The tool's results have been validated against commercial FEA software packages that showed good agreement with the EC estimates, presented as probability density functions. The results also indicated the variability and uncertainty associated with material choices. Importantly, the tool also offers a three-dimensional representation of the structural frame, which allows the user to check the input parameter variation.

3.4 IoT technology-based EC estimation

As outlined by IBM (2016), IoT is the 'concept of connecting any device (so long as it has an on/off switch) to the Internet and other connected devices through a giant network of connected things and people, all of which collect and share data about how they are used and the environment around them'. Studies 11 and 12 (as in Table 1) represent state-of-the-art current literature to use principles of IoT to optimize the accuracy of EC estimations.

The IoT-enabled greenhouse gas emission monitoring (GEM) tool that Tao et al. (2018) proposed 'can monitor real-time EC emissions when manufacturing prefabricated building components'. In this system, 'radio frequency identification (RFID) sensors are adopted to identify the component ID, and the corresponding material usage data are extracted from a database that is present in the GEM system. Laser sensors are installed in the production line to measure the running time of equipment so that energy usage can be calculated in real time' (Tao et al., 2018, p. 361). Besides, to implement wireless data transmission from the production line to the computing platform, a data service platform was developed to visually present the monitoring results (Tao et al., 2018).

The system framework developed by Tao et al. (2018, p. 361) 'further integrates a distributed sensor network to collect real-time emissions data and a BIM virtual model to enhance the monitoring of EC emissions to show the emission status of different construction activities'. The objective of this development enables the carbon emission sources to be identified from the three main activities of prefabricated components manufacturing, transportation, and on-site installation. In addition, RFID sensors were adopted to acquire and store carbon-related data in a database. Finally, to visualize the emissions at different process timelines, an online BIM platform was designed that could help the project team to take corrective action against potential EC emissions.

3.5 DT technology-based EC estimation

Gartner (2021) defined a DT as 'a digital representation of a real-world entity or system' while the implementation of a DT is 'an encapsulated software object or model that mirrors a unique physical object, process, organisation, person or other abstraction'. The study by Chen et al. (2021)

was an attempt to integrate DT with a few other supporting technologies/models to calculate EC in buildings more accurately. Moreover, the study initially used formulas for LCA and then presented a hybrid approach combining RFID with the semantic web with a relational database for BIM. The database finally integrated to design the LCA database by linking LCA with BIM.

4 Discussion

The pressing need to achieve global net zero carbon targets by 2050 has gained immense attention worldwide. However, the entire life cycle of buildings, including energy use and greenhouse gas emissions, extends beyond building operations. This includes the energy required to manufacture construction products, consumed by transport, construction processes, dismantling, and disposal of buildings, collectively considered as EC emissions. Despite the significant attention given to operational carbon emissions, the built environment research community has not adequately addressed EC issues in the construction industry (Pomponi and Moncaster, 2016). This study aimed to examine the state-of-the-art literature in the built environment research community to tackle EC emissions by overcoming the limitations of existing EC estimation tools using EDTs. Most of the shortlisted articles in this study identified the dominant performance feature(s) associated with the chosen EDT and experimented on how the feature(s) could be adapted to address the limitations of existing EC estimation tools, as demonstrated in Table 2.

4.1 ML algorithms and improved accuracy

The reviewed studies (7, 8, 9, and 10; see Table 1) primarily focused on the application of ML algorithms. ML algorithms are widely used in data mining, image processing, and predictive analytics (Mahesh, 2018). The primary advantage of ML is its ability to process work automatically once the algorithm has learnt how to handle data. Researchers used this capability by training and testing various ML algorithms to predict the EC of building materials or elements at the product level. The strength of ML algorithms has enabled researchers to contribute towards improving the accuracy of EC estimates. However, while ML algorithms are efficient in processing familiar data from a training set, limitations arise when integrating new sets of data. This highlights the need to develop algorithms that can adapt to new data, suggesting the need for further research in this area.

4.2 Distributed ledger (blockchain) for traceability

Studies 1 and 2 examined in this research (see Table 1), have explored the distributed ledger technology component of the blockchain system as a crucial area of investigation. This technology refers to a distributed record of transactions that are maintained by a consensus among a network of peer-to-peer nodes, according to Yaga et al. (2019). The researchers have successfully applied this feature to track and trace the activities of extended construction supply chains, including EC emissions. This approach enhances the accountability of uncaptured carbon information from the life-cycle stages A1–A3 and transacts them to a centralized database, thereby contributing to improved traceability and transparency of EC assessments. However, scalability and handling many transactions at once are potential limitations, particularly in an extensive public blockchain, as pointed out by Rodrigo et al. (2020). Hence, further research is necessary to develop blockchain solutions that are scalable and can manage high transaction volumes.

4.3 Virtual visualization for transparency

Studies 3, 4, 5, 6, and 13 examined in this study have demonstrated the potential of BIM and DT to overcome the current limitations of EC estimation tools. BIM is the most mature and commonly used EDT among all the discussed EDTs, enabling early-stage decision-making and lowering CO_2 emissions through virtual visualization of the design. The systematic integration of quantity take-off and BIM authoring tools with LCA databases has effectively standardized EC computations using standard measurement methods, primarily NRM 1. The use of BIM or DT-enabled EC estimation systems provides transparency of construction activities and methods, leading to more precise EC estimates. However, interoperability concerns arise when integrating BIM and DT with other support technologies, and the technical knowledge required to handle these tools could discourage users from using BIM/DT-enabled EC tools for EC estimation.

4.4 Automation and transparency

Studies 11 and 12 leveraged the 'automation' capabilities of IoT technology to produce more real-time and faster EC/LCA estimates. Up-to-date EC emission values are crucial because the existing tools use generic data multiplied by a CEF to estimate an approximate value. By integrating IoT with physical components such as sensors, EC emissions during the production of building elements, particularly prefabricated elements, can be detected. The data obtained from sensors are then automatically transmitted to a database via IoT automation platforms, enabling live databases to update quickly depending on process changes that facilitate more current and realistic EC estimates. However, involving physical objects like sensors requires additional human effort and incurs extra maintenance costs. Additionally, IoT-based EC/LCA estimations require standardizations to specify system boundaries, particularly to distinguish between EC and operational carbon, which remains a challenge.

5 Conclusion

This study aimed to conduct a systematic literature review using the PRISMA method to identify and evaluate EDTs that can provide accurate EC estimations for the building sector. The study identified and analysed 5 EDTs and 13 records in recent state-of-the-art literature to answer the research question. The results suggest that the use of EDTs can produce more realistic, precise, and content-specific EC estimations compared with current standalone EC tools. The study also found that researchers have used the key performance features of EDTs to address the limitations of current EC tools. Despite some limitations, the study highlights that the use of EDTs can significantly improve EC estimations. However, further investigations are necessary to ensure the interoperability of EDTs with other supporting technologies. Additionally, the study suggests that conducting more viability studies and 'technology readiness level' assessments can increase the credibility of EDTs for further investigation and future directions of research. Overall, this study provides valuable insights into the potential of EDTs in producing more accurate and efficient EC estimations in the building sector. However, more research is needed to address the limitations and ensure the seamless integration of EDTs with other supporting technologies.

6 References

Abanda, F. H., Oti, A. H., & Tah, J. H. M. (2017). Integrating BIM and new rules of measurement for embodied energy and CO_2 assessment. *Journal of Building Engineering*, *12*, 288–305. https://doi.org/10.1016/j.jobe.2017.06.017

Alwan, Z., Nawarathna, A., Ayman, R., Zhu, M., & ElGhazi, Y. (2021). Framework for parametric assessment of operational and embodied energy impacts utilising BIM. *Journal of Building Engineering*, *42*, Article 102768. https://doi.org/10.1016/j.jobe.2021.102768

Booth, A., O'Rourke, A. J., & Ford, N. J. (2000). Structuring the pre-search reference interview: A useful technique for handling clinical questions. *Bulletin of the Medical Library Association*, *88*(3), 239–247.

Cang, Y., Luo, Z., Yang, L., & Han, B. (2020). A new method for calculating the embodied carbon emissions from buildings in schematic design: Taking 'building element' as the basic unit. *Building and Environment*, 185, Article 107306. https://doi.org/10.1016/j.buildenv.2020.107306

Chen, C., Zhao, Z., Xiao, J., & Tiong, R. (2021). A conceptual framework for estimating building embodied carbon based on digital twin technology and life cycle assessment. *Sustainability*, 13(24), Article 13875. https://doi.org/10.3390/su132413875

D'Amico, B., Myers, R. J., Sykes, J., Voss, E., Cousins-Jenvey, B., Fawcett, W., & Pomponi, F. (2019). Machine learning for sustainable structures: A call for data. *Structures*, 19, 1–4. https://doi.org/10.1016/j.istruc.2018.11.013

Dewhurst, B. (2017, August 29). *Construction industry is one of the least digitised compared to other major industry sectors*. ICE Training. https://www.icetraining.org.uk/news/construction-industry-is-one-of-the-least-digitised-compared-to-other-major-industry-sectors

Ekundayo, D., Babatunde, S. O., Ekundayo, A., Perera, S., & Udeaja, C. (2019). Life cycle carbon emissions and comparative evaluation of selected open-source UK embodied carbon counting tools. *Construction Economics and Building*, *19*(2), 220–242. https://doi.org/10.5130/AJCEB.v19i2.6692

Gartner. (2021, August 23). *Gartner identifies key emerging technologies spurring innovation through trust, growth and change* [Press release]. https://www.gartner.com/en/newsroom/press-releases/2021-08-23-gartner-identifies-key-emerging-technologies-spurring-innovation-through-trust-growth-and-change

HM Government. (2012). *Industrial strategy: Government and industry in partnership building information modelling* [Policy paper]. Department for Business, Innovation & Skills, HM Government. https://www.gov.uk/government/publications/building-information-modelling

IBM. (2016). *IoT and IBM Cloud® are creating opportunities for growth*. https://www.ibm.com/cloud/internet-of-things#:~:text=The%20Internet%20of%20Things%20(IoT,all%20collecting%20and%20sharing%20data

IBM. (2020). *What is machine learning?* https://www.ibm.com/cloud/learn/machine-learning

Khan, K., Su, C.-W., & Khurshid, A. (2022). Circular economy: The silver bullet for emissions? *Journal of Cleaner Production*, *379*(2), Article 134819. https://doi.org/10.1016/j.jclepro.2022.134819

Koeleman, J., Ribeirinho, M. J., Rockhill, D., Sjödin, E., & Strube, G. (2019, August 20). *Decoding digital transformation in construction*. McKinsey & Company. https://www.mckinsey.com/business-functions/operations/our-insights/decoding-digital-transformation-in-construction

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *Journal of Clinical Epidemiology*, *62*(10), e1–e34. https://doi.org/10.1016/j.jclinepi.2009.06.006

Mahesh, B. (2018). Machine learning algorithms – A review. *International Journal of Science and Research*, *9*(1), 381–386.

Mao, C., Tao, X., Yang, H., Chen, R., & Liu, G. (2018). Real-time carbon emissions monitoring tool for prefabricated construction: An IoT-based system framework. In *Proceedings of the International Conference on Construction and Real Estate Management (ICCREM 2018)* (pp 121–127), Hong Kong. https://doi.org/10.1061/9780784481738.015

Minunno, R., O'Grady, T., Morrison, G. M., & Gruner, R. L. (2021). Investigating the embodied energy and carbon of buildings: A systematic literature review and meta-analysis of life cycle assessments. *Renewable and Sustainable Energy Reviews*, *143*, Article 110935. https://doi.org/10.1016/j.rser.2021.110935

Nizam, R. S., Zhang, C., & Tian, L. (2018). A BIM based tool for assessing embodied energy for buildings. *Energy and Buildings*, *170*, 1–14. https://doi.org/10.1016/j.enbuild.2018.03.067

Ostadtaghizadeh, A., Ardalan, A., Paton, D., Jabbari, H., & Khankeh, H. R. (2015). Community disaster resilience: A systematic review on assessment models and tools. *PLOS Currents*, *7*, 1–16. https://doi.org/10.1371/currents.dis.f224ef8efbdfcf1d508dd0de4d8210ed

Płoszaj-Mazurek, M., Ryńska, E., & Grochulska-Salak, M. (2020). Methods to optimize carbon footprint of buildings in regenerative architectural design with the use of machine learning, convolutional neural network, and parametric design. *Energies*, *13*(20), Article 5289. https://doi.org/10.3390/en13205289

Pomponi, F., & Moncaster, A. (2016). Furthering embodied carbon assessment in practice: Results of an industry-academia collaborative research project. *Energy and Buildings*, *167*, 177–186. https://doi.org/10.1016/j.enbuild.2018.02.052

Pomponi, F., Anguita, M. L., Lange, M., D'Amico, B., & Hart, E. (2021). Enhancing the practicality of tools to estimate the whole life embodied carbon of building structures via machine learning models. *Frontiers in Built Environment*, *7*, Article 745598. https://doi.org/10.3389/fbuil.2021.745598

Resch, E., Lausselet, C., Brattebø, H., & Andresen, I. (2020). An analytical method for evaluating and visualizing embodied carbon emissions of buildings. *Building and Environment*, *168*, Article 106476. https://doi.org/10.1016/j.buildenv.2019.106476

Rodrigo, M. N., Perera, S., Senaratne, S., & Jin, X. (2020). Potential application of blockchain technology for embodied carbon estimating in construction supply chains. *Buildings*, *10*(8), Article 140. https://doi.org/10.3390/buildings10080140

Rodrigo, M. N. N., Perera, S., Senaratne, S., & Jin, X. (2021). Systematic development of a data model for the blockchain-based embodied carbon (BEC) estimator for construction. *Engineering, Construction and Architectural Management*, *29*(9), 3311–3330. https://doi.org/10.1108/ECAM-02-2021-0130

Royal Institution of Chartered Surveyors. (2012). RICS new rules of measurement. NRM 1: Order of cost estimating and cost planning for capital works (2nd ed.). https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/construction-standards/nrm

Samarasinghe, G., Lagisz, M., Santamouris, M., Yenneti, K., Upadhyay, A. K., De La Peña Suarez, F., & Nakagawa, S. (2019). A visualized overview of systematic reviews and meta-analyses on low-carbon built environments: An evidence review map. *Solar Energy*, *186*, 291–299. https://doi.org/10.1016/j.solener.2019.04.062

Sinha, R., Lennartsson, M., & Frostell, B. (2016). Environmental footprint assessment of building structures: A comparative study. *Building and Environment*, *104*, 162–171. https://doi.org/10.1016/j.buildenv.2016.05.012

Su, C.-W., Dai, K., Ullah, S., & Andlib, Z. (2021). COVID-19 pandemic and unemployment dynamics in European economies. *Economic Research – Ekonomska Istraživanja*, *35*, 1–13. https://doi.org/10.1080/1331677X.2021.1912627

Tao, X., Mao, C., Xie, F., Liu, G., & Xu, P. (2018). Greenhouse gas emission monitoring system for manufacturing prefabricated components. *Automation in Construction*, *93*, 361–374. https://doi.org/10.1016/j.autcon.2018.05.015

Thilakarathna, P. S. M., Seo, S., Baduge, K. S. K., Lee, H., Mendis, P., & Foliente, G. (2020). Embodied carbon analysis and benchmarking emissions of high and ultra-high strength concrete using machine

learning algorithms. *Journal of Cleaner Production*, 262, Article 121281. https://doi.org/10.1016/j.jclepro.2020.121281

Thomas, D. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*, 237–246. https://doi.org/10.1177/1098214005283748

WorldGBC. (2019). *New report: the building and construction sector can reach net zero carbon emissions by 2050*. Press release. World Green Building Council. https://worldgbc.org/article/new-report-the-building-and-construction-sector-can-reach-net-zero-carbon-emissions-by-2050/

Yaga, D., Mell, P., Roby, N., & Scarfone, K. (2019). Blockchain technology overview. *arXiv preprint* arXiv:1906.11078. https://doi.org/10.6028/NIST.IR.8202

A proposed digital twin framework to enable lean strategic facility management

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Abstract: The concept of bringing a strategic approach to facility management is gaining traction as organizations are becoming more cognizant of the strong relationship between the built assets that facility managers are responsible for managing and the organization's core business and supporting service performance levels. Information aids in better decisions. Enterprise building information modelling (EBIM) expands facility management and integrated building information modelling (BIM). EBIM encourages digital collaboration and the sharing of up-to-date building-related data, information, and knowledge, allowing core businesses and building owners to capitalize on the potential of information ownership throughout the lifecycle of buildings or asset collections involving BIM, whereas a lean approach enables a streamlined and seamless deployment of BIM to address the concerns of variability and waste in facility management. Digital twins complement EBIM in facility management by allowing prospects to handle real-time data and by encouraging autonomous and analytical capabilities. This research adopts a design science research methodology to construct the proposed digital twin framework to support strategic facility management. The proposed framework presents a lean solution to facility management by integrating facility information into core business and strategy.

Keywords: building information modelling, enterprise building information modelling, digital twin, lean

1 Introduction

Facility management involves all areas of asset management to increase users' quality of life cost effectively and profitably within a client's core business and to continuously demonstrate value and improve performance in supporting core business in the operations phase of a built asset. It entails various disciplines to assure the functionality of the built environment by combining people, systems, locations, processes, and technology. Facility management is an integral function that supports business operations in built assets or infrastructure to allow the organization to fulfil its stated goals more effectively (Royal Institution of Chartered Surveyors [RICS], 2013). Facility managers are thus faced with justifying their unit's business value by demonstrating effective management and profitability (Terreno et al., 2019).

Facility management should thus involve strategically driven processes through the built asset lifecycle. Building information modelling (BIM) offers immense promise for improving organizational performance by ensuring that the right people receive the correct information at the right time and can achieve strategic decisions (Schley, 2012; Wanigarathna et al., 2019). However, a significant challenge to BIM implementation is the limited evidence of its value and understanding of the BIM implementation process for facility management within facility owner organizations, as there is not enough data to support a complete assessment of the value of BIM to these organizations, leading to a lack of top management support for BIM in facility management (Tsay et al., 2022). Furthermore, in justifying its value to facility owner organizations, core businesses, and support services, BIM must integrate and transmit interoperable information inside and between the facilities division and other divisions of the organization during the in-use phase (Wanigarathna et al., 2019) in driving strategic facility management.

Enterprise building information modelling (EBIM) is a new concept that integrates BIM into a holistic structure throughout the lifecycle of building assets. EBIM expanded facility management and integrated BIM encourage digital collaboration and the sharing of up-to-date building-related data, information, and knowledge, allowing core businesses and building owners to capitalize on the potential of information ownership throughout the lifecycle of the buildings or asset collections involved (Evjen et al., 2020) or on a virtual holistic representation of the built environment's lifecycle, optimized for business management, knowledge-sharing, and collaboration (Godager et al., 2021).

Digital twins complement BIM by enabling real-time data and better analytical, autonomous capabilities and integration capabilities; therefore, they can integrate with core businesses and support services in the delivery of optimized business outcomes. A lean approach further enables a streamlined and seamless deployment of BIM to address the concerns of variability and waste in facility management (Terreno et al., 2019). Moreover, using lean and associated procedures to support strategic facility management in lean strategic digital twins is necessary. This study uses design science research to propose a digital twin framework to enable lean strategic facility management.

2 Research methodology

Design science is a knowledge-creating activity like prescriptive research, with an emphasis on improving aspects of the built environment (Voordijk, 2009). Design science is also proposed as the practical research strategy for BIM research (Kehily & Underwood, 2015). It defines a cyclical development and evaluation process that can first outline an issue in the built environment, then

propose that a new process or technology can solve this issue, and finally evaluate whether the new solution is successful for its intended users and in its intended setting (Hevner et al., 2004; Johannesson & Perjons, 2012; Kehily & Underwood, 2015; Voordijk, 2009). Design science is a solution to a field problem that takes the form of an artificial construct 'artefact', which is described as an artificial object constructed by people to answer practical difficulties (Johannesson & Perjons, 2012). Artefacts might be real objects or drawings, a set of guidelines, or an information and communication technology solution. Following this principle, a framework can be defined as an artefact in design science. This research adopts a phased process to construct a digital twin framework for facility management.

The first stage entails conducting theoretical literature reviews to identify practical problems with research potential. The main problem is a lack of evidence and business tools to integrate facility management with the core business and a proper strategic decision-making approach that considers the client's strategic needs to improve core business capacities.

The second stage involves deriving existing knowledge constructs for the problem. The research assembles existing knowledge, such as facility management – management systems – requirements with guidance for use (BSI 2018a), the digital twin toolkit (Centre for Digital Built Britain [CDBB], 2021a), the Gemini principles (Bolton et al. 2018, p. 15), digital twin interactive navigator (CDBB, 2021b), BS EN ISO 19650 series procedure to creating a digital twin (BSI, 2020), and digital twin enabling technology and lean methodologies, for building an artefact solution to the problem, represented through a proposed digital twin framework to enable lean strategic facility management. In the second stage, the proposed framework is designed by explicitly linking the knowledge constructs and their relationships illustrated in Figures 1 and 2.

The third stage of the research process is evaluation, which requires determining how successful the proposed change is in addressing the problem in its environment. This necessitates conducting an evaluation survey to assess the research problem and the solution as well as to establish key performance measures and criteria that describe the effectiveness of the proposed solution. This research opted for an online questionnaire survey.

The fourth stage involves research exploration through semi-structured interviews with facility owners, operators, solution developers, and information managers. During research exploration, data are collected and analysed to better understand the problem-solving process, practical tools, and procedures used in the industry. As a result of new data and new ideas, the design of the proposed artefact can is changed with exploratory research findings.

The fifth stage involves research validation via focus groups to support the proposed framework. The focus group results are used to check for authenticity and validate the proposed conceptual framework to produce a comprehensive framework.

In the final stage, the research seeks to contribute to theory by providing prescriptive knowledge, which includes the solution constructs, representation of the proposed conceptual framework, its methods and constraints, and the extension of the problem area. This study presents research output from the first to the third stage of design science research: a proposed digital twin framework for lean strategic facility management.

3 Literature review

A comparison of operational expenses (OPEX) and capital expenditures (CAPEX) revealed that OPEX is the most expensive (Lawton, 2021). About 80% of the entire lifecycle cost of a facility is realized in built asset operations (Lawton, 2021). Valence (2004) asserts that we must face the challenges of facility management development within the OPEX phase in deriving whole-life value of built assets. The facility management business must dramatically shift its position for built assets to become a 'strategic' rather than just an 'operational' function by tying facility management to overall organizational strategy, which is critical to ensuring that built asset investments offer value to an organization's core business (Wanigarathna et al., 2019).

The shift from *operational* to *strategic* requires a long-term approach focused on value addition and cost savings (Valence, 2004); therefore, quality improvement through value addition and cost savings is a critical consideration for organizations looking to reduce the costs of facility management services (Costa et al., 2019). Matthias and Brown (2016) also assert that a lean approach should be considered a component of an organizational strategy, and an organizational strategy should be viewed as the primary driver of a lean approach. The integration of facility management into the delivery of organizational strategy, therefore, merits lean strategic facility management. In addition, a lean approach can help to maximize value and client satisfaction by decreasing wastage, lowering operational costs, improving team collaboration, and controlling the value chain in facility management (Rifqi et al., 2020).

There are ever-increasing amounts of information in modern construction projects (Godager et al., 2021), and it is well established that a considerable portion of the building information generated during the early stages of a project is important for the entire built asset's lifecycle (Tennyson et al., 2022). As a result, the use of building information models in facility management is sparking a debate around the world. Existing BIM practices and terminology are changing to establish a long-term roadmap for BIM-oriented processes and BIM-based applications for the asset's whole lifespan (Tennyson et al., 2022), without involving the complexity of daily activities and human movement patterns in buildings (Godager et al., 2021). With BIM becoming increasingly significant, there is a need to link these activities and the domain-specific business processes and business procedures that control the operation and performance of commercial buildings (Godager et al., 2021); facility managers must also understand how BIM can be strategically leveraged to influence facility management information in built assets for its greatest benefits to the core business (RICS, 2020).

The UK BIM framework guidance (BSI, 2020) specifies that BIM in operations should establish links and integrate towards BIM Level 3 to enable the development of fresh business models. However, little research has been conducted on BIM business value in asset management (Love et al., 2013; Munir et al., 2020). EBIM is a new, unexplored, holistic organizational concept that aims to support and optimize business management throughout the lifecycle of buildings and infrastructure; however, current EBIM understanding and implementation are uncommon owing to limited frameworks and ontologies (Godager et al., 2021). Developing a framework is an essential step in devising a consistent way of exchanging BIM data throughout the lifecycle of built assets in optimizing core business values (Godager et al., 2021).

BIM also contributes to the fulfilment of lean objectives, while lean processes further promote the adoption and continuous use of BIM across all project stages (Andújar-Montoya et al., 2020). On the other hand, Kiviniemi and Codinhoto (2014) concluded that BIM in facility management is hardly straightforward, with numerous missing links and intricacies. They observed main challenges in integration, attributed more to organizational structures and current work procedures, and recommended a lean approach in facility management as a tool for a procedural overhaul in BIM to achieve core business values. Thus, BIM as a lean tool should integrate and exchange information within and between facilities and other core and support services of the organization during the in-use phase through a strategically driven top-down organizational approach (Wanigarathna et al., 2019), in line with overall organizational strategy to achieving a lean enterprise.

Furthering the need for transformation in the construction industry, optimizing whole-life performance, and reducing waste, digital twins are introduced as a focus area for optimizing the performance of current built environments throughout an asset's lifecycle (National Infrastructure Commission, 2021). Digital twins can be seen as a natural maturity of BIM (BSI, 2018a, 2018b). The global digital twin market was valued at US$3.8 billion in 2019 and is expected to reach US$35.8 billion by 2025 (Graham, 2019). Digital twins promise value addition to meet key business performance indicators by utilizing an estimated 95% of unused data over the lifecycle of built assets (Seaton et al., 2022). Most large companies are expected to use digital twins to improve their efficiency as asset owners, and facility operators have been storing massive amounts of data for years, often with limited means to exploit their value. This study proposes a digital twin framework to enable lean strategic facility management.

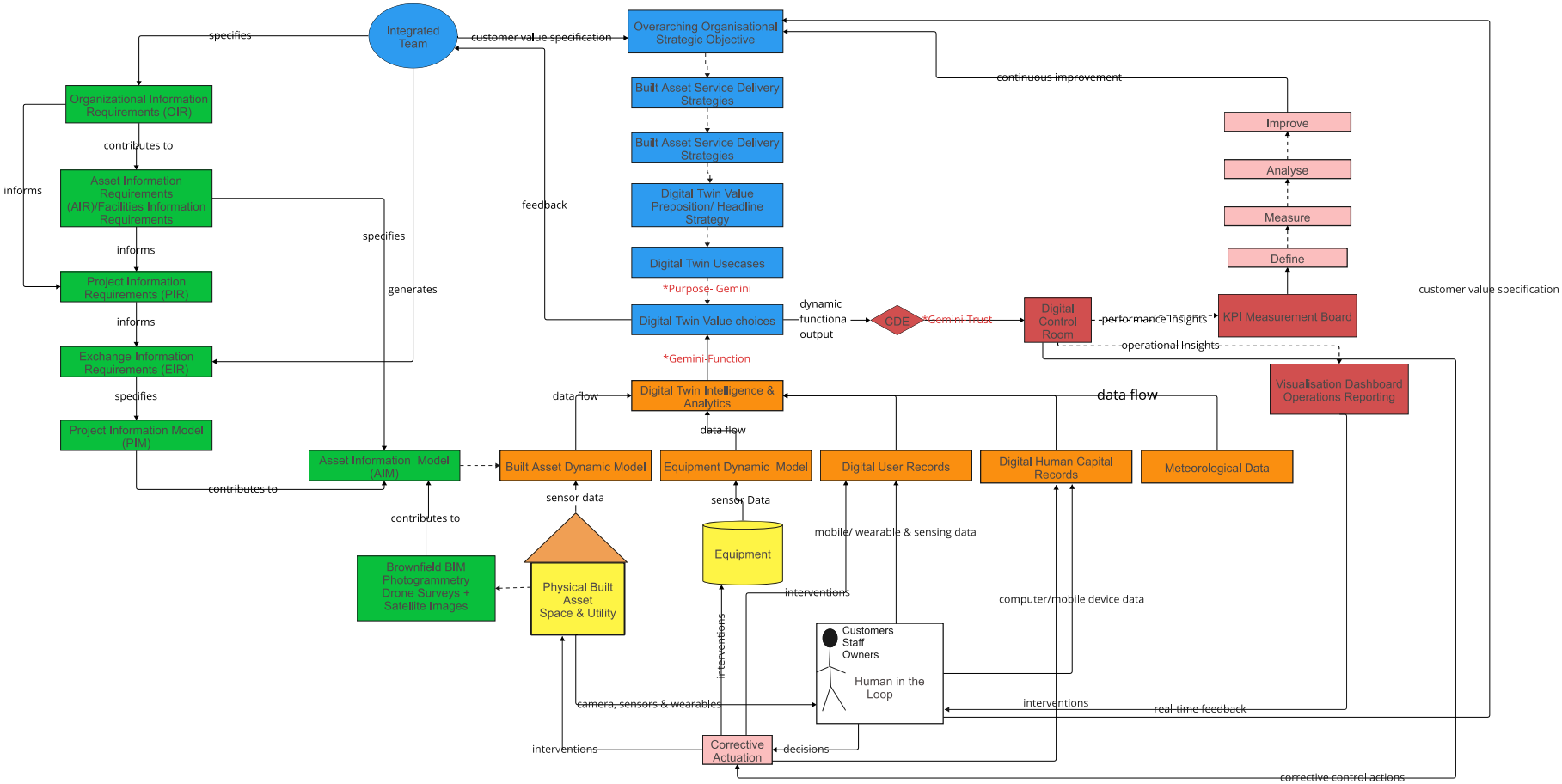
4 Results and discussion

The proposed digital twin framework for lean strategic facility management is presented in Figure 1. The proposed framework considers four lean approach procedures – plan, do, check, act – for continuous improvement, as demonstrated in the lean strategic service model in Figure 2.

In the proposed framework, planning involves developing the strategies and procedures to produce facility management outcomes aligned with customer needs and organizational strategy, whereas integrated planning is introduced to provide better perspectives to select the best value from a wealth of solution set alternatives. Lean thinking is recommended in strategic planning within the proposed framework, as BIM implementation in strategic facility management can benefit from applying lean strategies from the top down by using information gathered for strategic planning (Terreno et al., 2019).

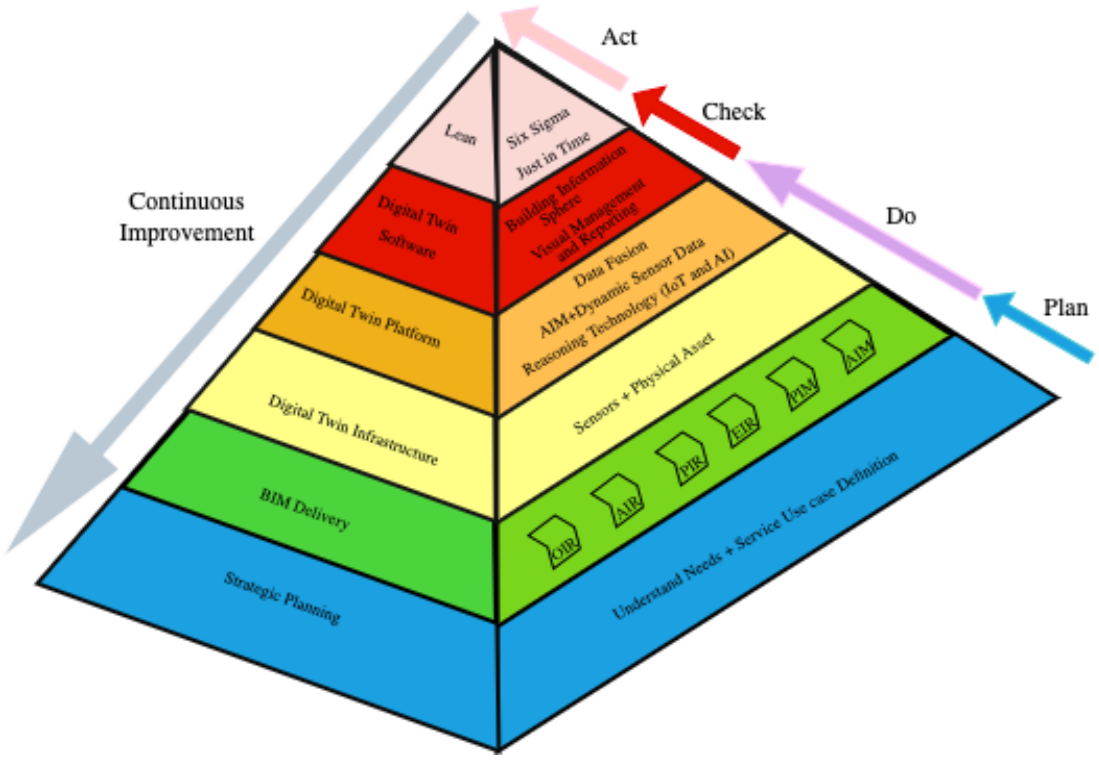
To integrate BIM with facility management, the first step must be integrated team planning, including early involvement of clients, builders, and end-users; as a result, the customer's facility management lean value specification is assessed (Barbosa et al., 2016; Ohno, 1978). Within the integrated team, appointing professionals to perform the information management job is also critical to ensuring good consistency in information management throughout a project's lifecycle and reflecting its long-term strategy for organization facility management (BSI, 2018b).

Figure 1: Proposed digital twin framework for lean strategic facility management



Source: Authors' own.

Figure 2: Lean strategic facility management service model based on the digital twin



Notes: AI, artificial intelligence; AIM, asset information model; AIR, asset information requirements; BIM, building information modelling; EIR, employer's information requirements; IoT, Internet of things; OIR, organizational information requirements; PIM, project information model; PIR, project information requirements.

Source: Authors' own.

For planning, within the proposed framework, an organization's management should exhibit leadership and commitment to the facility management system by ensuring that the built asset service delivery strategies are defined and compatible with the strategic direction of the demand organization. This ensures integration and support of the organization's core business operations, consistency and alignment with the organizational objectives, that those built asset service delivery strategies are measurable without exorbitant costs or paperwork, and that they can be monitored in line with the connection of strategic objectives (BSI, 2018a).

Digital twins are the maturity of BIM (BSI, 2018a, 2018b) within the proposed framework. It is essential to determine the strategic fit of the digital twin to the organizational strategy (CDBB, 2021b). The outcome should formulate a high-level digital twin headline strategy and the cases intended to be actualized in the project, particularly during the operational stage (CDBB, 2021b). The Gemini principles are designed to assist the industry in creating compatible digital twins that can become part of a national digital twin. The Gemini principles categorize three mandatory targets of a digital twin: (i) purpose, (ii) trust, and (iii) function (Bolton et al., 2018). It is critical at this level to consider the Gemini principle of purpose in creating a digital twin use case. Purpose is divided into three sub-themes of public good, value creation, and insight (Bolton et al., 2018). The use case must align the principle of purpose to ensure it generates public good, value creation, and insight. The proposed framework filters the use cases based on the principle of purpose to derive the digital twin value choices. Table 1 provides examples of essential strategic digital twin value choices following design science research. The third stage of this research's methodology is evaluation through the preliminary exploratory survey.

Table 1: Examples of essential digital twin value choices from the preliminary evaluation survey

• Management and control of building-related information and core services over the complete lifecycle of a building, reducing time in searching for information.
• Agnostics in defect and irregularity detection and troubleshooting, demand, and capacity planning to optimize service delivery and improve productivity.
• Performing predictive 'what if' scenarios that demonstrate impact on strategic decisions on operational efficiency and key performance indicators.
• Performing prescriptive 'how to' optimizations that support users to find the course of action that best meets their strategic needs.
• Key performance indicator insights for problem identification and impact assessment for the optimal action plan on performance and implementation strategy for business.
• Value stream mapping and evaluating the future impacts of strategic decisions in the delivery of value.
• Providing predictions to ensure the robustness of operational strategies.
• Providing a digital thread through the lifecycle of the physical asset, for historical data and to reduce occupational risk and optimize occupational safety.
• Connecting working digital twins into an ecosystem of upper digital twins (local and national twins) to enable optimal monitoring and allocation of resources.
• Keeping real-time track of obsolescence and deterioration of objects, services, or practices within organizations.
• Determining disruptions to operations that are most likely and most detrimental to core business performance.
• Digital self-inspections and reporting, reducing the need for physical condition-based surveys.
• Remote monitoring and control reducing the need for physical movement activity.
• Providing end-to-end real-time performance and visualization to the supply chain to improve response times, enabling time and cost savings.

Source: Authors' own.

In the proposed framework, the second procedure 'do' involves implementing the processes. BIM builds the groundwork for creating a digital twin (Gao & Pishdad-Bozorgi, 2019; Khajavi et al., 2019). According to the UK BIM Alliance (2021), the UK BIM framework, BS EN ISO 19650 series procedure (BSI 2020), should be utilized to obtain a digital twin output. The appointing party can establish strategic business objectives and their key performance indicators through organization information requirements (OIR) (BSI, 2018b). OIR should define metadata and data schema to support the OPEX and CAPEX strategic business objectives and inform decision-making throughout a project's lifecycle (BSI, 2018b). Following OIR, the lead appointing party determines the graphical and non-graphical data, information, and documentation required for the built asset's lifetime operation and management (BSI, 2018b) through asset information requirements (AIR). Following AIR, the lead appointing party derives high-level information from project information requirements (PIR) that need to be derived in part from OIR.

PIR focuses on the information required by the lead appointing party at critical decision points during the delivery of the design and construction project (BSI, 2018b). Employer information requirements (EIR) should specify the information that the client will require from their internal team and from suppliers for the development of the project and the operation of the fully built asset and should describe the expected information deliverables in terms of documents, model files, and structured information (BSI, 2018b). The project information model (PIM) is the information model created during a project's design and construction phase. EIR outlines the PIM criteria; it includes a federated building information model, non-graphical data, and accompanying documentation (BSI, 2018b). The asset information model (AIM) compiles the data and information required to enable asset management. It offers all data and information linked to or required to operate a built asset. AIM consists of models, data, documents, and other records connected to or necessary for a built asset's operating phase. AIM may deliver graphical and non-

graphical facts, information, documents, and metadata. It can be used for a single asset or a portfolio of assets. AIM can be constructed using existing asset information systems, new information, or information from a PIM established to construct a new asset. AIM can be developed from reality capture for brownfield built assets, such as point clouds, drone surveys, and satellite images (BuildingSMART, 2021).

BIM and digital twins are two distinct concepts with distinct differences, which are complementary and may enhance each other (Shahzad et al., 2022). BIM is not a digital twin but a core subset and enabler of a digital twin. On the other hand, digital twin technology relies on combining data from various data sources to optimize the efficiency of data processing and better decision-making (Bolton et al., 2018); thus; digital twins are designed to complement BIM models with real-time enabling technologies that grow the digital twin to different maturity levels and outline efficiency usage levels. The proposed framework deems that a digital twin must be a credible and reliable digital representation of the physical; it must include feedback loops that enable near-real-time data transfer and synchronization between the virtual replication and physical worlds (Philp, 2019). Real-time data from the physical are capable of being captured by sensor technology (Iberdrola, 2023), communicating with each other and manipulating physical instruments, sensing, and acting in the real world (Sawhney et al., 2020). The intimate interconnection of its physical components and virtual equivalents and their balance is determined by the user context and desired functionality (Rabiser & Zoitl, 2021).

The transformational impact of digital twins rests in their connectivity, with other diverse digital twins (Graham, 2019), to a flourishing system; this allows them to extract greater value from the built environment (Burgess et al., 2020) through improvement in performance of built asset operation processes (Barricelli et al., 2019). The proposed framework links built environment digital twins to other digital twins such as machine and equipment, digital user twins, and meteorological dynamic twins, yielding greater strategic business value. To establish a digital twin platform to yield the selected digital twin value choices, data fusion should be accomplished by integrating data from models and dynamic sensor data, using digital twin enabling and intelligence technologies illustrated in Table 2.

Table 2: Digital twin enabling and intelligence technologies

Technological enabler	Digital twin maturity level	Outline usage
Decision automation	Transformative	• Complete autonomous operations
Remote assistance and immersive operations	Prescriptive	• Remote and immersive operations, control the physical from the digital, and validation model
Artificial intelligence	Prescriptive	• Risk management, real-time alerts, and what-if scenarios • Predictive maintenance
Cloud computing and data analytics	Informative	• Collaboration • Automated reporting • Record keeping
Real-time data aggregation via the internet of things	Descriptive	• Operational efficiency; reduced cost and time and preventative maintenance
Sensors	Informative	• Real-time monitoring and tracking and operational efficiency; reduced cost and time

Source: Authors' compilation based on BuildingSMART (2021).

The lean cycle continues within the proposed framework towards checking. Checking includes monitoring and measuring operational and functional processes against strategy, objectives, and requirements and reporting the findings (BSI, 2018a). The Gemini principle of function ensures effectiveness in the digital twin by considering (i) its federation based on a standard connected

environment; (ii) its curation, with clear ownership, governance, and regulation; and finally, (iii) its evolution, as technology and society evolve (Bolton et al., 2018). Governance and information handling procedures should be applied within the proposed framework based on a specified and agreed-upon set of standards for the governance of facility management information (e.g. ISO 41001, facility management system; ISO 19650-3:2020, information management using BIM – operational phase; ISO 19650-5:2020, information management using BIM security-minded approach to information management; ISO 27001, information security management system; and ISO 19650-4, information management using BIM).

In the proposed framework, digital twins must ensure that they can serve as a safe, unified source of truth by using a common data environment that aggregates data from digital twins into a central data repository for optimum asset management. A common data environment provides the necessary standards and procedures to eliminate data silos and duplicate data, resulting in a single source of truth (Keen, 2021). Common data management should consist of governance and information handling procedures based on a specified and agreed-upon set of standards for the governance of facility management information, including security, ownership, accuracy, rationality, review, electronic transmission standards, information sharing guidelines, and accessibility (Kaya, 2011). In addition, the Gemini principle of trust should be considered, ensuring security, openness, and quality of information (Bolton et al., 2018).

The proposed framework presents a digital control room as a solution that aims to deliver a consistent approach to measuring, monitoring, and visualization. It enables stakeholders to track real-time project performance and act on insights. It also allows stakeholders to compare what was planned versus what was delivered objectively (Davies, 2021). In addition, a digital control room may link core business information inside current user records with operational data, resulting in performance insights that can aid in demand and capacity planning, optimize service delivery, and further improve productivity (Blackman, 2019). The advantages of the digital control room include enhanced communication and collaboration between partners and clients; improved productivity, quality, and performance through greater visibility and forecasting; improved resource allocation, project management, and waste reduction; improved information sharing inside and between project delivery partners and supply chains; and creation of new business and delivery models that shape and assist dissemination of information (Davies, 2021).

What cannot be measured cannot be managed, and what gets measured gets performed; as a result, it is critical to assess, monitor, and optimize facility processes (Amaratunga, 2000). Performance measurements should be straightforward and simple to understand, have a visual component, be focused on progress and variance, and be visible to everybody (Atkinson & Brander Brown, 2001; Lea & Parker, 1989). Performance metrics should be derived from strategy, provide timely and reliable feedback, be linked to facility management objectives, be based on variables that can be impacted or controlled by the user or in collaboration with others, and be clearly expressed (Atkinson & Brander Brown, 2001; Lea & Parker, 1989). Following measurement of the link effect of strategic facility management with the organization's key performance metrics, stage three of design science research, through preliminary evaluation, sought to establish examples of performance metrics applicable in the commercial, residential, healthcare, and education sectors (mean results are illustrated in Table 3).

Table 3: Mean results of examples of strategic facility management metrics

Measures/industry sectors	Commercial	Residential	Healthcare	Education
Human behaviour	5	4	4	5
Space utilization	5	5	4	5
Equipment utilization	5	4	4	5
Footfall	4	4	4	4
Customer satisfaction	5	4	5	5
Customer service requests/work orders	5	4	4	5
Cost-effectiveness/value for money	5	5	5	5
Cost savings	5	5	4	5
Response time	4	4	4	5
Downtime	4	4	4	5
Waiting time	5	5	4	5
Turnaround time	4	4	4	5
Service reliability	5	5	5	5
Energy consumption	4	4	4	4
Water footprint	4	4	4	4
Carbon footprint	4	4	4	4
Net present values	4	4	5	4
Safety and accidents	4	4	4	5
Maintenance efficiency	4	4	4	4
Security risks	4	4	4	5

Notes: 1 = Strongly disagree, 2 = Disagree, 3 = Unsure, 4 = Agree, 5 = Strongly agree.

Source: Authors' own.

In the proposed framework, lean visual management and Andon are identified as visual components. Visual management is a lean approach that actively incorporates visual information into processes to promote process transparency commonly used in operational settings to aid in increased information sharing and collaboration, worker autonomy, elimination of information-related non-value-added activities, fewer operational defects/errors to promote continuous improvement, and rapid detection of irregularities (Galsworth, 1997; Hamilton & Greif, 2017; Tezel, 2015; Tezel et al., 2016). Andon, on the other hand, functions as a warning system and notification is accomplished using acoustic or visual cues (Ohno, 1978). As a result, with visual components within the proposed framework, problems of the service system are immediately identified and the service continues uninterrupted.

The final 'act' procedure involves taking steps to continuously improve the performance of a process (BSI, 2018a). Therefore, there is a need to conduct in-depth problem-solving on non-conforming cases, emphasizing organizational strategy and established performance measurements. Lean six sigma is a continuous improvement technique that focuses on understanding and creating value for the customer (Tjahjono et al., 2010). The six sigma process used is to 'define, measure, analyse, improve, and control' outlined in Table 4 to establish a continuous improvement system to ensure sustainability of the lean cycle.

In the proposed framework, real-time remote monitoring and corrective actuation of digital twins is proposed. This can improve business disruption response with real-time visibility and monitoring, for example, by enabling efficient preventative maintenance. Corresponding to the lean principle of pull is a just-in-time inventory that can be applied to lean operations. Just-in-time inventory is a management method that directly links material orders from suppliers with production schedules (Ohno, 1978). Just-in-time inventory is incorporated within the proposed

framework to boost efficiency and reduce waste by scheduling service requests, work orders, and product supply as needed from the supply chain, which lowers risks and expenses.

Table 4: Sigma six process

Step	Process
Define	Definition of the problem to be solved by identifying what consumers need for a specific product to be successful and connecting it to strategic objectives.
Measure	Following the definition of the problem is quantifying present process performance using suitable measurements (e.g., in Table 3) to identify when the measured result does not meet the desired strategic objectives.
Analyse	Succeeding measurement is to derive a data-driven diagnosis of present process performance.
Improve	Following diagnosis, initiatives to remove waste and inefficiencies are applied.
Control	Finally, the new process is closely monitored to ensure better results are retained through continuous improvement.

Source: Authors' own.

5 Conclusion and future work

This research aims to make both practical and academic contributions by identifying problems in the operations phase of built assets, leading to the need for strategic facility management. BIM and lean approaches are presented as solutions to challenges facing the operations phase; however, digital twins are built to optimize BIM in facility management. This study proposes a first-of-its-kind digital twin framework for lean strategic facility management by maturing BIM to digital twins and harnessing lean leverage towards strategic facility management. The proposed framework presents a solution for better facility information management practice, connecting core business strategy and facility operations to generate actions and decisions that strategically value built assets while reducing the wastage of resources in the built asset's lifecycle.

The study contributes to strengthening the research philosophy in digital twins by understanding BIM challenges in facility management, BIM maturity, digital twin capabilities, and lean interactions. Furthermore, it contributes to future advances in facility management strategies to provide a built asset strategic link to core business performance towards a long-term strategic influence on a built asset's operational and occupational efficiency. Future work will focus on research exploration and validating the proposed conceptual framework through semi-structured interviews. In addition, a comprehensive analysis of the results can refine the proposed conceptual framework to realize an inclusive conceptual framework, solutions applicability, and constraints.

6 References

Amaratunga, D. (2000). Assessment of facilities management performance. *Property Management*, *18*(4), 258–266. https://doi.org/10.1108/02637470010348816

Andújar-Montoya, M. D., Galiano-Garrigós, A., Echarri-Iribarren, V., & Rizo-Maestre, C. (2020). BIM-lean as a methodology to save execution costs in building construction: An experience under the Spanish framework. *Applied Sciences*, *10*(6), 1913. https://doi.org/10.3390/app10061913

Atkinson, H., & Brander Brown, J. (2001). Rethinking performance measures: assessing progress in UK hotels. *International Journal of Contemporary Hospitality Management*, *13*(3), 128–136. https://doi.org/10.1108/09596110110388918

Barbosa, M. J., Pauwels, P., Ferreira, V., & Mateus, L. (2016). Towards increased BIM usage for existing building interventions. *Structural Survey*, *34*(2), 168–190. https://doi.org/10.1108/SS-01-2015-0002

Barricelli, B. R., Casiraghi, E., & Fogli, D. (2019). A survey on digital twin: Definitions, characteristics, applications, and design implications. *IEEE Access*, *7*, 167653–167671. https://doi.org/10.1109/ACCESS.2019.2953499

Blackman, J. (2019, October 2). NHS trust signs £25m deal with Hitachi for digital twin and control centre. *RCR Wireless News*. https://enterpriseiotinsights.com/20191002/channels/news/nhs-signs-with-hitachi-for-digital-twin-and-control-centre

Bolton, A., Butler, L., Dabson, I., Enzer, M., Evans, M., Fenemore, T., & Harradence, F. (2018). *The Gemini principles: Guiding values for the national digital twin and information management framework* (pp. 1–28). University of Cambridge, United Kingdom. https://www.cdbb.cam.ac.uk/system/files/documents/TheGeminiPrinciples.pdf

BSI. (2018a). *ISO 41001:2018 – Facility management – management systems – requirements with guidance for use*. https://www.iso.org/standard/68021.html

BSI. (2018b). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling, Part 2: Delivery phase of the assets*. https://www.iso.org/standard/68080.html

BSI. (2020). *BS EN ISO 19650-3:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Part 3: Operational phase of the assets*. https://www.iso.org/obp/ui/#iso:std:iso:19650:-3:ed-1:v1:en

BuildingSMART. (2021). *Take BIM processes to the next level with digital twins*. BuildingSMART International. https://www.buildingsmart.org/take-bim-processes-to-the-next-level-with-digital-twins/

Burgess, G., Enzer, M., & Schooling, J. (2020). *Flourishing systems: Re-envisioning infrastructure as a platform for human flourishing* (pp. 1–13). Centre for Digital Built Britain and Cambridge Centre for Smart Infrastructure & Construction. https://www.cdbb.cam.ac.uk/files/flourishing-systems_revised_200908.pdf

Centre for Digital Built Britain. (2021a). *Digital twin toolkit*. https://digitaltwinhub.co.uk/files/file/62-digital-twin-toolkit/?_fromLogin=1

Centre for Digital Built Britain. (2021b). *Digital twin interactive navigator*. www.cdbb.cam.ac.uk/what-we-do/national-digital-twin-programme; https://www.cdbb.cam.ac.uk/files/cdbb_dt_navigator_with_links_11.05.2021.pdf

Costa, P. H., Lima, Y., Senna, P., Reis, A. C., Dias, A. C. (2019). Lean six/sigma: A facilities management case study. *Journal of Lean Systems*, *4*(4), 21–52.

Davies, B. (2021, January 11). *'NASA-style' control rooms to improve performance & reduce waste in construction* [General discussion]. DT Hub Community, Digital Twin Hub. https://digitaltwinhub.co.uk/forums/topic/328-'nasa-style'-control-rooms-to-improve-performance-reduce-waste-in-construction/

Evjen, T. Å., Raviz, S. R. H., Petersen, S. A., & Krogstie, J. (2020). Smart facility management: Future healthcare organization through indoor positioning systems in the light of enterprise BIM. *Smart Cities*, *3*(3), 793–805. https://doi.org/10.3390/smartcities3030040

Galsworth, G. D. (1997). *Visual systems: Harnessing the power of a visual workplace*. Amacom Books.

Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. *Advanced Engineering Informatics*, *39*, 227–247. https://doi.org/10.1016/j.aei.2019.01.005

Graham, S. (2019, October 9). Digital twins for the built environment. *BIMToday*. https://www.pbctoday.co.uk/news/bim-news/digital-twin-4-0/64519/

Godager, B., Onstein, E., & Huang, L. (2021). The concept of enterprise BIM: Current research practice and future trends. *IEEE Access*, *9*, 42265–42290. https://doi.org/10.1109/ACCESS.2021.3065116

Hamilton, B., & Greif, M. (2017). *The visual factory: Building participation through shared information*. Productivity Press.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly: Management Information Systems*, *28*(1), 75–105. https://doi.org/10.2307/25148625

Iberdrola. (2023). *What is a digital twin: Advantages and applications*. https://www.iberdrola.com/innovation/digital-twin

Johannesson, P., & Perjons, E. (2012). *A design science primer*. CreateSpace Independent Publishing.

Kaya, S. (2011). *Facilities management information and data management*. RICS information paper (1st ed.), IP25/2011. RICS Practice Standards. https://communities.rics.org/gf2.ti/f/200194/6691941.1/PDF/-/Facilities_management_information_and_data_management_1st_ed_IP.pdf

Keen, M. (2021, April 18). What is a digital twin? *Digital Builder, AutoDesk Construction Cloud*. https://constructionblog.autodesk.com/digital-twin/

Kehily, D., & Underwood, J. (2015, November 12–13). *Design science: Choosing an appropriate methodology for research in BIM*. CITA BIM Gathering 2015. https://arrow.tudublin.ie/cgi/viewcontent.cgi?article=1115&context=beschreccon

Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmstrom, J. (2019). Digital twin: Vision, benefits, boundaries, and creation for buildings. *IEEE Access*, *7*, 147406–147419. https://doi.org/10.1109/ACCESS.2019.2946515

Kiviniemi, A., & Codinhoto, R. (2014). Challenges in the implementation of BIM for FM – Case Manchester town hall complex. In *Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering* (pp. 665–672). https://doi.org/10.1061/9780784413616.083

Lawton, G. (2021, June 6). Autodesk discloses digital-twin platform for AEC industry. *Venture Beat*. https://venturebeat.com/2021/06/06/autodesk-discloses-digital-twin-platform-for-aec-industry/

Lea, R., & Parker, B. (1989). The JIT spiral of continuous improvement. *Industrial Management & Data Systems*, *89*(4), 10–13. https://doi.org/10.1108/EUM0000000001409

Love, P. E. D., Simpson, I., Hill, A., & Standing, C. (2013). From justification to evaluation: Building information modelling for asset owners. *Automation in Construction*, *35*, 208–216. https://doi.org/10.1016/j.autcon.2013.05.008

Matthias, O., & Brown, S. (2016). Implementing operations strategy through lean processes within health care: The example of NHS in the UK. *International Journal of Operations & Production Management*, *36*(11), 1435–1457. https://doi.org/10.1108/IJOPM-04-2015-0194

Michel. (2022, May 13). Does six sigma work in facility management? *Facility Leadership*. http://facilityleadership.com/blog/performance-management/does-six-sigma-work-in-facility-management

Munir, M., Kiviniemi, A., Finnegan, S., & Jones, S. W. (2020). BIM business value for asset owners through effective asset information management. *Facilities*, *38*(3–4), 181–200. https://doi.org/10.1108/F-03-2019-0036

National Infrastructure Commission. (2021). *Transforming Infrastructure Performance: Roadmap to 2030* [Policy paper]. https://www.gov.uk/government/publications/transforming-infrastructure-performance-roadmap-to-2030

Ohno, T. (1978). *Toyota production system: Beyond large-scale production*. http://dspace.vnbrims.org:13000/jspui/bitstream/123456789/4694/1/Toyota%20Production%20System%20Beyond%20Large-Scale%20Production.pdf

Philp, D. (2019, June 8–9). Exploring the 'digital twin' construct. The digital twin issue: Putting theory into practice. *BIMToday*. https://www.pbctoday.co.uk/news/wp-content/uploads/2019/05/BIM18-WEB.pdf

Rabiser, R., & Zoitl, A. (2021). Towards mastering variability in software-intensive cyber-physical production systems. *Procedia Computer Science*, *180*, 50–59. https://doi.org/10.1016/j.procs.2021.01.128

Rifqi, H., Ben Souda, S., Zamma, A., & Kassami, S. (2020). Lean facility management 4.0: A case study. *International Journal of Emerging Trends in Engineering Research*, *8*(10), 7363–7370. https://doi.org/10.30534/ijeter/2020/1138102020

Royal Institution of Chartered Surveyors. (2013). *RICS professional guidance, global: Strategic facilities management* (1st ed.). https://www.slideshare.net/secretaryIfma/rics-strategic-facilities-management-1st-edition

Royal Institution of Chartered Surveyors. (2020, January 20). *Introducing . . . strategic facilities management*. RICS News & Opinion. https://www.rics.org/news-insights/introducing-strategic-facilities-management

Sawhney, A., Riley, M., Irizarry, J., Pishdad-Bozorgi, P., Gao, X., & Shelden, D. R. (2020). Introduction to cyber-physical systems in the built environment. *Construction 4.0*, March, 23–41. https://doi.org/10.1201/9780429398100-2

Schley, M. (2012). *BIM for facility management: Managing for the building lifecycle*. https://www.ifma-afc.org/docs/submissions/2012-04-BIM.pdf

Seaton, H., Sepasgozar, S. M. E., & Sawhney, A. (2022). *Digital twins from design to handover of constructed assets*. https://www.rics.org/news-insights/research-and-insights/digital-twins-from-design-to-handover-of-constructed-assets

Shahzad, M., Shafiq, M. T., Douglas, D., & Kassem, M. (2022). Digital twins in built environments: An investigation of the characteristics, applications, and challenges. *Buildings*, *12*(2), Article 120. https://doi.org/10.3390/buildings12020120

Tennyson, R., Ravnestad, B., Hadromi, N., O'Gorman, D., Eckhardt, S., Dennison, S., & Ghorbani, Z. (2022). *What do facility managers need from BIM? Case 4: Asset management for hospitals. A perspective from the building room*. BuildingSMART International. https://www.gs1ie.org/download_files/construction-files/bsi-whitepaper-facility-managers-bim.pdf

Terreno, S., Asadi, S., & Anumba, C. (2019). An exploration of synergies between lean concepts and BIM in FM: A review and directions for future research. *Buildings*, *9*(6), Article 147. https://doi.org/10.3390/buildings9060147

Tezel, A. (2015). *Visual controls at the workface of road construction and maintenance: Preliminary report* [Monograph]. University of Salford. https://usir.salford.ac.uk/id/eprint/35593/1/Visual_Controls_at_Workface_of_Higway_Construction_and_Maintenance_Preliminary_Report.pdf

Tezel, A., Koskela, L., & Tzortzopoulos, P. (2016). Visual management in production management: A literature synthesis. *Journal of Manufacturing Technology Management*, *27*(6), 766–799. https://doi.org/10.1108/JMTM-08-2015-0071

Tjahjono, B., Ball, P., Vitanov, V. I., Scorzafave, C., Nogueira, J., Calleja, J., Minguet, M., Narasimha, L., Rivas, A., Srivastava, A., Srivastava, S., & Yadav, A. (2010). Six sigma: A literature review. *International Journal of Lean Six Sigma*, *1*(3), 216–233. https://doi.org/10.1108/20401461011075017

Tsay, G. S., Staub-French, S., & Poirier, É. (2022). BIM for facilities management: An investigation into the asset information delivery process and the associated challenges. *Applied Sciences*, *12*(19), Article 9542. https://doi.org/10.3390/app12199542

UK BIM Alliance. (2021). *BIM and digital twins: UK BIM Alliance positioning statement*. https://ukbimalliance.co.uk/wp-content/uploads/2021/06/UKBIMA_BIM_DigitalTwins.pdf

Valence, G. (2004, May 12–14). The FM industry and adding value for clients. In J. Brochner & T. I. Haugen (Eds.), *Proceedings of the Third European Research Symposium in Facilities Management* (pp. 13–23), Copenhagen. https://www.irbnet.de/daten/iconda/CIB6394.pdf

Voordijk, H. (2009). Construction management and economics: The epistemology of a multidisciplinary design science. *Construction Management and Economics*, *27*(8), 713–720. https://doi.org/10.1080/01446190903117777

Wanigarathna, N., Jones, K., Bell, A., & Kapogiannis, G. (2019). Building information modelling to support maintenance management of healthcare built assets. *Facilities*, *37*(7–8), 415–434. https://doi.org/10.1108/F-01-2018-0012

Analysing the influence of automation adoption on building information modelling and lean construction use

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Abstract: There are obstacles in the design and construction field, including construction delays, cash flow complications, coordination problems, quality control difficulties, data validation, and data verification. The escalation of building information modelling (BIM) improves the complete project life cycle and supports a culture of continuous improvement. The critical need for additional cost-saving, improved quality, and time-saving has driven BIM and lean construction integration to enhance the BIM process from the managerial standpoint and improve its results. Integrating BIM and lean construction develops construction management by bringing all the difficulties to the surface and analysing activities including value-added, non-added value, and workflow issues. Automation engagement facilitates the integration between BIM and lean construction by eliminating all the repetitive work, auto-checking for project data to measure data alignment with standards and providing a critical way of thinking in taking decisions to guarantee the process's success. Although auditing the adoption of the standards within the project takes a significant amount of time and effort, automation provides an auto-check of the project and automates the repetitive work; the project outcomes will have additional time-saving, cost-saving, and quality improvement. This study discusses the impact of automation involvement for each phase along a project's life cycle, highlighting the threats of automation usage.

Keywords: automation, BIM, construction, lean management

Acknowledgements: The first author acknowledges and sincerely thanks their supervisors, Professor Jason Underwood and Andrew Fleming, for constant guidance that made it possible to complete this project.

1 Introduction

The traditional method in the design and construction field proved its non-fulfilment to rectify the field needs because of the complexity of buildings, the amount of information required within the drawings, and the management's attention to data to ensure data consistency, avoiding data duplication or data loss. Latiffi et al. (2014, p. 625) mentioned that 'the complexities of construction projects result from a thousand documents and drawings being used manually. Engineering work used 2D drawings, pencils, papers, and sketches for years, but as a normal result of the growth and expansion in other sectors, the design and construction field moved towards upgrading to accommodate the need for more buildings'. Osuizugbo (2018) added that the reason this project delivery method is referred to as 'traditional' is that it has been around for a very long time and has typically been the only choice for clients in the building services sector.

The preliminary step of the development and shift from paper use was the involvement of computer-aided design (CAD). This development was considerable, coordination meetings became more manageable, and CAD usage was a revolution in the field of design and construction compared with paper-based work. According to Czmocha and PĆkala (2014), the evolution of CAD software has been gradual. Building information modelling (BIM), lean construction, and automation have all contributed towards enhancement and the potential for future development and renovation of CAD software to meet construction needs as well as client demands. The high demand to meet client requirements pushed for the involvement of BIM. According to Arayici et al. (2011, p. 189), 'BIM technology adoption should be undertaken with a bottom-up approach rather than a top-down approach for successful change management and dealing with the resistance to change'. The development passed through different stages, including tools development, using three-dimensional (3D) modelling tools instead of two-dimensional (2D) tools, facilitating quantification, information workflow enhancement, and involvement of lean construction to enhance management strategies. Bayhan et al. (2019, p. 7) highlighted that 'lean construction is introduced to the construction industry in order to best manage construction processes'. Cloud services, which are known as common data environment, and recently automation deployment are widely used to achieve enhanced results for any project. Tezel and Aziz (2017) suggested that construction operations may be transformed and facilitated by lean construction, which is a process-orientated methodology as well as an emerging information technology tool.

Automation is a term that could be used to describe two kinds of practices: (i) automated solutions during the design phase or (ii) the use of smart systems and intelligent devices integrated with design and construction, enabling a smart operation phase. Brooks et al. (2019, p. 1) clarified that 'intelligent buildings or building automation and control systems are becoming common, driven by the commercial need for functionality, sharing of information, reduced costs, and sustainable buildings'. Moreover, the collaboration between BIM and automation is based on the opportunity to improve results during the design stage by automating repetitive work or compliance auto-check. Preidel and Borrmann (2015) highlighted that automated code compliance checking establishes the foundation for a new genre of process automation in the construction industry.

The study methodology explores two aspects: (i) understanding the connection among BIM methodology, lean construction, and automation deployment, highlighting the benefits of their implementation along project stages, and mentioning the impact of the involvement of each of these on project outcomes and management strategies; and (ii) defining the obstacles and threats to automation usage. This study aims to highlight the impact of automation deployment on a project's life cycle and to discuss its added value versus threats.

2 Benefits and drivers of automation integration with BIM and lean construction

The collaboration among BIM, lean construction, and automation is based on getting improved results during the design stage, construction stage, or post-construction stage. BIM supports the complete life cycle of a project. According to Huang et al. (2021), although BIM is thought to represent a paradigm shift concerning life-cycle processes and management in the architecture, engineering, and construction (AEC) industry, product life-cycle management and BIM have some fundamental similarities.. Lean construction is implemented to eliminate waste and properly manage value-added tasks enabled through the integration of BIM, lean construction, and automation. The integration between BIM and the pull–push technique as per lean construction principles is called KanBIM. Sacks et al. (2010, p. 644) highlighted that 'the goal of the KanBIM research as a whole is to propose, develop, and test a BIM-enabled system to support production planning and day-to-day production control on construction sites'. Automation within digital construction is involved to enhance the design and construction field results after the involvement of BIM and lean construction. According to Brissi and Debs (2019), automation should increase quality and productivity because its aim is to decrease time, cost, and human-caused error in production processes. This is similar to how lean production concepts work, where every stage of a project is automated. Banfi et al. (2017) added that a high level of BIM automation offers a precise, creative, and quick-generation solution to the time, cost, and flexibility issues that plague modelling practices. In fact, the cost of modelling is crucial for businesses and studios in the AEC industry. Automation involvement provides a unique contribution and enhancement within each phase. Table 1 shows a summary of different project stages identified by the Royal Institute of British Architects (RIBA, 2020) and the required outcome to measure the impact of BIM, lean construction, and automation involvement.

Table 1: Summary of project phases as per RIBA (2020) and impact of BIM, lean construction, and automation per phase

Project phase	The required outcome as per RIBA (2020)	BIM impact	Lean construction impact	Automation impact
Strategic definition	Defining client requirements	• Development of exchange information requirement (EIR)	• Working on long-term relationships • Selection of thoroughly tested technology	• EIR auto-check code
Preparation and briefing	Define project brief	• Generation of BIM execution plan (BxP) • Arrangement of templates	• Define workflow and workload strategies • Eliminate waste	• Batch families autoload • Auto-check for BxP implementation
Concept design	Concept generation	• Understand the complete project life cycle • Sustainability consideration	• Management support • Decision-making support	• Generative design involvement

Spatial coordination	Coordinated architecture–engineering project	• Generation of level of development (LOD) 300 models	• Workload and workflow management • Information transition control	• Auto-check for clashes and provides solutions • Highlight clashes causing technical issues • Design criteria auto-check • Elimination of repetitive work
Technical design	Information addition	• Generation of LOD 350 models • Issuing site package		• Auto-generation of builder's work
Manufacturing and construction	Construction and commissioning	• Project control through four and five dimensions • Connecting all stakeholders	• Getting all the problems on the surface • Slow decisions, fast actions • Material control • Preparation of Obeya room (large room)	• Pre-fabrication
Handover	Involvement in facility management	• Generation of LOD 500 models	• Control data transfer	• Internet of things • Unified format for data sharing
Use	Operation	• Upgradable model	• Material control	• Quick response (QR) coding

Source: Authors' own.

During strategic definition, the BIM effect is achievable by creating exchange information requirements reflecting client requirements. Lean involvement appears to satisfy customer requirements that consider eliminating waste and building a long-term relationship. Moreover, selecting the required software and ensuring its workability, different BIM platforms (e.g. ArchiCAD, Revit, Solibri, Sketchup, and Navisworks) generate models and ensure the coordination process. Various software is used to enhance design and construction activities, but the most commonly used software is Autodesk Revit. Lévy and Ouellette (2019) added that the most popular BIM-authoring platform for building design in the United States is Autodesk Revit. The annual upgrade and added modifications are the reason behind Revit propagation. In addition, the collaboration between different disciplines inside a single platform (Revit) enhanced the communication process and facilitated discipline integration. Luo and Tang (2015, p. 2552) mentioned that 'through collaborative design technology of the application of Revit in the main control building project, an 80% reduction in the designer communication project design time, total time reduced by 50% to the traditional model, and achieved good application effect and economic benefit'. After defining the project requirements and criteria, the impact of automation begins to reflect these requirements into auto-check codes to automate the process and ensure results.

During the preparation and briefing stage, BIM requires arranging a BIM execution plan (BxP) and creating project templates. During BxP creation, lean construction is integrated with BIM to enable better communication, data management, information exchange methodology, and workflow practice generation to define detailed and specified maps required for project generation. As collated from Herrera et al. (2021), BIM and lean concepts enhance information exchange while

creating an additional unified community with increased collaboration and connections between teams. After the development of BxP, automation saves time by enabling autoload for project families, auto-checking the templates and their consistency with BxP, and information flow control. Luo and Gong (2014) demonstrated that BIM-based verification strengthens both the effectiveness and the accuracy of code compliance verification..

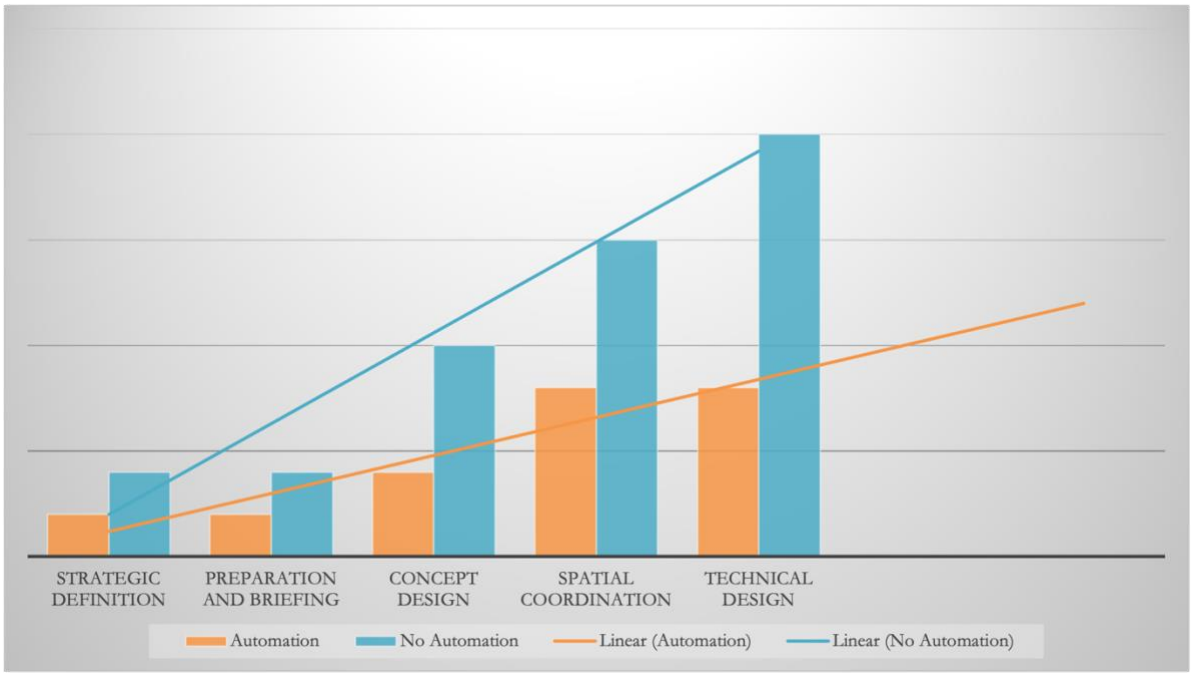
During the concept stage, BIM supports the idea of a complete project life cycle; the cost is considered and estimated even during the early stages. Sacks et al. (2018) clarified that the team in charge could use BIM from the start of the design to enhance their comprehension of the project demands and to derive cost estimates during design development. The generated model at concept stands alongside the project because of the use of 3D tools. Lean construction is involved in managing information flow and improving workload using different management strategies. Lean construction considers visualization a vital process based on how building elements are graphically represented. Having 3D models that help understand buildings and improve the design process is advantageous. According to Schimanski et al. (2021, p. 2), 'the (digital) Kanban system should help to balance the load to capacity, optimize flow through limited work-in-progress [. . .], and to improve visual management. Automation provides the automated generative design method to enable faster, more reliable and more efficient design options to facilitate the selection of the most suitable concept that will be developed later'. Gan (2022) added that automation can provide a prototype system, create a 3D BIM model, evaluate the fitness of each alternative, and alter the spatial attribute parameters of volumetric modules to help identify a set of ideal solutions.

The spatial coordination phase emphasizes the benefits of BIM. The generated 3D model data are consistent with all discipline's data and reflect the technical calculation. These models are supposed to be level of development (LOD) 300, as per the LOD forum. The generation of coordinated zero-clash models enhances project performance, cuts costs, and saves time. J. X. Zhou et al. (2021) mentioned that real-time clash detection refers to the use of 3D BIM animation to mimic the precise site situation and look for any inconsistency, disruption, or safety issues.. Due to the 3D visual presentation enabled by BIM, lean construction could support decision-making and adjustment of workflow. Automation achieves automated design review, check of clashes, and easy to understand presentation of problems. Nawari (2020) defined the engineering design review as the procedure of comparing a design to the requirements of codes and standards in order to validate the accuracy and quality of the design and to identify problems before construction begins.

The technical design stage is the link between the design and construction phases; it enables the issuing of coordinated BIM models. BIM involvement provides coordinated and consistent schedules. Moreover, BIM enables the creation of four- and five-dimensional simulations to monitor project time and cost. During this stage, both scheduling and coordination between all disciplines are mandatory. Faghihi et al. (2015) highlighted that as a reliable source of project data, BIM can work with any scheduling techniques and models that require it. Lean involvement enables the interaction of the team with the site situation. It improves communication through different platforms to enable enhanced decisions. Dave et al. (2016) clarified that by including site teams in the decision-making process and having them report back to the production management system, lean construction methodologies, such as the Last Planner System™, have partially addressed this issue. Early change always comes at a lower cost than continuing and making changes later. If a problem arises, there should be a brief stop to address the crucial issue to fully resolve the problem without harming various disciplines because changes at the design stage are less expensive than changes during the construction phase. For more clarification, coordination between the interior design package, the architecture package, and the mechanical–electrical–plumbing package requires frequent changes by all disciplines until the project is fully coordinated. As a result, the effects of every modification must be reviewed for each package before work is started. Automation involvement at the design stage positively affects the complete life cycle of a

project. iFieldSmart Blogs (2021) mentioned that the use of automation in BIM during the design process has a major and impressive saving compared with when automation was not used. Figure 1 provides a graphical comparison to measure the impact of automation contribution on time. Automation involvement reduces the duration of each project phase, so the overall saving is significant compared with no automation involvement.

Figure 1: Impact of automation involvement during design phase



Source: Authors' own

During the manufacturing and construction phase, BIM provides the link between 3D models, time, and cost. Elghaish and Abrishami (2020) mentioned that BIM had adopted the traditional mechanism for developing planning and scheduling models, such that manually inputting the list of activities creates no link between the estimated activity duration and the resources in the 3D BIM model. Lean construction involvement appears brightly during this stage. Sacks et al. (2010) added that BIM platforms should serve as the foundation for production management systems for the construction industry, which should also implement Kanban-style pull process flow and Andon alerts. This idea was given the name 'KanBIM'. Lean construction provides solutions for material control, site work management, and involvement of the Obeya room, including all project data visualized in an arranged and controlled method. Controlling materials and the site layout are other ways that BIM and lean construction interact. Such interaction between BIM and lean construction is an additional benefit that will result in time and cost savings.

Additionally, lean construction is updating the contractual part of projects: contracts are developed to accommodate the new process for the benefit of the project. Lean construction proposes various techniques for either the utilization of human resources or the strategies of project production. Automation can be involved during this stage to implement pre-fabrication methodologies and reduce site errors. Taking advantage of the BIM approach, López de Lacalle and Posada (2020) highlighted that a digital process flow advances automation and information flow efficiency in some business processes by using computational design and digital fabrication techniques. The term 'digital fabrication' describes production methods that are managed by computers. Transferring information about building components to manufacturing lines will enable prefabrication based on reliable data, speeding up construction site work and project

completion. Moreover, Tang et al. (2019) added that Internet of things, BIM prefabrication, and lean construction management could be greatly automated with the integration of Internet of things devices.

In the handing-over phase, construction data transfer to the operator to create maintenance and operation plans. BIM facilitates data control while lean construction facilitates data management; all data are placed on a single platform from the starting day of the project until handing over to the facility management phase. Moreover, BIM supports smart systems integration and usage within the buildings. Yang et al. (2021) mentioned that SmartBIM, a model with smart objects and user tasks, is necessary for the application of a smart design system. Moreover, smart systems connect with design models, commonly known as the 'Internet of things', and using such technology supplies the possibility of using quick response (QR) codes to link the design, construction, and facility management data. J. X. Zhou et al. (2021) added that the interaction between all project phases creates full control for information and ease of data access. Automation can be involved to unify the data formats because each party has its format for data generated during construction, but when it comes to the operation phase, all data shall be similarly formatted.

In the use phase, automation can be the bridge between all the previous phases and the running phase. Installed equipment data within the building can be located with a single QR code attached to the equipment. Such QR code is scannable, connected directly to the model, and shows all related data, including the maintenance history. According to Pishdad-Bozorgi et al. (2020, p. 28), 'barcodes, Radio-frequency Identification (RFID), and AR, together with BIM, are developed to facilitate maintenance and repair activities by providing relevant information in a timely and intuitive fashion'. Implementing QR code methodology provides a fast, dependable, and efficient method for accessing data within the models and connecting them with the added data during the operation phase. Lorenzo et al. (2014) indicated that this management procedure ensures that each piece of equipment or temporary structure is accompanied by its corresponding handbook at the designated workplace in addition to having copies of the manuals available in the site offices. Appold (2015) added that keyless data entry, immediate real-time information, standardization, legibility, and chain of custody tracking are all made possible by bar codes.

Automation involvement during design and construction requires the involvement of an intermediate to edit the used tool and support completing additional tasks with less time. The intermediate is a plug-in or add-in, usually known as the application programming interface (API), that loads within the software. Different programming languages generate APIs such as add-ins as C, Python, Dynamo, or any .NET language. APIs drive BIM to advanced levels and a new wave of development. H. Zhou et al. (2021) mentioned that the robust API of Revit, a potent parametric 3D modelling tool, makes it simple for developers to incorporate additional applications into the Revit platform.

3 Barriers and threats to automation deployment

Barriers facing automation usage can be sorted into two aspects – technology and human factors – that are typically also barriers to BIM implementation. The technology barrier reflects the difficulties of learning a programming language or the shortage of capabilities of using Dynamo if Dynamo is not considered a programming language. Li et al. (2019) suggested that Dynamo's visual aid was limited because of the absence of geometry data. However, automation can be performed using different programming methodologies, but Dynamo is considered the most accessible practice to run the automated process without learning a programming language. In addition, experts are collaborating to solve issues raised during writing scripts, but the available support

involvement is not sufficient for the market needs. A faster, more reliable, and more efficient technical support is required.

Despite the positive impact of using auto-check for models, Isaac and Shimanovich (2021) mentioned that the use of automated tracking technologies necessitates the development of methods for more detailed and precise planning of activity execution; problems are guaranteed if the checklist input within the plug-in is not correct. Ruzicka et al. (2022) added that current methodologies and assessment schemes do not adhere to BIM data structure, which is the primary issue with an automatic complex quality building assessment. Auto-check performs the manual task in a shorter and more consistent manner, but if the reference data are not correct, then the result of the automated process is fake and cannot be part of the project. A practical example for this point is that auto-check can be used to ensure the model has zero clashes, and in case of clashes, they shall be solved based on pre-entered criteria; such criteria reflect the technical solution if these clashes were solved manually. As a result, the plug-in will follow the instruction and generate a zero-clash model, but the model consistency becomes questionable if the pre-defined solving conditions are not entered correctly. The result will be a zero-clash model, but its constructability is not rectified.

Furthermore, a significant threat to automation use is security. Rong et al. (2013) confirmed that the most important issue to address to promote the widespread use of cloud computing is security. As building plans are shared in the cloud, and the Internet protocol (IP) system is currently the primary option for designing building systems, the issue is that not enough security attention is being paid to it. Kharade et al. (2019, p. 63) defined data theft as 'a criminal activity in which data of [an] organization or institution are stolen from various devices', such as desktop computers and servers. As a result, it is simple to comprehend an entire building while seated in front of a computer. For easier comprehension, consider the scenario where a villa's design layout is completed on cloud servers, the surveillance system is almost certainly IP, and home automation is planned and operated remotely or via a user's mobile device. In this scenario, it would be simple to hack the design, identify its weaknesses, and take control of the building using the IP system. Since engineering, science, and all other fields are continually developing, using this scenario is not a fantasy, as Internet hacking and fraud crimes have practically doubled over the past five years, although crime techniques have also altered.

4 Conclusion

The future of BIM is not BIM alone. Sacks et al. (2018) stated that BIM technology continues to develop rapidly. Just as the concepts of how BIM tools should work has driven their technological development, a renewed vision of the future of building with BIM emphasizing workflows and construction practices is now needed. To achieve their completest capabilities, it is necessary to merge BIM, lean construction, and automation. According to Ali et al. (2021, p. 17), 'it is expected that the possibility of having more than one technology working together with BIM is quite close to realisation'. Additional improvement could still occur by automation and lean construction usage. Automation propagation and usage is a vital side of BIM and lean construction as the impact of automation is experienced by all parties. Each involved party would have a measurable cost and time saving in addition to the improved quality.

Future studies are expected to solve the barriers facing automation involvement and propose a different framework to enhance the integration process. In addition, more studies are needed to explain the possibilities of automation merging with BIM and lean management to achieve better

design and construction results. Finally, future research is also expected to explore different case studies and measure the impact of automation use.

5 References

Ali, K., Haijiang, L., Guoqian, R., & Song, L. (2021). Towards future BIM technology innovations: A bibliometric analysis of the literature. *Applied Sciences*, *11*(3), Article 1232. https://doi.org/10.3390/app11031232

Appold, K. (2015). Raising the bar: Using bar coding, automation and lean to drive efficiency. *Journal of Continuing Education Topics & Issues*, *17*(3), 66.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*, *20*(2), 189–195. https://doi.org/10.1016/j.autcon.2010.09.016

Banfi, F., Fai, S., & Brumana, R. (2017). BIM automation: Advanced modeling generative process for complex structures. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *4*(2), 9–16. https://doi.org/10.5194/isprs-annals-IV-2-W2-9-2017

Bayhan, H. G., Demirkesen, S., & Jayamanne, E. (2019). Enablers and barriers of lean implementation in construction projects. *IOP Conference Series: Materials Science and Engineering*, *471*(2), Article 22002. https://doi.org/10.1088/1757-899X/471/2/022002

Brissi, S. G., & Debs, L. (2019, July 3–5). Lean, automation and modularization in construction. Proceedings of the *27th Annual Conference of the International Group for Lean Construction (IGLC)* (pp. 711–722), Dublin, Ireland. https://doi.org/10.24928/2019/0177

Brooks, D. J., Coole, M., & Haskell-Dowland, P. (2019). Intelligent building systems: Security and facility professionals' understanding of system threats, vulnerabilities and mitigation practice. *Security Journal*, *33*(2), 244–265. https://doi.org/10.1057/s41284-019-00183-9

Czmocha, I., & PĆkala, A. (2014). Traditional design versus BIM based design. *Procedia Engineering*, *91*, 210–215. https://doi.org/10.1016/j.proeng.2014.12.048

Dave, B., Kubler, S., Främling, K., & Koskela, L. (2016). Opportunities for enhanced lean construction management using Internet of Things standards. *Automation in Construction*, 61, 86–97. https://doi.org/10.1016/j.autcon.2015.10.009

Elghaish, F., & Abrishami, S. (2020). Developing a framework to revolutionise the 4D BIM process: IPD-based solution. *Construction Innovation*, *20*(3), 401–420. https://doi.org/10.1108/CI-11-2019-0127

Faghihi, V., Nejat, A., Reinschmidt, K. F., & Kang, J. H. (2015). Automation in construction scheduling: A review of the literature. *International Journal of Advanced Manufacturing Technology*, *81*(9–12), 1845–1856. https://doi.org/10.1007/s00170-015-7339-0

Gan, V. J. L. (2022). BIM-based graph data model for automatic generative design of modular buildings. *Automation in Construction*, *134*, Article 104062. https://doi.org/10.1016/j.autcon.2021.104062

Herrera, R. F., Mourgues, C., Alarcón, L. F., & Pellicer, E. (2021). Comparing team interactions in traditional and BIM-lean design management. *Buildings (Basel)*, *11*(10), Article 447. https://doi.org/10.3390/buildings11100447

Huang, M. Q., Ninić, J., & Zhang, Q. B. (2021). BIM, machine learning and computer vision techniques in underground construction: Current status and future perspectives. *Tunnelling and Underground Space Technology*, *108*, Article 103677. https://doi.org/10.1016/j.tust.2020.103677

iFieldSmart Blogs. (2021). *Advantages of deploying automation in BIM*. https://www.ifieldsmart.com/blogs/index.php/2021/03/04/advantages-of-deploying-automation-in-bim/

Isaac, S., & Shimanovich, M. (2021). Automated scheduling and control of mechanical and electrical works with BIM. *Automation in Construction*, *124*, Article 103600. https://doi.org/10.1016/j.autcon.2021.103600

Kharade, K., Kharade, S., & Katkar, S. (2019). Cyber security – A method of generic authentication of data with IP security. *International Journal of Information Systems*, *9*(2), 63–65.

Latiffi, A. A., Brahim, J., & Fathi, M. S. (2014). The development of building information modeling (BIM) definition. *Applied Mechanics and Materials*, *567*, 625–630. https://doi.org/10.4028/www.scientific.net/AMM.567.625

Lévy, F., & Ouellette, J. W. (2019). *BIM for design firms: Data rich architecture at small and medium scales*. John Wiley & Sons. https://doi.org/10.1002/9781119252849

Li, J., Li, N., Afsari, K., Peng, J., Wu, Z., & Cui, H. (2019). Integration of building information modeling and web service application programming interface for assessing building surroundings in early design stages. *Building and Environment*, *153*, 91–100. https://doi.org/10.1016/j.buildenv.2019.02.024

López de Lacalle, L. N., & Posada, J. (2020). *New industry 4.0 advances in industrial IoT and visual computing for manufacturing processes*. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/app9204323

Lorenzo, T. M., Benedetta, B., Manuele, C., & Davide, T. (2014). BIM and QR-code. A synergic application in construction site management. *Procedia Engineering*, *85*, 520–528. https://doi.org/10.1016/j.proeng.2014.10.579

Luo, H., & Gong, P. (2014). A BIM-based code compliance checking process of deep foundation construction plans. *Journal of Intelligent and Robotic Systems*, *79*(3-4), 549–576. https://doi.org/10.1007/s10846-014-0120-z

Luo, P., & Tang, J. (2015). Research on collaborative design practice of REVIT based on BIM. *Applied Mechanics and Materials*, *713–715*, 2552–2555. https://doi.org/10.4028/www.scientific.net/AMM.713-715.2552

Nawari, N. O. (2020). Generalised adaptive framework for computerising the building design review process. *Journal of Architectural Engineering*, *26*(1), Article 4019026. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000382

Osuizugbo, I. C. (2018). Traditional building – construction problems: Need for espousal of sustainable construction in Nigeria. *International Journal of Scientific and Research Publications*, *8*(12), 194–199. https://doi.org/10.29322/IJSRP.8.12.2018.p8427

Pishdad-Bozorgi, P., Gao, X., & Shelden, D. R. (2020). Introduction to cyber-physical systems in the built environment. In A. Sawhney, M. Riley, & J. Irizarry (Eds.), *Construction 4.0: An innovation platform for the built environment* (1st ed., Chapter 2, pp. 23–41). Routledge. https://doi.org/10.1201/9780429398100

Preidel, C., & Borrmann, A. (2015,). Automated code compliance checking based on a visual language and building information modeling. In *Proceedings of the 32nd International Symposium on Automation and Robotics in Construction and Mining (ISARC 2015)* (pp. 1–8), Oulu, Finland. https://doi.org/10.22260/ISARC2015/0033

Rong, C., Nguyen, S. T., & Jaatun, M. G. (2013). Beyond lightning: A survey on security challenges in cloud computing. *Computers & Electrical Engineering*, *39*(1), 47–54. https://doi.org/10.1016/j.compeleceng.2012.04.015

Royal Institute of British Architects. (2020). *RIBA plan of work 2020: Overview* (p. 146). RIBA. https://www.architecture.com/knowledge-and-resources/resources-landing-page/riba-plan-of-work

Ruzicka, J., Veselka, J., Rudovský, Z., Vitásek, S., & Hájek, P. (2022). BIM and automation in complex building assessment. *Sustainability (Basel, Switzerland)*, *14*(4), Article 2237. https://doi.org/10.3390/su14042237

Sacks, R., Eastman, C., Lee, G., & Teicholz, P., (2018). The future: Building with BIM. In *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers* (Chapter 9, pp. 364–397). John Wiley & Sons. https://doi.org/10.1002/9781119287568.ch9

Sacks, R., Radosavljevic, M., & Barak, R. (2010). Requirements for building information modeling based lean production management systems for construction. *Automation in Construction*, *19*(5), 641–655. https://doi.org/10.1016/j.autcon.2010.02.010

Schimanski, C. P., Pradhan, N. L., Chaltsev, D., Pasetti Monizza, G., & Matt, D. T. (2021). Integrating BIM with lean construction approach: Functional requirements and production management software. *Automation in Construction*, *132*, Article 103969. https://doi.org/10.1016/j.autcon.2021.103969

Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2019). A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. *Automation in Construction*, *101*, 127–139. https://doi.org/10.1016/j.autcon.2019.01.020

Tezel, A., & Aziz, Z. (2017). From conventional to it based visual management: A conceptual discussion for lean construction. *Journal of Information Technology in Construction*, *22*, 220–246.

Yang, A., Han, M., Zeng, Q., & Sun, Y. (2021). Adopting building information modeling (BIM) for the development of smart buildings: A review of enabling applications and challenges. *Advances in Civil Engineering*, *2021*, 1–26. https://doi.org/10.1155/2021/8811476

Zhou, H., He, X., & Leng, X. L. (2021). Development and application of a Revit-ANSYS model transformation interface. *IOP Conference Series: Earth and Environmental Science*, *861*(7), Article 072058. https://doi.org/10.1088/1755-1315/861/7/072058

Zhou, J. X., Shen, G. Q., Yoon, S. H., & Jin, X. (2021). Customisation of on-site assembly services by integrating the internet of things and BIM technologies in modular integrated construction. *Automation in Construction*, *126*, Article 103663. https://doi.org/10.1016/j.autcon.2021.103663

Building-as-a-service, smart applications, and the digital twin

Contradiction, challenge, or chance?

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Abstract: The application of information management based on building information modelling (BIM) has long been considered a way to revolutionize the inertial and currently digitally evolving construction industry. However, this deployment is only a first but crucial step in the industry's digital transformation. Further steps include the development of a digital twin that is in constant exchange with its physical image to enable further data-related tasks. This will necessitate more comprehensive approaches and activities than have already been initiated if this digital twin is to become a reality. One such advanced approach consists of smart applications, which are data-supported tools in the operational phase of a building based on the static data in BIM models combined with dynamic data from data-generating devices. Using the data successfully, this approach manifests itself with the sustainable development goals of the United Nations, which no longer view buildings as a collection of building materials and goods, but as a service model, which implies a higher service-based approach instead of the exchange of 'money for assets'. The technical provision of data in real time is necessary to make these smart applications functional in planning, execution, and operation of assets. The purpose of this study is to examine this background and provide a status quo. It is intended to show which hurdles must be overcome for users to be able to use this triumvirate of data tools in projects in the long term. This study is part of a three-part research project that collects new findings from design science research. In this first part, the principles of the three approaches are explored via literature research and contextualized.

Keywords: building-as-a-service, building information modelling, digital twin, smart applications

1 Introduction

Traditionally, the construction industry is characterized by a high proportion of manual work, a significant proportion of unskilled workforce (Dewan et al., 2021) and a lack of standardization of roles, processes, phases, and data structures (Wu et al., 2021), which has resulted in a reputation for not being particularly innovative or using digitally supported technologies (Bertschek et al., 2019). Therefore, innovation-related issues are often treated sceptically by involved parties, such as the evolving building information modelling (BIM) and the eventual digital twin. This approach is discussed controversially and contradictorily in industry and academia (Sacks, Brilakis et al., 2020). Depending on the respective authorship, digital twin is looked upon as a successor, as exclusion, as further development of BIM or, in the worst case, even as the same approach. Still, most of these publications and discussions conclude that the digital transformation of the construction industry is a necessity to overcome the efficiency and effectiveness gap of the last decades. Unfortunately, the lack of own digitalization capability of the construction and real estate industry is constantly neglected to the detriment of customers and users. In addition, there is a constant confusion of erratic and imprecise terminology that rarely provides users with confidence. Initial approaches to this transformation point to uniformly formulated requirements at the national and international level, which are being addressed in a consolidated manner by public sector clients (Barratano et al., 2017) and the generically formulated ISO standards for information management based on BIM (Krieger and Schapke, 2019). For the full functionality of a digital twin, dynamic data are required that immediately transfer any and every change of state in sub-areas of the physical twin to the digital twin.

Here, smart applications could serve as a bridge between physical and digital worlds. The concept of smart applications combines non-modifiable data (such as 'static' data, rooms, volumes, areas, etc.) that can be retrieved from BIM models or databases and be combined with dynamic data providers such as sensors, Internet-of-things devices to give users added value in the use of an asset. The difference between static and dynamic data is primarily that static data does not change on a regular basis, as described by Moreno et al. (2022).

It is indeed a question whether the construction industry and especially the users of assets are prepared for this transition from BIM to digital twin. Is it necessary, is it contradictory, or is it an opportunity for the construction industry to have a place in its digital transformation?

2 Methodology

This study uses the underlying principles of design science research (DSR) in a multi-stage approach. DSR is considered a knowledge-creating research (Kehily & Underwood, 2015). This is particularly important in the rapidly digitally evolving construction industry (Da Rocha et al., 2022), where insights and innovations from the interaction between physical realization and digital development need to be quickly developed, tested and widely applied (Sivunen et al., 2013) to provide appropriate added value in return for the resources invested. In addition, DSR aims to improve aspects of assets in the context of enabling continuous improvement (Agyei-Owuso et al., 2021; Voordijk, 2009). Van Aken (2005, p. 20) considers it a research strategy 'to develop knowledge that can be used by professionals in the field to design solutions to their field problems' applying an iterative concept. It is a similar approach to the development of software artefacts in information and communication technology. These artefacts can be 'constructs, models, methods, or instantations [*sic*] that add value in a specific context' (Baiyere et al., 2015). Expressed simply,

DSR is used to provide solutions and to solve problems (Dresch et al., 2015, p. 13) in a timely manner to enable innovation and provide appropriate results that can be evaluated and applied.

The approach of this study, therefore, is to elicit the fundamentals of building-as-a-service (BaaS), digital twin, and smart applications with literature research. The purpose is to determine whether it is possible to further drive digital innovation in the built environment and to create more data-based business models. In a further step, a framework on how to enable BaaS is created in another study based on this present one (Wildenauer et al., 2022), including a case study to prove these concepts.

3 Theoretical foundations, terminology, and dependencies

3.1 BaaS

The sustainable development goals of the United Nations (2015) tend to promote assets in the built environment not only as an amalgamation of labour and material but also as a compound of services associated with them. This approach is a potential resource-saving measure if buildings are used as necessitated by the situation of the users at the time. The holistic, physical and digital contemplation of a building is not a new concept, but it is gaining new importance in the course of advancing digitalization of the real estate sector (European Commission, 2019).

Considering the building itself as a data provider rather than the data-based services provided in the building by different roles, resources, and systems can be considered a possible strategy. Therefore, the approach of BaaS can be defined as 'demand-oriented deployment of resources respectively assets. Costs for these resources arise mainly from their use (OPEX) [. . .] with usually no costs for their initial acquisition (CAPEX)' (Wildenauer and Basl (2022, p. 168) based on Fehling and Leymann (2018)). In this context, there will be a considerable change in the currently prevailing classical distribution of roles. Users of non-residential properties no longer become a monetary resource that can be planned in the long term in the sense of 'money for the provision of an asset in the built environment'. The approach enables the building, as a communicating part of the built environment, to offer flexible, short- or medium-term services to users. It thus provides the opportunity to offer in-house services based on available data, instead of providing services in the building, which lead to separate and additional interfaces. Thus, the focus shifts from the associated services in the building to the consideration of the building as a service-dominant, logic-based asset.[1] This shift is causing a fundamental change in the traditional understanding of roles: construction companies and possibly also planners are becoming providers of real estate-related services, beginning with the identification of necessities, financing, planning, construction, and even operation and maintenance of the asset. This is accompanied by the need for new types of business models that support the user in targeted data-based decisions.

3.2 BIM

BIM is defined by the International Organization for Standardization (ISO, 2018, p. 13) generically as 'use of a shared digital representation of an asset to facilitate design, construction and operation processes to form a reliable basis for decisions'. This is the epitome of information management, not dependent on the industry sector or participant. Although this information management based on BIM is one of the ways to call the construction and real estate industry out of its digital lethargy

[1] Refer to the work of Weiß et al. (2018) in the context of service-dominant architecture of enterprises.

(Faltejsek & Chudikova, 2019), its end-to-end application in construction projects over the life cycle of a building project is at a level that can be improved (Burghardt, 2020). The application of BIM is not a recent development and has been demanded by public clients for several years (EUBIM Taskgroup, 2019). The pertinent and necessary data governance is either not known and/or executed properly, and if executed, mostly on a project basis (Lundesjö, 2015). This project-specific consideration leads to considerable additional costs for all parties involved: clients pay for project-specific adaptations and planners and contractors have to provide them on a project basis. Nieto-Rodrigues (2021) points to an important contributing factor, namely that project management has focused 'far too much on inputs and outputs (planning, estimation, cost, time, scope, risk management) and not nearly enough on outcomes and value (purpose, rationale, benefits, impact, and strategy)'. Adding to this, a complementary reason could be that data are not valued or treated as assets in the industry (Lis & Otto, 2021). However, information management, including the associated data governance, is the foundation for implementing data-intensive technologies and applications such as the digital twin (Pan & Zhang, 2021). BIM, although diversely considered an information management method as well as a data management tool, can be considered an enabler in this context.

3.3 Smart applications

Smart applications can be defined as 'data-supported tools that provide added value for the user based on stored, static data in a BIM-supported database, combined with dynamically retrieved data, supporting the user in making regular decisions' (Wildenauer, 2023). An example here is the booking of a meeting room. The location of the room can be found as non-modifiable, 'static' value in the above-mentioned digital representation, as well as the accessibility, area, and volume of the room and the permissible number of potential meeting participants. This information can be stored in external databases or transferred to the computer-aided facility management (CAFM) system. Dynamic data such as the current location of the user, the accessibility of the meeting room, and further information such as the last disinfection or cleaning cycle are data from the operation, which are collected by staff via technical devices (e.g. tablets) or automatically via sensors or similar devices. These data are bundled in other accessible databases. However, all data must be brought together to provide added value, which can be solved by means of a standardized application programming interface, for example. These smart applications thus represent a bridge between the (mostly) static BIM models that are transferred in CAFM systems and the dynamic data from occupancies, movements, and captures. Resource-optimized use of data makes it possible to avoid additional expenditure and, for example, to optimally maintain the building.

3.4 Digital twin

The term 'digital twin' originates from the space industry and refers to the digital doppelganger of a real object that is in constant exchange with it (Grieves, 2014). These attributes are not sector-specific and can be seen as the main characteristics of a digital twin in construction. According to Tao et al. (2019), the physical product, the digital image of the same, and the constant exchange of data between the two artefacts are compulsory. The goal is to plan and build assets in the built environment as digital twins. The long-term goal here is to be able to implement data-supported methods and allow valid decisions to be made during every stage of the life cycle of a building project (Panteli et al., 2020). The view of construction projects as complex will change to service-oriented products (Weiß et al., 2018). Besides a service-dominant logic, effortless data exchange is one of the most important requirements (Xu et al., 2022). Adding to this, Halmetoja (2022) states that the respective digital twin must represent the digital information structure of the physical system, constituting an autonomous entirety. Consequently, the underlying data structures need to be defined at an early stage, with BIM providing a suitable data structure.

Progressive research, however, is changing this rigid definition and the associated scope of digital twins. Nowadays, a digital twin is considered as up-to-date digital representations of the physical and functional properties of a system, which may be a 'composite system (such as a construction project)' (Sacks, Brilakis et al., 2020, p. e14-2) but is still a novel field of studies (Abdelmoneim et al., 2021). To the best of our knowledge, there is no commonly agreed conceptualization or definition of the term currently, which leads to various interpretations and definitions. This is backed up by Hyre et al. (2022), stating that there is no consensus definition for a digital twin. They note that even in the manufacturing industry, which is considered a paragon for the construction industry, no consensus has been reached. However, digital twin is usually understood in academic literature as the tripartite division of a physical and digital product and the constant exchange of data between both.

4 Discussion

4.1 Data management as fundamentals of BIM and digital twins

Ozturk (2021, p. 2) recalls in his extensive literature research that the 'effectiveness of the AECO-FM industry activities heavily relies on continuous acquisition, share, store, and use of information via integration with available digital and cognitive technologies, and real-time data'.[2] The data required to record options, variants and alternatives during a construction project are an unquantifiable quantity (Pan & Zhang, 2021). Opoku et al. (2021) agree with this in their research, but also point out that the adoption of digital technologies is progressing very slowly (obviously too slow), which is also because of misconceptions about the potential of BIM and thus information management. Formerly a leader in technological and technical advancement, and one of the pioneers of information management (Klinc & Turk, 2019), the construction industry is struggling with current advancements. Especially in the development of information management as a basis for decision-making, misunderstandings and different interpretations prevail (Sacks, Girolami, & Brilakis, 2020). This is not a new or current development, however, but has manifested itself over decades, considering well-known industrial reports from the United Kingdom (Egan, 1998; Barber, 2005; Wolstenholme, 2009).

This leads to paradox situations. With new approaches and technologies such as BIM, significantly more data are created, edited, collected, stored, updated, and made available, but decisions cannot be made correctly because of the lack of relevant data. Decisions in the longer FM phase of an asset are made based on 'acts-on-faith' and not justified by the available data (Jupp & Awad, 2017, p. 312). Shaw et al. (2021, p. 123) confirm and reference that FM 'suffers from poor data integration with other disciplines and earlier life-cycle phases [. . .] but no comprehensive alignment'. BIM is largely accepted in the planning phase and mostly also in the realization phase, but not completely in the significantly longer operational phase (Gao & Pishdad-Bozorgi, 2019), although the advantages of the application and implementation of BIM are known (Zheng et al., 2017).

The definition of the digital twin describes the specific purpose: the product development of multiple, repetitive products that require specific monitoring during operation to improve the actual product, especially in the operational phase. In this long-term phase of operating an asset, a digital representation of the physical building should provide the greatest benefit by linking the

[2] AECO-FM refers to the collaborative environment of the architecture, engineering, construction, operation (AECO) and facility management (FM) industries.

data generated in the management directly with the existing static data. This is compounded by the fact that the associated systems and definitions of digital twin are not fully formulated, digital twin is often confused with BIM and cyber-physical systems, and the developments from these are still considered as being too recent to be able to fully assess them (Jiang et al., 2021).

4.2 Construction 4.0 as an enabler for smart applications and BaaS

Oesterreich and Teuteberg (2016) confirm that the potential improvements in productivity and quality from the Industry 4.0 approach are little known in the construction industry. The manufacturing industry is primarily focused on automation and the provision of other technologies to provide a supportive technological, machine–human environment for production. Begić and Galić (2021) label this shift in the construction industry as 'Construction 4.0' and conclude it is 'the convergence of industrial production, CPSs [cyber-physical systems], and digital technologies with the ultimate goal of creating a digital construction site'. The consistent integration of the fundamental principles of Industry 4.0, and its equivalent Construction 4.0, is based on permanent access to all required information for the automation of processes by the use of networking between persons, processes, and application, preferably in the form of intelligent user interfaces (Gorecky et al., 2014). The authors refer to the Industry 4.0 paradigm that manufacturing plant objects must be equipped with integrated processing and communication capabilities. BIM is seen here as a facilitator of communication, collaboration, and coordination for its abilities in visualizing, virtualizing, and providing easier access to information (Goh et al., 2014). This is a potential that must be further unlocked, for example, with the consistent application of data governance (Wildenauer & Basl, 2021).

However, it is valuable to differentiate among a digital model, a digital shadow, and a digital twin (Davila Delgado & Oyedele, 2021). These definitions differ in the increasing degree of automation and integration between the physical and digital image of the asset. In addition, cross-company and cross-project processes involving the entire supply chain are combined to support and promote alliances in the sense of creating ecosystems not only at the product level but also for research and development and other business areas (Kagermann et al., 2016). This requires that the products produced have an exceedingly high similarity and can be manufactured repetitively. The construction industry, by contrast, repeatedly alleges that it implements individual products in projects and that these are not comparable with each other (Kofner, 2000). One reason for this could be that finished projects result in products that are immobile, complex, durable, costly, and have a high degree of social responsibility for their purpose (Fernández-Solís, 2008). The first approaches for interaction between Industry 4.0 components exist in this context, which are similar to the considerations for data exchange in the construction industry (Bock et al., 2016).

Perrier et al. (2020) point out that the Industry 4.0 approaches cannot be transferred one-to-one to the construction industry because of the different preconditions and production environments and is still far from being efficiently and effectively applied in the construction industry. This observation was already stated in 2011 and has not yet altered significantly (Underwood & Isikdag, 2011). Based on the work of Dallasega et al. (2018), Perrier et al. (2020) summarize: 'The concept of Construction 4.0 also implies a comprehensive and profound transformation of the project management processes of construction firms through the use and exploitation of data collected in real time using new or existing technologies for decision-making purposes.'

In this development of progressive digitalization in the industry, there are tendencies to adopt approved findings from other industries. One example is the lean manufacturing approach that is encouraged to be applied identically in the real estate industry. The focus should not be on optimizing established operational processes but on considering the need for new processes due to the new or changed digital possibilities that are now a possibility (Hatoum et al., 2021).

4.3 Smart applications as a bridge to the digital twin

Construction is becoming increasingly digitized, with a number of technological and engineering pioneers involved in so-called lighthouse projects commissioned primarily by technologically advanced sectors and clients (Lindblad & Guerrero, 2020). These projects do not usually implement overarching technical innovations but sometimes optimize (small and specialized) process steps without applying an overall strategy (Bertschek et al., 2019, p. 7). However, such a comprehensive strategy is required for the complex change of roles, processes, applications, technologies, and tools to be achieved using a digital twin in an interwoven ecosystem.

A possible concept can be drawn as follows: BIM with fundamental data management and governance principles as building data modelling 'provides procedures, technologies and data schemas to enable a standardised semantic representation of building components and systems' (Boje et al., 2020). The overarching concept of a digital twin is to build on this to enable a more holistic socio-technical and process-oriented characterization. The resulting complex delivery results, called artefacts by Boje et al. (2020), should ensure bidirectional data flows, that is, linking data from dynamic data sources with static data. In summary, these digital twins can be seen as a model to more complex structures and combining both static BIM data with dynamic data from devices (Stavropoulos & Mourtzis, 2022).

Given the lack of digitalization capabilities in the construction industry, the comprehensive application of a digital twin in an overarching ecosystem is not achievable in the near future, as more far-reaching measures need to be taken here. This is also described by Davila Delgado and Oyedele (2021), who point out that a certain homogenization phase is always needed to be able to guarantee the intended range of applications. To bridge the gap between long-term academic and technical developments and short-term enabling of additional services, there is potential to offer 'smart applications' to users of assets. In this context, they represent a bridging technology, as the benefits of these smart applications can also be demonstrated with a digital twin in the long term. To put it differently, smart applications can perform immediate services in the short term that can only be fully fulfilled in the long term using a digital twin.

4.4 BaaS's flexibility as key for sustainability

The combination of smart applications and BIM will be capable of providing an asset according to the BaaS approach. In this context, reference should be made to the sustainable development goals of the United Nations (2015), where there is a considerable demand for action on the part of the construction industry (Daniotti et al., 2022). It is necessary not to constantly seal new vacant land but to deal with existing resources in a targeted manner and to optimize construction activities in the most sustainable way possible. This has already been noted by Spence and Mulligan (1995) and called not only for specific actions by the government(s) but also for technical applications, a better, sustainable design, and changed procedures in planning and constructing assets. However, these actions also include the better use of vacant buildings. In 2017, for example, 2.1 million residential units were vacant in Germany alone, despite increasing construction activity (Halfar & Liebmann, 2022). This is because they were built from parts of the country that are now demographically 'unsuitable', were inadequate investments, or there was a rural migration into cities. However, buildings tend to be constructed for a single use, with limited flexibility when it concerns the issue of conversion, interim or further use (Israelsson & Hansson, 2009). Saari and Heikkilä (2008, p. 239) refer to this as the three necessary flexibilities for buildings: '(a) service flexibility is important for the users of the building, (b) modifiability interests mainly the owner, and (c) long-term adaptability is a key factor especially in the stratification of the urban structure and cultural environment'. Assets built in the past often lack this flexibility and adaptability for future needs due to their operational longevity, as they were built at times when digital methods

were not widely used. Cavalliere et al. (2019) consider this approach as a sustainability-led design and propose six selective criteria by combining BIM and visual programming tools to calculate the flexibility of an asset. This approach must be thought through further, and buildings continually examined for their flexibility in the operational phase. As soon as this flexibility can be considered over the entire life cycle of a building project, there are lower impediments to provide and use floors, parts thereof, or whole buildings for partial use according to the BaaS approach.

4.5 Challenges

Information management and its consistent use are of decisive importance in this context, but not a new development. This is a condition already named by Kofner (2000): 'Efforts must be made to expand the use of information technology at all levels and in all phases of the construction process. This is currently still being impeded by a lack of standards for data exchange between clients, planners, construction supervisors, bidders, contractors and their subcontractors.' These challenges have not been overcome in over two decades. The consideration of the necessary increase in efficiency and effectiveness in long-term studies is nevertheless subject to the productivity paradox: this refers to the phenomenon of low productivity increases despite advancing digitalization (Ebert, 2020).

The unsatisfactory status quo of conflating terms from the manufacturing industry and its cyber-physical systems to a construction industry that is not-so-digital does not do justice to the need for the digital transformation of the construction industry and simplifies complex interrelationships overly.

However, this technological innovation does not necessarily lead to a gain in efficiency. Although there is a significantly higher availability of knowledge, the productivity indices (e.g. total factor productivity) do not show any significant enhancements (Mayenberger & Perez-Castillo, 2022). Technology must be applicable and linked to the needs of the business to generate added value (Brunner et al., 2021).

5 Conclusion

The overdue digitalization of the construction industry is welcomed and must be pursued further. However, it is doubtful whether this strategy of skipping evolutionary steps in innovation design is the right path for the construction industry. This must also be seen in light of the fragmented, mostly generic foundations and the challenges due to a remarkable digital illiteracy in the industry. The construction industry must be vigilant not to follow the same rule that other industries did unsuccessfully: innovation for the sake of innovation, without making it tangible and operational. BaaS as a long-term goal, based on a functional digital twin and in the medium term on smart applications, can serve as an initial trigger for the digital transformation of the construction industry and enable additional data-driven business models. The concept of smart applications and BaaS can be a step in the right direction of digitally and technologically empowering the construction industry on the one hand and developing and applying new business models on an incremental level on the other. This requires consistent application of unified and industry-wide accepted standards, some of which still need to be developed, and the endeavour of the industry to find consistent solutions.

6 References

Abdelmoneim, M., Shafiq, M. T., & Ur Rehman, M. S. (2021, October 26–28). Applications of digital twins for asset management in AEC/FM industry – A literature review. In K. Tabet Aoul (Ed.), *Zero energy mass custom home international conference ZEMCH21* (Vol. 1, pp. 408–415). ZEMCH, Dubai.

Agyei-Owuso, B., Annan, G. C. F., Asamoah, D., & Andoh-Baidoo, F. K. (2021, November 21–23). A design science research approach to continuous process improvement. In *51st Annual conference of the Decision Sciences Institute: Decision sciences in the age of connectivity* (pp. 1354–1366) [Online]. Decision Sciences Institute.

Baiyere, A., Hevner, A., Gregor, S., & Rossi, M. (2015). Artifact and/or theory? Publishing design science research in IS: Panel. In *36th International Conference of Information Systems* (pp. 1–5). Fort Worth.

Barber, R. B. (2005). Understanding internally generated risks in projects. *International Journal of Project Management*, *23*(8), 584–590. https://doi.org/10.1016/j.ijproman.2005.05.006

Barratano, P., Ciribini, A. L., Bew, M., Blackwell, B., Haug, D., Koehorst, B., van der Voort, H., Lane, R., Lewen, I., Carlstedt, J., Matthews, A., May, I., Soubra, S., Sulakatko, V., Torrico, J., & Sanchez, E. P. (2017). *Handbook for the introduction of building information modelling by the European public sector. Strategic action for construction sector performance: driving value, innovation and growth*. EUBIM Taskgroup. http://www.eubim.eu/downloads/EU_BIM_Task_Group_Handbook_FINAL.PDF

Begić, H., & Galić, M. (2021). A systematic review of Construction 4.0 in the context of the BIM 4.0 premise. *Buildings*, *11*(8), Article 337. https://doi.org/10.3390/buildings11080337

Bertschek, I., Niebel, T., & Ohnemus, J. (2019). *Zukunft Bau – Beitrag der Digitalisierung zur Produktivität in der Baubranche: Endbericht*. BBSR Online Publikation XX/2019, 1–119. http://ftp.zew.de/pub/zew-docs/gutachten/ZukunftBau_BBSR_Endbericht2019.pdf

Bock, J., Diedrich, C., Gössling, A., Graeser, O., Hänisch, R., Kraft, A., Niggemann, O., Pethig, F., Reich, J., & Vollmar, F. (2016). *Interaction model for Industrie 4.0 components*. Federal Ministry for Economic Affairs and Energy (BMWi). https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/interaction-model-I40-components.pdf?__blob=publicationFile&v=7

Boje, C., Guerriero, A., Kubicki, S., & Rezgui, Y. (2020). Towards a semantic construction digital twin: Directions for future research. *Automation in Construction*, *114*, Article 103179. https://doi.org/10.1016/j.autcon.2020.103179

Brunner, A., Wildenauer, A. A., & Tatar (2021). Die Verwendung von BIM mittels 'business use cases': Anforderungen aus dem Business verstehen, um BIM optimal anzuwenden. *Der Eisenbahningenieur*, *72*(2), 14–17.

Burghardt, P. (2020). *Digitalisierungsindex Mittelstand 2019/2020: Der digitale Status Quo im deutschen Baugewerbe*. https://www.digitalisierungsindex.de/wp-content/uploads/2021/01/Telekom_Digitalisierungsindex_2020_BRANCHENBERICHT_BAUGEWERBE.pdf

Cavalliere, C., Habert, G., Dell'Osso, G. R., & Hollberg, A. (2019). Continuous BIM-based assessment of embodied environmental impacts throughout the design process. *Journal of Cleaner Production*, *211*, 941–952. https://doi.org/10.1016/j.jclepro.2018.11.247

Da Rocha, A. B. T., Oliveira, K. B. de, Espuny, M., Da Motta Reis, J. S., & Oliveira, O. J. (2022). Business transformation through sustainability based on Industry 4.0. *Heliyon*, Article e10015. https://doi.org/10.1016/j.heliyon.2022.e10015

Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry*, *99*, 205–225. https://doi.org/10.1016/j.compind.2018.03.039

Daniotti, B., Masera, G., Bolognesi, C. M., Lupica Spagnolo, S., Pavan, A., Iannaccone, G., Signorini, M., Ciuffreda, S., Mirarchi, C., Lucky, M., & Cucuzza, M. (2022). The development of a BIM-based interoperable toolkit for efficient renovation in buildings: From BIM to digital twin. *Buildings*, *12*(2), Article 231. https://doi.org/10.3390/buildings12020231

Davila Delgado, J. M., & Oyedele, L. (2021). Digital twins for the built environment: Learning from conceptual and process models in manufacturing. *Advanced Engineering Informatics*, *49*, Article 101332. https://doi.org/10.1016/j.aei.2021.101332

Dewan, R., Patel, A. S., & Kuraishy, O. M. (2021). Implementation of total quality management in construction industry. In N. A. Siddiqui, K. D. Bahukhandi, S. M. Tauseef, & N. Koranga (Eds.), *Advances in environment engineering and management: Proceedings of the 1st national conference on sustainable management of environment and natural resource through innovation in science and technology* (1st ed., pp. 251–266). Springer International Publishing. https://doi.org/10.1007/978-3-030-79065-3_21

Dresch, A., Lacerda, D. P., & Antunes Júnior, J. A. (2015). *Design science research: A method for science and technology advancement*. Springer International Publishing. https://doi.org/10.1007/978-3-319-07374-3

Ebert, E. (2020). *Schwache Produktivität am Bau: wo liegen die Potenziale für das effiziente Bauen?* Institut für Mittelstandsforschung (ifm) Universität Mannheim. https://www.kompetenzzentrum-planen-und-bauen.digital/kos/WNetz?art=News.show&id=756

Egan, J. (1998). *Rethinking construction: The Egan report.* Report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction. http://constructingexcellence.org.uk/resources/rethinking-construction-the-egan-report/

EUBIM Taskgroup. (2019, October 2). *Part 1 – Presentation of national experiences*. General Assembly, Brussels. EUBIM Taskgroup. http://www.eubim.eu/wp-content/uploads/2019/10/02102019_EUBIMTG_GA_part-1-strategy-per-country.pdf

European Commission. (2019). *Digitalisation in the construction industry.* BUILD UP – The European portal for energy efficiency in buildings. https://www.buildup.eu/en/news/overview-digitalisation-construction-industry

Faltejsek, M., & Chudikova, B. (2019). Facility management and building information modeling during operation and maintenance. *MATEC Web of Conferences*, *277*, Article 02022. https://doi.org/10.1051/matecconf/201927702022

Fehling, C., & Leymann, F. (2018). *Everything as a service (EaaS).* https://wirtschaftslexikon.gabler.de/definition/everything-service-eaas-53366/version-276459

Fernández-Solís, J. L. (2008). The systemic nature of the construction industry. *Architectural Engineering and Design Management*, *4*(1), 31–46. https://doi.org/10.3763/aedm.2008.S807

Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. *Advanced Engineering Informatics*, *39*, 227–247. https://doi.org/10.1016/j.aei.2019.01.005

Goh, K. C., Goh, H. H., Toh, S. H., & Peniel Ang, S. E. (2014). Enhancing communication in construction industry through BIM. In L. Yang, J. Kantola, A. de Hoyas, K. Kaminishi, & G. Duysters (Eds.), *Proceedings of the 11th International Conference on Innovation and Management* (Vols. I and II, pp. 313–324). Wuhan University Technology Press.

Gorecky, D., Schmitt, M., Loskyll, M., & Zuhlke, D. (2014). Human–machine interaction in the industry 4.0 era. In *12th IEEE International Conference on Industrial Informatics (INDIN)* (pp. 289–294). IEEE. https://doi.org/10.1109/INDIN.2014.6945523

Grieves, M. (2014). *Digital twin: Manufacturing excellence through virtual factory replication* [Self-published white paper]. https://www.researchgate.net/publication/275211047_Digital_Twin_Manufacturing_Excellence_through_Virtual_Factory_Replication

Halfar, Y., & Liebmann, H. (2022). Wohnungsleerstand in Deutschland: Wo sind die Herausforderungen besonders groß? *Demografie Portal Blog.* https://www.demografie-

portal.de/DE/Service/Blog/191028-Wohnungsleerstand-in-Deutschland-Wo-sind-die-Herausforderungen-besonders-gross.html

Halmetoja, E. (2022). The Role of digital twins and their application for the built environment. In M. Bolpagni, R. Gavina, & D. Ribeiro (Eds.), *Structural integrity: Industry 4.0 for the built environment* (Vol. 20, pp. 415–442). Springer International Publishing. https://doi.org/10.1007/978-3-030-82430-3_18

Hatoum, M. B., Nassereddine, H., & Badurdeen, F. (2021). Reengineering construction processes in the era of Construction 4.0: A lean-based framework. In *Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC)* (pp. 403–412), Lima, Peru. https://doi.org/10.24928/2021/0126

Hyre, A., Harris, G., Osho, J., Pantelidakis, M., Mykoniatis, K., & Liu, J. (2022). Digital twins: Representation, replication, reality, and relational (4Rs). *Manufacturing Letters*, *31*, 20–23. https://doi.org/10.1016/j.mfglet.2021.12.004

International Organization for Standardization (ISO). (2018). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM): Information management using building information modelling—Part 1: Concepts and principles* (ISO 19650-1:2018). ISO. https://www.iso.org/standard/68078.html

Israelsson, N., & Hansson, B. (2009). Factors influencing flexibility in buildings. *Structural Survey*, *27*(2), 138–147. https://doi.org/10.1108/02630800910956461

Jiang, F., Ma, L., Broyd, T., & Chen, K. (2021). Digital twin and its implementations in the civil engineering sector. *Automation in Construction*, *130*, Article 103838. https://doi.org/10.1016/j.autcon.2021.103838

Jupp, J., & Awad, R. (2017). BIM-FM and information requirements management: Missing links in the AEC and FM interface. In J. Ríos, A. Bernard, A. Bouras, & S. Foufou (Eds.), *IFIP advances in information and communication technology: Product lifecycle management and the industry of the future* (Vol. 517, pp. 311–323). Springer International Publishing. https://doi.org/10.1007/978-3-319-72905-3_28

Kagermann, H., Anderl, R., Gausemeier, J., Schuh, G., & Wahlster, W. (Eds.). (2016). *Industrie 4.0 im globalen Kontext: Strategien der Zusammenarbeit mit internationalen Partnern (acatech STUDIE)*. Herbert Utz Verlag GmbH. http://web.archive.org/web/20170625121129/http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Projektberichte/acatech_de_STUDIE_Industrie40_global_Web.pdf

Kehily, D., & Underwood, J. (2015). *Design science: Choosing an appropriate methodology for research in BIM. CITA BIM Gathering 2015* [Online]. CITA. http://usir.salford.ac.uk/id/eprint/38522/

Klinc, R., & Turk, Ž. (2019). Construction 4.0 – Digital transformation of one of the oldest industries. *Economic and Business Review*, *21*(3). https://doi.org/10.15458/ebr.92

Kofner, S. (2000). *V. Strategieempfehlungen für die Bauwirtschaft*. https://www.fes.de/fulltext/fo-wirtschaft/00384toc.htm

Krieger, V., & Schapke, S.-E. (2019). Interview by anonymous. Rome. https://www.architekturzeitung.com/architekturmagazin/91-fachartikel/3747-interview-iso-19650-informationsmanagement-mit-bim

Lindblad, H., & Guerrero, J. R. (2020). Client's role in promoting BIM implementation and innovation in construction. *Construction Management and Economics*, *38*(5), 468–482. https://doi.org/10.1080/01446193.2020.1716989

Lis, D., & Otto, B. (2021). Towards a taxonomy of ecosystem data governance. In T. Bui (Ed.), *Proceedings of the 54th Hawaii International Conference on System Sciences* (pp. 6067–6076). https://doi.org/10.24251/HICSS.2021.733

Lundesjö (Ed.). (2015). *Supply chain management and logistics in construction: Delivering tomorrow's built environment*. KoganPage.

Mayenberger, C. S., & Perez-Castillo, D. (2022). Does technological innovation divide economic growth from sustainable development? *International Journal of Social Ecology and Sustainable Development*, *13*(7), 1–16. https://doi.org/10.4018/ijsesd.290391

Moreno, J. V., Machete, R., Falcão, A. P., Gonçalves, A. B., & Bento, R. (2022). Dynamic data feeding into BIM for facility management: A prototype application to a university building. *Buildings*, *12*(5), 645. https://doi.org/10.3390/buildings12050645

Nieto-Rodrigues, A. (2021, November–December). The project economy has arrived. *Harvard Business Review*. https://hbr.org/2021/11/the-project-economy-has-arrived

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, *83*, 121–139. https://doi.org/10.1016/j.compind.2016.09.006

Opoku, D.-G. J., Perera, S., Osei-Kyei, R., & Rashidi, M. (2021). Digital twin application in the construction industry: A literature review. *Journal of Building Engineering*, *40*, Article 102726. https://doi.org/10.1016/J.JOBE.2021.102726

Ozturk, G. B. (2021). Digital twin research in the AECO-FM industry. *Journal of Building Engineering*, *40*, Article 102730. https://doi.org/10.1016/J.JOBE.2021.102730

Pan, Y., & Zhang, L. (2021). A BIM-data mining integrated digital twin framework for advanced project management. *Automation in Construction*, *124*, Article 103564. https://doi.org/10.1016/j.autcon.2021.103564

Panteli, C., Kylili, A., & Fokaides, P. A. (2020). Building information modelling applications in smart buildings. From design to commissioning and beyond: A critical review. *Journal of Cleaner Production*, *265*, Article 121766. https://doi.org/10.1016/j.jclepro.2020.121766

Perrier, N., Bled, A., Bourgault, M., Cousin, N., Danjou, C., Pellerin, R., & Roland, T. (2020). Construction 4.0: A survey of research trends. *Journal of Information Technology in Construction*, *25*, 416–437. https://doi.org/10.36680/j.itcon.2020.024

Saari, A., & Heikkilä, P. (2008). Building flexibility management. *The Open Construction & Building Technology Journal*, *2*(1), 239–242. https://doi.org/10.2174/1874836800802010239

Sacks, R., Brilakis, I., Pikas, E., Xie, H. S., & Girolami, M. (2020). Construction with digital twin information systems. *Data-Centric Engineering*, *1*, Article e14. https://doi.org/10.1017/dce.2020.16

Sacks, R., Girolami, M., & Brilakis, I. (2020). Building information modelling, artificial intelligence and construction tech. *Developments in the Built Environment*, *4*, Article 100011. https://doi.org/10.1016/j.dibe.2020.100011

Shaw, C., Andrade Pereira, F. de, McNally, C., & O'Donnell, J. (2021, July 26–28). Facilities management domain review: potential contributions towards digitisation. In *Proceedings of the 2021 European Conference on Computing in Construction* [Online] (pp. 123–130). https://doi.org/10.35490/EC3.2021.211

Sivunen, M., Pulkka, L., Heinonen, J., Kajander, J.-K., & Junnila, S. (2013). Service-dominant innovation in the built environment. *Construction Innovation*, *13*(2), 146–164. https://doi.org/10.1108/14714171311322138

Spence, R., & Mulligan, H. (1995). Sustainable development and the construction industry. *Habitat International*, *19*(3), 279–292. https://doi.org/10.1016/0197-3975(94)00071-9

Stavropoulos, P., & Mourtzis, D. (2022). Chapter 10 – Digital twins in industry 4.0. In D. Mourtzis (Ed.), *Design and Operation of Production Networks for Mass Personalization in the Era of Cloud Technology* (pp. 277–316). Elsevier. https://doi.org/10.1016/B978-0-12-823657-4.00010-5

Tao, F., Zhang, M., & Nee, A. Y. C. (2019). *Digital twin driven smart manufacturing*. Academic Press. https://doi.org/10.1016/B978-0-12-817630-6.00010-2

Underwood, J., & Isikdag, U. (2011). Emerging technologies for BIM 2.0. *Construction Innovation*, *11*(3), 252–258. https://doi.org/10.1108/14714171111148990

United Nations. (2015). *The 17 goals: Sustainable development goals*. https://sdgs.un.org/goals

Van Aken, J. E. (2005). Management research as a design science: Articulating the research products of Mode 2 knowledge production in management. *British Journal of Management*, *16*(1), 19–36. https://doi.org/10.1111/j.1467-8551.2005.00437.x

Voordijk, H. (2009). Construction management and economics: The epistemology of a multidisciplinary design science. *Construction Management and Economics*, *27*(8), 713–720. https://doi.org/10.1080/01446190903117777

Weiß, P., Zolnowski, A., Warg, M., & Schuster, T. (2018). Service dominant architecture: Conceptualizing the foundation for execution of digital strategies based on S-D logic. In T. Bui (Ed.), *Proceedings of the 51st Hawaii International Conference on System Sciences* (pp. 1630–1639). https://doi.org/10.24251/HICSS.2018.204

Wildenauer, A. A. (2023). *Intelligent data structuring for facility management as basis for smart applications* [Unpublished PhD thesis, University of Economics and Business, Prague]. VSE Repository. https://vskp.vse.cz/english/87690_intelligent-data-structuring-for-facility-management-as-basis-for-smart-applications?author=Wildenauer&page=1

Wildenauer, A. A., & Basl, J. (2021). Unlocking the full potential of building information modelling by applying the principles of Industry 4.0 and data governance such as COBIT. In *EG-ICE 2021 Workshop on Intelligent Computing in Engineering* (Vol. 28, pp. 118–134). Universitätsverlag der TU Berlin. https://depositonce.tu-berlin.de/handle/11303/13226

Wildenauer, A. A., & Basl, J. (2022). Building-as-a-service: The opportunities of service-dominant logic for construction. In M. Überwimmer, R. Füreder, & P. Kwialek (Eds.), *Cross-cultural business conference 2022: Proceedings* (pp. 166–180). Shaker Verlag. https://doi.org/10.46286/msi.2022.17.3.5

Wildenauer, A. A., Mbabu, A., Underwood, J., & Basl, J. (2022). Building-as-a-service: Theoretical foundations and conceptual framework. *Buildings*, *12*(10), 1594. https://doi.org/10.3390/buildings12101594

Wolstenholme, A. (2009). *Never waste a good crisis: A review of progress since* Rethinking Construction *and thoughts for our future*. http://constructingexcellence.org.uk/wp-content/uploads/2014/10/Wolstenholme_Report_Oct_2009.pdf

Wu, W., Mayo, G. K., McCuen, T. L., Issa, R. R., & Smith, D. K. (2021). *Developing BIM talent: A guide to the BIM body of knowledge with metrics, KSAs, and learning outcomes*. Wiley.

Xu, L., Vrieze, P. de, Lu, X., & Wang, W. (2022). Digital twins approach for sustainable industry. In J. Horkoff, E. Serral, & J. Zdravkovic (Eds.), *Lecture Notes in Business Information Processing. Advanced Information Systems Engineering Workshops* (Vol. 451, pp. 126–134). Springer International Publishing. https://doi.org/10.1007/978-3-031-07478-3_11

Zheng, L., Lu, W., Chen, K., Chau, K. W., & Niu, Y. (2017). Benefit sharing for BIM implementation: Tackling the moral hazard dilemma in inter-firm cooperation. *International Journal of Project Management*, *35*(3), 393–405. https://doi.org/10.1016/j.ijproman.2017.01.006

A digital twin-oriented building information modelling excellence strategy for architectural education

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Abstract: This study aims to debate building information modelling (BIM) and its relationship to the digital twin (DT). The study presents and discusses a new strategic framework that systematically integrates BIM into architectural education to establish a DT-oriented curriculum that focuses on the professional competence development of architectural students to prepare for DT-oriented design practice. This study consists of three interconnected parts: (i) a systematic literature review to clarify the need for a DT-oriented architectural curriculum to be underpinned by modules relating to the digital design, construction, and operation of buildings; (ii) a strategic framework to facilitate BIM-pervasive learning in architectural education that can develop the body of knowledge of DT for students of architecture; and (iii) a structured discussion to reflect essential connections from the described strategic framework to the core curriculum of the Royal Institute of British Architects in continuing professional development and current practices on DT in the architecture, engineering, construction, and operation sectors towards the Industry 5.0 revolution. This study can inform both academic research and education practice in architectural studies for the development of an inclusive curriculum for students to be better prepared for professional collaborations in DT-driven practices. For academic research into DT for the built environment, this study establishes a view on the scope and structure of professional knowledge in architecture to support BIM-driven DT practices. For education practice in the built environment, a strategic framework is put forward that can enable development of a BIM-integrated architectural curriculum to reflect the need for professional competence in DT practices.

Keywords: architectural education, BIM, digital twins, educational framework, strategic planning

Acknowledgements: This paper partially fulfils the primary author's (Ozaer Zaed) PhD requirements at the University of Strathclyde, Glasgow, United Kingdom. The author would like to express gratitude to their supervisor, Dr. Zhen Chen, for their support and substantial input. Additionally, the author appreciates the reviewers for their enriching commentary, which helped to enhance the quality of this study presentation.

1 Introduction

Traditional architectural and construction processes are under transition, with technological innovation focusing on digital transformation towards Industry 5.0. Therefore, digital innovation and related technological advancements must be embraced and applied throughout the built environment, particularly in construction and architectural practices, as digital technologies such as digital twin (DT) and building information modelling (BIM) are critical components of Industry 5.0. It is crucial for architecture, engineering, and construction (AEC) education curricula and contents to be updated in relation to digital technologies and professional skills development (David et al., 2018; Liljaniemi and Paavilainen, 2020). Students, educators, and professionals can all benefit from the use of emerging digital technologies such as BIM and DT. In addition, these technologies can affect students' employability and the competitiveness of firms (Liljaniemi and Paavilainen, 2020).

Among the several technologies that are transforming today's physical and digital worlds in professional practices, this study has elected to focus on BIM in education and its relationship with DT, because BIM technology is a foundation for growing DT skills and knowledge in professional practices. Additionally, BIM is strongly connected to the construction and modernization of buildings, structures, and the built environment. The development of such education programmes should also move quickly and objectively towards teaching DT, in which BIM occupies an essential position.

Technological advancements and requirements to change skills have driven the ongoing need for academic and professional collaborations to develop a current architectural curriculum related to the professional skills needed. Universities have a critical role in fulfilling future demands for skills and developing intellectual graduates for a highly trained workforce.

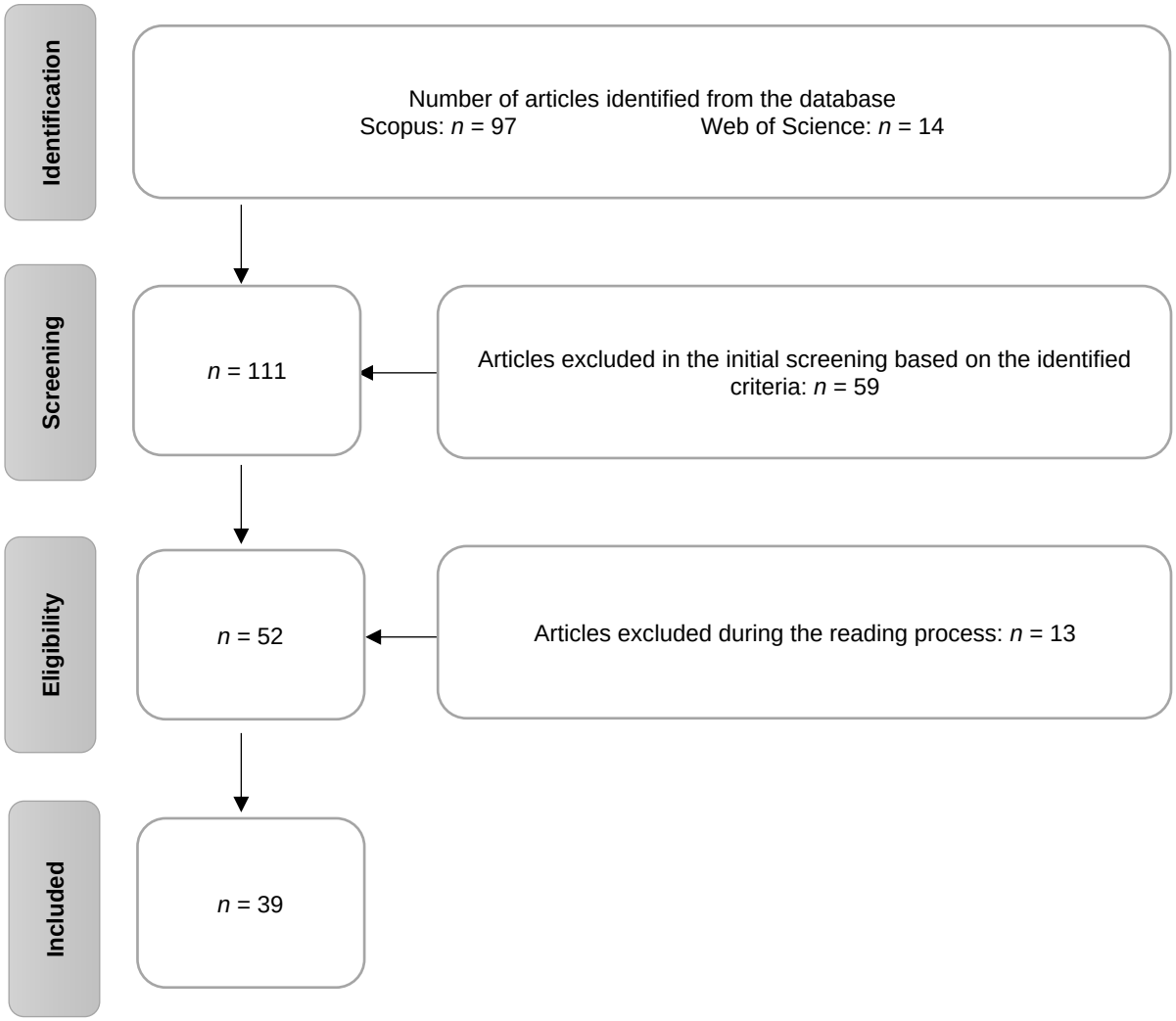
This study presents outcomes from current research into a framework for excellence in BIM education in the context of architectural education in Libya. Under the overall research aim, this study has the following three objectives:

- to review and discuss BIM and its connection with DT;
- to identify the challenges of BIM education and its importance in favour of DT technology; and
- to develop a strategic framework that integrates BIM into architectural education, which focuses on the professional competence development of students of architecture to be prepared for DT-related design practice.

2 Methodology

This research was influenced by the literature retrieved throughout the search process illustrated in Figure 1, which included search terms such as 'digital twin' AND 'built environment' OR 'construction' OR 'architectural'. To expand the research and to build a relationship between DT and BIM, the following terms were used in the search process: 'BIM education' OR 'BIM curriculum' OR 'BIM teaching' OR 'BIM education challenges', among others.

Figure 1: The process of literature search



Source: Authors' own.

The databases chosen for data collection in this research includes the Web of Science and Scopus. Table 1 summarizes the exclusion criteria used to find relevant literature from academic publications.

Table 1: Exclusion criteria for relevant literature

Stages	Exclusion criteria
Screening	• Repeated article • Not open-source/ not accessible in full-text versions • Not written in English • Sourced not from peer-reviewed articles • Published within more than 10 years
Eligibility	• The articles did not discuss at least one of the following topics: adoption, integration, application, and supporting technologies related to DT and BIM • The articles did not provide any relationship between DT and BIM.

Notes: DT, digital twin; BIM, building information modelling.

Source: Authors' own.

3 DT and BIM

This section aims to establish the relationship between DT and BIM and to understand how DT uses the BIM model. The concept of BIM is quite close to the concept of DT; however, there is an issue regarding the relationship and the differences between DT and BIM, and how DT applies BIM. These points are discussed in more detail in Sections 3.1–3.3.

3.1 The relationship between BIM and DT

BIM processes and DT strategies share several essential characteristics. Both are concerned with increasing process visibility, aligning stakeholders, and assisting in planning. In addition, BIM and DT are incredibly beneficial in helping teams view assets as ongoing projects. DT is considered a continuance development of the BIM model, where BIM serves as a primary platform for the emergence of DT in the built environment (Boje et al., 2020).

Successful BIM implementation processes can help to establish a clear project vision that supports business objectives before design or on-site work. However, after work has begun, it requires real-time insights to continuously improve and adjust programmes to give better value to everyone; this is where DT proves to be highly beneficial (Khajavi et al., 2019).

DT uses actual data to enable the visualization, monitoring, and optimization of operational assets, processes, and resources. This provides critical information on performances and activities in real time. DT is considered the core output of a BIM process; it is effectively a live representation of the project or asset that BIM procedures are designed to develop; it can evolve and transform in real time as the asset is used (Badenko et al., 2021). To maximize the value of each asset throughout its definition, design, implementation, and maintenance phases, subsequent infrastructure investment projects should contribute to the continuing creation of a DT through the use of the BIM process. The DT will serve as a single source of information for the asset across its existence; it will also serve as a template for future technological development by upgrading a process to a project (Douglas et al., 2021).

3.2 The differences between BIM and DT

The preceding analysis demonstrates considerable overlaps in the definition and scope of BIM and DT. However, there are two significant differences. The first notable difference is that, unlike most BIM models, DT addresses the duplication of the physical object and a two-way link that provides both the digital copy to be updated and the actual asset to be controlled. Although a BIM model may contain all the information necessary for constructing and operating a built asset, it lacks a well-defined relationship to the actual asset. In comparison, DT is a flexible approach that facilitates a data flow between physical and digital assets and vice versa (Davila Delgado and Oyedele, 2021).

The second notable difference pertains to implementation of BIM throughout the asset's lifecycle. BIM examines an asset's entire project lifecycle, whereas DT focuses exclusively on maintenance and operation (Khajavi et al., 2019). Most DT implementations in the built environment are concentrated on asset management and monitoring, and there is no unified framework for using DTs to assist with design and construction.

BIM has been applied for the entire lifecycle of an asset, especially in the design, construction, and operation stages. Operational BIM implementations diverge significantly from the DT concept for supporting built asset operations. For example, the BIM model for facility management is focused

on getting data about the delivered built asset to promote inventory and space management, general maintenance, and building services maintenance. However, it is not intended as a responsive model that is constantly updated to reflect the asset's condition and performance. Although BIM models for facility management are created after the built asset is constructed to provide owners and operators with a record of the asset, they do not directly enable asset control and monitoring because BIM models are not conceptualized to include continuously updated data or control physical assets. (Davila Delgado and Oyedele, 2021). Additionally, most estimates and simulations (structural, illumination, thermal and ventilation, and acoustic) are conducted to forecast future building performance rather than predict future building operations.

3.3 BIM for DT

DT provides multidimensional perspectives into the design and performance of an asset, including tenant behaviour, traffic patterns, space utilization, and usage practices. It provides simulation for what-if situations, such as the effect of design alterations, weather interruptions, and security incidents. It gathers enough data in a centralized environment. In contrast, BIM integrates data generated throughout the design and planning stage (Alonso et al., 2019). DT expands to the asset's development and operating phases and can drive future project planning and design. As a foundation for DT, BIM can assist countries in modernizing their construction industry and achieving cost and schedule efficiencies. BIM is frequently misunderstood as a three-dimensional (3D) modelling tool or a piece of design software used to obtain the information required at the appropriate time for the construction or maintenance of an asset. Therefore, BIM provides more than digital design; it enables the collation and cross-checking of plans against risk, cost, environmental, and social factors. At its core, BIM allows engineers to make data-driven decisions, which is the objective of a DT (Davila Delgado and Oyedele, 2021).

To fully realize the potential of DTs, it is necessary to have multidisciplinary models at the core and integrate technologies and data across processes and between firms. BIM seems to be the most efficient method for creating a high-quality DT.

4 Transformation of DT-oriented BIM education

BIM is now primarily viewed as a significant milestone in the construction sector as it can be used for various purposes throughout a project's lifecycle and positively affects the construction sector's productivity. It is a method for generating and processing visual representations of a building throughout its lifecycle, during the design, construction, operation, and maintenance phases. As a result, BIM education is critical for professional competence development. BIM education lays the groundwork for rethinking architectural education by assisting in generation of the diverse knowledge and skills needed for the construction industry, enabling technological, manageable, and policy-driven advancements in architectural research as a first step towards introducing DTs into the digital world.

BIM education is a complex and evolving process that is notoriously difficult to fit into conventional architectural educational frameworks. However, several countries have begun to include BIM education in architectural education programmes. Educators are attempting to develop appropriate curricula and are interested in developing BIM courses. Benner and McArthur (2019a) suggested how an experimental approach to BIM-enabled student engagement in the BIM course through iterative design–analysis–synthesis cycles. Students developed a significant ability to model and evaluate design iterations using BIM-generated data throughout the course, which allowed them to better understand how design decisions affect capital expenditures and energy

consumption and promote critical thinking throughout the design process (Benner and McArthur 2019b). Additionally, students demonstrated an increased understanding of construction physics and economics from their participation in the use of BIM to conduct a simple analysis and evaluate it to make informed design refinement decisions. Students consistently demonstrated their ability to use BIM for analysis, synthesis, and evaluation, thereby establishing a foundation for achieving higher learning outcomes (Benner and McArthur, 2019b).

The construction industry's high demand for higher education graduates drives the need for practical skills and theoretical knowledge of spatial and digital imaging and the latest technology and software. Therefore, students should begin preparing for the technological advancements in the professional industry early on as failure to do so in the educational system puts students' competitive edge and professional skills in the labour market at risk. This raises several challenges for educators about how, when, and what type of technologies must be included in the architectural curriculum (Shull, 2018).

The introduction of digital visualization is critical for students of architecture, as it benefits students when they use it in their core courses. For example, (i) digital visualization may alleviate some technical difficulties students may encounter when expressing their ideas and exploring complex architectural forms that they cannot communicate using manual methods; (ii) digital visualization may enable students to consider a more significant number of alternatives in a shorter time, resulting in a complete understanding of the design problem and a more effective solution; and (iii) digital visualization may assist students in visualizing and numerically comprehending the implications of their design decisions and better integration of the technical aspects typically covered in other courses into their studio design projects (Shull, 2018).

Pedagogical intervention in the architectural curriculum aims to provide students with immersive experiences through digital visualization technology, thereby enabling spatial visualization. The ideal outcome of this intervention will be for students to better understand 2D and 3D drawings, which will prepare them for future careers (Shull, 2018). Visualizing a 3D object based on 2D representations is effortless; however, others struggle to comprehend things due to their limited 3D visualization abilities.

The benefits of providing an engaging and immersive environment have improved interest in virtual reality (VR) and augmented reality (AR); they have been implemented in architectural education and professional training. Both AR and VR as components of the mixed reality continuum rely on human–computer interaction, with technologies combining environmental mapping and a 3D virtual environment (Jin et al., 2020). Thus, the DT can be spatially and temporally referenced. Regardless of the definition of DT used, all factors affect AR and VR and influence the DT selection process. The incorporation of methods into the architectural curriculum can result in a more conducive learning environment and, as a result, improved learning outcomes, particularly when it comes to BIM education. Teaching BIM in conjunction with VR and AR can result in a more engaging learning environment that offers a unique learning experience and keeps students engaged throughout the educational process (Wang et al., 2020).

The use of 3D visualization technology, such as AR, to visualize collaborative architectural design based on BIM allows for more effective project monitoring and information exchange with stakeholders. However, AR has some technical limitations regarding compatibility with personal devices and rendering quality. AR offers significant advantages and opportunities for collaborative development when used in conjunction with BIM (Jin et al., 2020) and affects the evolution of BIM education towards a DT.

5 Challenges of BIM integration in architectural education

The incorporation of BIM into architectural education in particular, and civil engineering and construction management education in general, has been hindered by several obstacles that have prevented its full implementation. During the process of developing a university programme, it is not uncommon for the incorporation of any emerging technology to be without obstacles. The predominant concerns for BIM education include technologies, processes, individuals, and policies (Badrinath et al., 2016).

The introduction of an emerging information and communication technology such as BIM requires a modern laboratory with the necessary equipment. Moreover, this necessitates a server with the requisite specifications to manage the extensive storage capacity of BIM users. BIM software and hardware are frequently expensive, and reports indicate that university instructors have difficulty deciding on the most appropriate tools (Maina, 2018). In addition to professional and well-trained technical support personnel, laboratories must be maintained in terms of hardware and software. There are also issues with software licences, interoperability, and a lack of intelligent BIM software for error detection and correction (Belayutham et al., 2018). Other organizational issues include a lack of space to accommodate new classes; this pertains to both the curriculum and the estate in terms of physical space (Shibani et al., 2020). To address these issues, it is also necessary to provide adequate financial support for the development of educational infrastructure, software, hardware, and teacher training.

The collaboration between academic and industry practices is fundamental to BIM education. However, this collaboration is missing, demonstrating the current disparity between industry expectations and educational outcomes (Bozoglu, 2016). This issue must be addressed by forming partnerships between educators and professionals. Additionally, the BIM process requires construction expertise that students frequently lack (usually due to inexperience). It is advantageous for students to have the opportunity to gain work experience and acquire industry skills so that they can apply their academic knowledge in real-world settings.

There is a clear need for academics to take a stance on issues regarding the integration of BIM education policies. The resistance to change and the lack of educational initiative to provide BIM courses must be eliminated. The primary opposition to the implementation of new BIM modules in academia stems from the need to develop new teaching and learning methods (Babatunde and Ekundayo, 2019). The lack of staff skills in BIM tools is a significant issue that must be addressed by providing teachers and tutors with ongoing professional development in BIM tools (Puolitaival et al., 2017). Universities that want to implement BIM may face additional obstacles. Many of these, however, will be institutional, such as promoting BIM integration among and between different disciplines and aligning programmes with those of other departments. BIM education be included in a university's vision to promote BIM among faculty and students. All these issues must be addressed, indicating the need to develop a comprehensive plan for the integration of BIM into architectural education as both a tool and a central theme.

The discussion in this section identified the main education criteria that need to be considered during the development of a BIM education framework to overcome the current BIM education challenges that include (i) BIM education vision and mission, (ii) education infrastructure including software, hardware, and teaching spaces, (iii) professional competence and development related to BIM, (iv) curriculum design and development, (v) academic and professional collaborations, and (vi) education process enhancement (Zaed et al., 2021).

6 A strategic framework for DT-oriented BIM integration

The importance of BIM in connection with the theory and practice of DT, which heavily relies on BIM technology and sets of data and information from digital modelling, has been outlined in the discussion in earlier sections. However, BIM and DT implementation face several challenges that can be tackled by providing appropriate education and training to students who are future professionals. In this scenario, embedding BIM in architectural education prepares students with practical skills related to digital technologies, and one important step to do this is to establish a DT-oriented BIM excellence strategy for architectural education.

This section describes a strategic framework to facilitate a DT-oriented BIM integration process in architectural education. The strategy to develop BIM education in the field of architecture focuses on three work stages in connection with the following six identified evaluation criteria:

- university vision/BIM education vision and mission,
- education infrastructure development,
- professional competence and development,
- curriculum design and development,
- academic and professional collaborations, and
- education process enhancement.

Table 2 describes the strategic framework for developing a DT-oriented BIM integration into architectural education. Additional descriptions about these three work stages in response to the six evaluation criteria for education development are given in Sections 6.1–6.3.

Table 2: Strategic framework for developing a DT-oriented BIM integration into architectural education

Domains of evaluation criteria	Work stages of BIM-integrated education development		
	1. Programme preparation	2. Programme deployment	3. Programme improvement
A. University vision	1.1. Identifying the purpose of BIM education	2.1. Deploying a BIM education programme in accordance with the university's implementation plan	3.1. Teaching BIM as a methodology in teaching and learning activities
B. Infrastructure development (software, hardware, and facilities)	1.2. Diagnosing current educational infrastructure 1.3. Proposing a plan for enhancing the existing educational infrastructure (software and equipment)	2.2. Installing main BIM software and providing licences for staff and students	3.2. Installing different software in all BIM teaching spaces
		2.3. Providing suitable hardware to use BIM in the university	3.3. Providing proper hardware with BIM use, with plans to develop a continuous improvement programme
		2.4. Creating suitable spaces for teaching and learning BIM	3.4. Teaching BIM in a collaborative learning environment with student engagement from different disciplines
C. Professional competence and development	1.4. Developing a plan to promote BIM learning in the faculty 1.5. Staff training	2.5. Periodic training according to the BIM implementation plan	3.5. BIM requirements in the competency matrix for teacher recruitment
D. Curriculum design and development	1.6. Developing and creating new	2.6. Developing existing modules to integrate BIM	3.6. Integrating BIM with the core architectural courses and related disciplines

	courses/modules related to BIM		
E. Academic and professional collaborations	1.7. Creating relationships between academics and professionals	2.7. Professional assistance in developing BIM courses and providing practical training for teachers on BIM tools	3.7. Professional presentations of real BIM case studies to students
F. Education process enhancement	1.8. Providing improvements to the educational process through publications, evaluation, and even students' perceptions		

Source: Authors' own.

6.1 Stage 1: Programme preparation

The initial stage consists of the university's inclination to include BIM in the architectural programme. This demands the following steps: the first step in integrating BIM into architectural education is to build the university's vision for BIM by identifying the objective of BIM education and incorporating BIM into the institution's vision and mission. The vision does not specify BIM but presents a formula for policies and activities consistent with the expansion of architectural education. For instance, an architecture university's future vision and strategy may include providing students with better quality education in new technology in the built environment. The university can plan to implement BIM to optimize students' future potential and boost their employability and competitiveness.

After the university's purpose of teaching BIM has been defined, there is a need to review and evaluate the existing curriculum and education infrastructure. At this stage, the institution needs to agree with a software and hardware developer to provide the university with BIM-compatible equipment. The integration of BIM into architectural education necessitates the implementation of appropriate teaching and learning resources, software hardware, and facilities infrastructure, which are essential during the programme preparation phase to propose a plan for the current infrastructure software and equipment based on the identified learning objectives and BIM vision defined by the department.

It is also essential to provide education and training to educators. Even if teachers are experts in their fields, they may lack the requisite expertise and practical knowledge of BIM models. This can be done with help from professionals interested in BIM curriculum development. In addition, there is a need to create a programme to encourage BIM learning among the faculty, which can be done by arranging workshops for educators on the importance of BIM in digital construction and practice; this is because motivation is key to lecturers who decide to adopt BIM in their methods and techniques.

It is essential to establish formal relationships between academics and professionals; initial partnerships may involve the university's information and technology department. In the initial adoption phase, the information and technology team can aid in diagnosing the status of the available hardware and software in the architectural laboratories. In addition, establishing collaborations with professionals can assist educators in producing comprehensive course materials that identify the most important BIM competencies required in practice; it also aids in providing teachers with practical training on BIM technologies. After determining the BIM abilities necessary for professional practice, the instructors can construct and adapt the existing BIM module and produce the required instructional materials to initiate the BIM curriculum in the architectural department.

6.2 Stage 2: Programme deployment

The second stage is the university's implementation of BIM, which is accomplished through some BIM-related activities, such as boosting the university's BIM mission by including BIM strategic planning in the architectural curriculum. Ideally, the university should incorporate BIM implementation plans, policies, recommendations, and methodologies aligned with their current and future goals to encourage and motivate teachers to actively adopt BIM education.

The university should provide adequate hardware, install the primary BIM software, and provide staff and student licences. At this time, a university intending to offer BIM must have adequate information technology and hardware infrastructure, such as computers, to introduce BIM standalone courses. Additionally, proper spaces for teaching and learning BIM must be provided.

According to the BIM implementation strategy, the institution and educator must recognize the significance of continued professional development and give periodic training accordingly. Universities should also foster interdepartmental collaboration throughout the programme deployment phase, allocating resources and adopting consistent processes across AEC divisions. This partnership could eliminate the repetition and duplication of instructional materials, lowering staff strain. In addition, professionals can continue to assist in building BIM courses and in providing teachers with real BIM tool training.

In curriculum design and development, it is necessary to integrate BIM into current modules, with a focus on imparting conceptual knowledge and practical abilities on BIM based on academic years. It is suggested that modules be given gradually to avoid a catastrophic failure. This integration can be progressively attained through disciplines; for instance, the architectural curriculum can first be modified and then other fields of study.

6.3 Stage 3: Programme improvement

The third stage is the continuous and gradual improvement in quality, repeatability, and predictability within BIM capabilities. In this stage, the university should evaluate the complete implementation of BIM education with the architectural programme, including comparing the final results to the BIM education vision and mission given in the first stage of implementation. After completion, evaluations are done and feedback is collected for continuously improving the process until the university achieves the intended BIM learning outcomes that represent the effective integration of BIM education. The university should have the ability to integrate BIM via:

- teaching BIM as a methodology in teaching and learning activities;
- installing different software in all BIM teaching spaces;
- providing proper hardware with BIM use, with plans to develop a continuous improvement programme;
- teaching BIM in a collaborative learning environment with student engagement from different disciplines;
- having BIM requirements in the competency matrix for teacher recruitment;
- integrating BIM with the core architectural courses and related disciplines; and
- professional presentations of real BIM case studies to students.

7 Conclusion

This study presents an initial review of the relationship between BIM and DT, with a focus on DT-oriented BIM integration into architectural education. This study also makes an academic contribution to the importance of transforming architectural education in the digital world towards BIM and DT technologies. These two technologies are implemented in the AEC sector and are becoming pillars of building national DTs. Therefore, digital transformations in teaching are changing educational processes and the entire economics of these processes, which must also be considered when developing architectural education.

BIM and DT can be applied successfully only by understanding their roles, and this requires proper training. Therefore, BIM and DT should be embedded into architectural education in all the related subjects in the curriculum. This study presents the development of a strategic framework for initial BIM education in three phases as connected to the identified evaluation criteria for integration of BIM education, which includes university vision, infrastructure development, professional competence and development, curriculum design and development, academic and professional collaborations, and education process enhancement.

8 References

Alonso, R., Borras, M., Koppelaar, R. H. E. M., Lodigiani, A., Loscos, E., & Yöntem, E. (2019). BIM digital twin platform. *Proceedings*, *20*(1), 9. https://doi.org/10.3390/proceedings2019020009

Babatunde, S. O., & Ekundayo, D. (2019). Barriers to the incorporation of BIM into quantity surveying undergraduate curriculum in the Nigerian universities. *Journal of Engineering, Design and Technology*, *17*(3), 629–648. https://doi.org/10.1108/JEDT-10-2018-0181

Badenko, V. L., Bolshakov, N. S., Tishchenko, E. B., Fedotov, A. A., Celani, A. C., & Yadykin, V. K. (2021). Integration of digital twin and BIM technologies within factories of the future. *Magazine of Civil Engineering*, *101*(1), Article 10114. https://doi.org/10.34910/MCE.101.14

Badrinath, A. C., Chang, Y. T., & Hsieh, S. H. (2016). A review of tertiary BIM education for advanced engineering communication with visualization. *Visualization in Engineering*, *4*(1), 1–17.

Belayutham, S., Zabidin, N. S., & Ibrahim, C. K. I. (2018). Dynamic representation of barriers for adopting building information modelling in Malaysian tertiary education. *Construction Economics and Building*, *18*(4), 24–44. https://doi.org/10.5130/ajceb.v18i4.6228

Benner, J., & McArthur, J. J. (2019a). Lessons learned from a multi-year initiative to integrate data-driven design using BIM into undergraduate architectural education. In I. Mutis & T. Hartmann (Eds.), *Advances in informatics and computing in civil and construction engineering* (pp. 857–864). Springer International Publishing. https://doi.org/10.1007/978-3-030-00220-6_103

Benner, J., & McArthur, J. J. (2019b). Data-driven design as a vehicle for BIM and sustainability education. *Buildings*, *9*(5), 103. https://doi.org/10.3390/buildings9050103

Boje, C., Guerriero, A., Kubicki, S., & Rezgui, Y. (2020). Towards a semantic construction digital twin: Directions for future research. *Automation in Construction*, *114*, Article 103179. https://doi.org/10.1016/j.autcon.2020.103179

Bozoglu, J. (2016). Collaboration and coordination learning modules for BIM education. *Journal of Information Technology in Construction*, *21*, 152–163. http://www.itcon.org/2016/10

David, J., Lobov, A., & Lanz, M. (2018, October 21–23). Learning experiences involving digital twins. In *Proceedings of the 44th Annual Conference of the IEEE Industrial Electronics Society (IECON 2018)* (pp. 3681–3686), Washington DC. https://doi.org/10.1109/IECON.2018.8591460

Davila Delgado, J. M., & Oyedele, L. (2021). Digital twins for the built environment: Learning from conceptual and process models in manufacturing. *Advanced Engineering Informatics*, *49*(March), Article 101332. https://doi.org/10.1016/j.aei.2021.101332

Douglas, D., Kelly, G., & Kassem, K. (2021, July 26–28). BIM, digital twin and cyber-physical systems: Crossing and blurring boundaries. In *Proceedings of the 2021 European Conference on Computing in Construction* (pp. 204–211), Northumbria University and BIM Academy, United Kingdom. https://doi.org/10.35490/ec3.2021.196

Jin, Y., Seo, J. O., Lee, J. G., Ahn, S., & Han, S. U. (2020). BIM-based spatial augmented reality (SAR) for architectural design collaboration: A proof of concept. *Applied Sciences (Switzerland)*, *10*(17), Article 5915. https://doi.org/10.3390/app10175915

Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmstrom, J. (2019). Digital twin: Vision, benefits, boundaries, and creation for buildings. *IEEE Access*, *7*, 147406–147419. https://doi.org/10.1109/ACCESS.2019.2946515

Liljaniemi, A., & Paavilainen, H. (2020). Using digital twin technology in engineering education-course concept to explore benefits and barriers. *Open Engineering*, *10*(1), 377–385. https://doi.org/10.1515/eng-2020-0040

Maina, J. J. (2018). Barriers to effective use of CAD and BIM in architecture education in Nigeria. *International Journal of Built Environment and Sustainability*, *5*(3), 175–186. https://doi.org/10.11113/ijbes.v5.n3.275

Puolitaival, T., Booth, T., Ghaffarianhoseini, A., & Park, K. (2017). BIM education: Case New Zealand. In M. Lamb (Ed.), *Australasian Universities Building Education Association Conference 2017* (Vol. 1, pp. 210–218). EasyChair.

Shibani, A., Awwad, K. A., & Ghostin, M. (2020, March 10–12). Investigating the barriers of building information modelling (BIM) implementation in the higher education in Morocco. In *Proceedings of the 10th Annual International Conference on Industrial Engineering and Operations Management* (pp. 471–480), Dubai, United Arab Emirates.

Shull, K. (2018) Implementing digital visualization technology within AEC education: A pedagogical intervention (Publication No. 10814121) [Master's thesis, Colorado State University]. ProQuest Dissertations and Theses Global. https://www.proquest.com/openview/d928e8629f77b90458a77b04cca35679/1?pq-origsite=gscholar&cbl=18750

Wang, L., Yan, X., Fan, B., Jin, R., Yang, T., & Kapogiannis, G. (2020). Incorporating BIM in the final semester undergraduate project of construction management — A case study in Fuzhou University. *KSCE Journal of Civil Engineering*, *24*(8), 2403–2418. https://doi.org/10.1007/s12205-020-1971-4

Zaed, O., Chen, Z., Grant, M., & Dimitrijevic, B. (2021, March 17). Challenges and solution of BIM integrated architectural education towards construction excellence. In *Proceedings of the 5th Construction Conference: Exploring contemporary issues and challenges in the construction industry (CCC2021)* (pp. 1–5), Coventry, United Kingdom.

Innovation in Architecture and Construction

Themes of well-being associated with daylighting practice and shading systems in the working environment

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Abstract: Daylighting conditions throughout an internal space directly affect the health and well-being of building occupants. Various physiological and psychological benefits have been attributed to the presence of daylight in buildings. To enhance the performance of building façades, shading systems are one of the most preferred methods. The advantages of shading are limited to protecting a building façade from direct sunlight and controlling the amount of natural light in a space. The primary focus of daylighting design recommendations is improving energy efficiency rather than enhancing health and well-being. Although some of the biological influences associated with the amount of daylight received by building occupants and its impact on their stress, level of productivity, and sleep quality are well documented, there is a general ambiguity in the literature about measuring occupant well-being related to daylighting design. Many studies assess daylight exposure as an indicator to directly measure health and well-being of individuals. Other studies measure visual comfort from having enough contrast in daylighting illuminance to quantify well-being. This study aims to define themes of well-being related to daylight design founded in studies referring to the role of shading systems to improve daylight inside the working environment. This study is structured as three sections. The first section aims to provide background information to those who are not deeply involved in the topic through a review of what well-being means in theory and why work and well-being are important. The second section is a critical review of 12 relevant studies using thematic analysis to extract the approaches used to quantify well-being related to daylighting and shading systems. The final section provides a summary, highlights the main knowledge contributions, and provides future research recommendations. The findings illustrate the gaps found in well-being assessment tools and the need to establish a holistic approach consisting of three factors: daylight, outside view, and shading systems.

Keywords: daylighting, health and well-being, shading systems, working environment

1 Introduction

The World Health Organization (2022) has indicated that employee well-being must be a priority for solving mental health problems. Many studies show that one in four people have significant mental health issues from workplace disability (World Health Organization, 2022; Valente, 2010; National Alliance on Mental Health, 2022). Every year the European Union spends over 135 euros on alleviating mental health problems of building occupants (Dewa & McDavid, 2011), the United States spends between 150 billion and 300 billion US dollars per year (American Psychological Association, 2013), and Canada spends around US$50 billion each year (Mental Health Commission of Canada, 2022). In the United Kingdom, work stresses, depression, and anxiety account for more than 600 people in working environments and the average sick days per person is 21 days; well-being illnesses such as depression and stress affect more than 40% of employees in the United Kingdom (Gill and Butler, 2020). Daylight inside a building is associated with many physiological and psychological benefits that affect occupant well-being. Daylight conditions throughout an indoor environment directly affect the health and well-being of building occupants (Dobrica et al., 2020; Owl Labs, 2021; Kelloway and Cooper, 2021; Canada Standards Association, 2013; Zhou, et al., 2020). Although light is predominantly perceived as a visual phenomenon, it also affects human physiology, behaviour, and mood, summarized as non-visual effects (International Commission on Illumination, 2008). The visual effects of daylight refer to the photometric measurements used to analyse how much light is present in a given space for tasks. In contrast, non-visual effects are subjective assessments that evaluate how the light is perceived (colour, intensity, distribution, uniformity, etc.).

The façade is a central element to compromise between comfort requirements of an inside space and the dynamic external environment parameters. Some working spaces stimulate occupant well-being and feelings of happiness, visual interest, and excitement. In addition, installing a shading system to the façade could lead to better daylight quality. The advantages of shading are limited not only to protecting a building façade from being directly exposed to sunlight (Ticleanu 2021; Couvelas et al., 2018) but also to controlling the amount of daylight in a space. Shading systems are one of the most preferred methods to enhance the performance of building facades (Kirimtat et al., 2016). In contrast, other façades stimulate disturbance, gloom, and discomfort depending on the daylighting conditions, which could be optimized using shading systems. Klein (2021) presents a classification of façade systems based on recent and future functions, but there is no reference to a façade system for health and well-being achievements.

For the past 40 years, daylighting visual effects have been assessed and measured using a variety of daylight metrics. However, recommended practices in daylighting design primarily focus on improving the energy efficiency of buildings and the comfort of building occupants rather than on optimizing its role in enhancing occupant' health and well-being (Elkadi & Al-Maiyah, 2021). Several studies have examined the relationship between daylight and well-being for the workplace and indicate the challenges that come with balancing competing environmental goals for indoor environments. To provide an overview of the current state of research in this topic, a literature review of specialist academic journal articles published during the last decade and limitations of the methods used to assess daylighting, non-visual effects, and well-being as well as the practical implications of this knowledge were examined. This study begins with a historical background about the definition of well-being and the themes associated with daylighting quality. A summary of the literature review is followed by a summary of the findings; these findings are organized into three categories based on the trends identified: (i) study focus, (ii) methods, and (iii) well-being themes.

2 Well-being and daylighting in architectural practice

The concept of well-being refers to what is intrinsically valuable to an individual. It consists of two dimensions – the personal and the social dimension – that explain how individuals feel and function (Crisp, 2020). The well-being of a person is ultimately good for that person and is in that person's self-interest (Andrews & McKennell, 1982). In another definition, well-being is 'a special case of attitude' (Steemers, 2021) consisting of two key elements: feeling good and functioning well (Fletcher, 2016, p. 148). Theories of well-being aim to clarify the state features responsible for a person's well-being. Hedonistic theories equate well-being with the balance of pleasure over pain. Desire theories state that well-being consists of desire satisfaction: the higher the number of satisfied desires, the higher the well-being. Objective list theories state that a person's well-being depends on a list of factors that may include both subjective and objective elements (Rea et al., 2005).

To explain the relationship between daylighting and well-being in the lighting community, a philosophical shift occurred to define the new knowledge related to architectural practice (Newsham et al., 2010).

One of the prior clarifications concluded by J. A. Veitch, who illustrated a model based on the objective list theory of well-being, states that a person's well-being depends on a list of factors such as mood and comfort. Furthermore, according to architecture practice, Veitch (in Rea, 2005) identifies four factors to integrate with lighting quality: (i) form, (ii) composition, (iii) style and codes, and (iv) standards regulation.

Several standards have been published to outline ideal environmental parameters for workplace environments, such as daylighting, energy consumption, thermal comfort, and visual comfort, among others. This study is limited to daylighting; therefore, the working environment in terms of daylight has two targets to be achieved: (i) the quality of daylight in the space and (ii) the quantity of task illuminance recommended by daylighting standards. One of the most critical aspects or additions in current building standards is introducing the WELLv2™ building standard, which states new metrics related to occupant health and well-being. WELLv2 building standards are much more comprehensive than sustainability rating systems. They address nearly all health-related indoor environmental concerns cited in academic research (Newsham et al., 2010). These metrics could be achieved by controlling daylight conditions through a façade design (McArthur & Powell, 2020; The WELL Building Standard, 2021). WELLv2™ recommends that a psychological advantage, such as daylight, is associated with an occupant's ability to interact with the outside view through windows. This connection can enhance occupant comfort and well-being by reducing stress and improves worker performance (Schweizer et al., 2007).

3 Methodology

3.1 Search process

This study presents a deep analysis to identify the most relevant publications on daylighting, health, well-being and shading systems over the last 10 years. Numerous databases are widely available online, and the most prominent sources such as Scopus, Web of Science and Google Scholar were used for keyword searches. The literature was chosen after systematically searching Google Scholar and SCOPUS for recent daylighting-related articles. The research was limited to journal papers, and combinations of the following keywords were used: daylight, health and well-being. Only

articles exploring daylighting effects on 'occupant well-being' were selected to form the paper sample. Studies analysing daylight comfort in terms of thermal consumption, energy and artificial light, unless they refer to the interaction of occupant comfort and well-being, were excluded. The criteria matched with 12 published papers in essential daylight, shading, and well-being (see Table 1).

Table 1: Search terms in Scopus and Google Scholar

Scopus	(**Daylight** and **Well-being** and **View** and **Shading** (Title/Abstract) AND daylight, natural light (Title/Abstract)) NOT Thermal (All fields)
Google Scholar	(**Daylight** and **Well-being** and **View** and **Shading** (Title/Abstract) AND daylight, natural light (Title/Abstract)) NOT Thermal (Engineering field)

Source: Authors' own.

3.2 Data extraction

The following data were extracted from the studies, if available: (i) Research information including name and year of publishing; (ii) focus of study (i.e. well-being, comfort, health, and people's perception of the ambient conditions of natural light, and quality of view); (iii) characteristic element; (iv) daylight metrics; and (v) themes of well-being. These data are enumerated in Table 2.

Table 2: Data extraction

1	2	3	4	5
Research information	Methods	Characteristic element	Daylight metrics	Themes of well-being
12 papers	3 methods	12 samples	4 metrics	4 themes

Source: Authors' own.

4 Themes of well-being in daylighting studies

Berson et al. (2002) discovered intrinsically photosensitive retinal ganglion cells (ipRGCs), which led to an increased interest in the non-visual effects of light. Several experiments have been performed to assess the impact of non-visual responses on different daylighting conditions, such as melatonin suppression, sleep quality, subjective and objective visual interest and mood (Thapan et al., 2001; Brainard et al., 2001; Berson et al., 2002; Khademagha et al., 2016). These experimental studies help to understand non-visual effects and provide guidelines for daylighting designs and systems that positively affect human health and well-being. Experiments in laboratories have revealed the light factors that influence non-visual effects. The International Commission on Illumination (2016) released a technical report on healthy interior daylighting recommendations that provided researchers with a research roadmap. To understand how light exposure influences its effects, we define non-visual effects. A healthy and comforting daylighting environment consists of three main components: (i) circadian rhythm, (ii) visual interest, and (iii) mood (Hui et al., 2021).

Based on these parameters, the selected samples present three themes of well-being associated with the non-visual effects of daylighting as follows: (i) Circadian rhythm (Acosta et al., 2019; Boubekri et al., 2020); (ii) visual interests and impressions (Amundadottir et al., 2017); and (iii) satisfaction with access to the outside view content (Elzeyadi, 2011), view access (Jamrozik et al., 2019; Boubekri et al., 2020), and daylight quality (Sherif et al., 2015).

4.1 Circadian rhythm

Some studies have focused on how better daylight conditions can improve human health and well-being by improving the occupants' biological clock, which affects their circadian stimulus (Acosta et al., 2019; Boubekri et al., 2020). Acosta et al. (2019) discussed the minimum window-to-wall ratio (WWR) effects on the colour temperature in a classroom. In this study, circadian stimulus autonomy was measured as the percentage of days per year that circadian stimulus exceeds a threshold in a classroom. However, natural and electrical light can improve circadian stimulus. The experiment occurred in a classroom with large windows of variable WWR of 30%, 45%, and 60% with different positions and orientations and under three typical sky conditions. Comparing the circadian stimulus values for the three window sizes reveals that, in comparison with the medium-sized window, when the window-to-façade ratio is 60%, it shows an average increase in circadian stimulus of about 15%, whereas when the window-to-façade ratio is 45%, there is an increase in circadian stimulus of 14% over the small window. This approach could be helpful to show how window design parameters and daylight conditions can improve occupant well-being. In another study, Boubekri et al. (2020) illustrate the advantages of daylight exposure and the clear view of the outside environment. Their study linked the impact of daylight exposure to circadian rhythm, which can affect occupant well-being by improving sleep quality and productivity in working spaces.

4.2 Visual interests and impressions

Quantitative studies on the visual effects of daylighting measure daylighting metrics, such as daylight factor, glare, luminance distribution, and daylight autonomy in a given space for task performance, whereas qualitative studies on the non-visual effects of daylighting aim to explain health and well-being themes, such as circadian rhythm, visual interest, and mood on occupant satisfaction, impressions, and cognition. Amundadottir et al. (2017) introduce a new approach for improving occupant well-being in the working space by recording their visual interest behaviour. This new approach considers that field of view received at occupant eye level plays an essential factor in occupant perception of daylight conditions. Amundadottir et al. (2017) used visual reality to assess three factors: (i) non-visual health aspects, (ii) visual interest, and (iii) gaze motion. Comparing the results of each factor illustrates how humans respond to daylight in a space. This experiment was implemented in a controlled laboratory where gaze movements were scored using an immersive spatial approach. The results show that daylight distribution has a variable effect on non-visual health aspects and visual interest.

4.3 Satisfaction with view and daylight quality

Another type of research aimed to investigate the ability of shading systems with non-visual effects (Altomonte, 2009; Elzeyadi, 2011; Sherif et al., 2015). The shading parameters became dependent parameters, aiming to improve occupant comfort and well-being by improving daylighting visual comfort aspects such as glare and distribution and occupant perception of the outside view quality that will enhance occupant mood and well-being. The complexity of this type of research that connects quantitative and qualitative measurements is needed for further investigation. Altomonte (2009) studied the impact of using a blind as a shading device to improve occupant perception towards daylight conditions in a workspace. This impact aimed to assess human perception and well-being by defining a framework showing some recommendations on which type of blind configuration will suit the type of work. Altomonte's (2009) experimental study was conducted in two seasons, winter and summer, at 10 a.m. with a fixed orientation to the east. In the winter, glare was an issue because of the low sun angle. It was observed that occupants preferred to do paperwork tasks rather than screen tasks during the morning. Their perception of daylight provision and view outside made them feel better and increased their activity. Altomonte (2009)

also tested two combinations (vertical and horizontal) of this blind to assess the luminance ratio and colour temperature as the most critical indicators that affect occupant perception in a workspace.

Subsequently, context impact and outside view composition became dependent parameters in investigating the non-visual effects of daylight. Elzeyadi (2011) conducted a study to quantify how daylight conditions and outside view quality could affect employee health and well-being. To illustrate this effect, the author relied on the biophilic approach to show the relationship between natural outside view and daylight and their impacts on sick leave for employees. Elzeyadi (2011) used different pictures from different locations and 98 full-time employees to assess outside view quality. The employees were asked to rank 12 selected photographic images of different outside views surrounding the working area. After that, a questionnaire was administered to learn what employees preferred to see while sitting in offices on campus, including forest, urban, and street view scenes. In addition, the study analysed daylight using high dynamic range images taken from the setpoint for each employee to define glare issues associated with the outside view. Further, qualitative multiple sorting techniques were conducted following an interview with the participants to connect sick leave ratio with the outside view content. Participants were asked to rank the outside view scenes. Elzeyadi (2011) argued that the highest ratio of employee sick leave was scored in workspaces with a natural outside view such as a forest or urban greenery scenes. Hellinga & Hordijk (2014) developed a new method to describe the relationship between daylight and the view to the outside through a window in the workspace. This method uses the 180° equidistant projection technique to show the view through a window to the outside environment. Furthermore, Hellinga & Hordijk (2014) used the luminance ratio to quantify the daylighting level inside the workspace. The mean value of the luminance ratio to the working area should not be more than 1:10 and to avoid visual discomfort, that of the background of the working area (called the 'inner field of vision') should be 1:30. Their study assessed view quality via a questionnaire that asked participants to rank 23 pictures taken in different outside view environments from most favourite to least favourite. These pictures have different view content such as greenery view, street view, context, and sky view.

Regarding the ability of shading systems to integrate with non-visual effects and the outside environment, shading system parameters became dependent values to control what daylighting brought internally and occupant well-being to the outside view quality. Jamrozik et al. (2019) conducted an experiment using two shading devices – dynamic tint and motorized mesh shades – for the window in the working space. These devices show the impact of different daylighting and views of the outside environment on occupant satisfaction. Although having a window in the working space has many advantages, occupants may suffer from glare. Therefore, the authors implemented an actual experiment in a working space using two types of shading devices. The first type of shade was manual-automated control shading. The second one used material advantages for the tinting glass as a shading device. This experiment aimed to reach the optimal values to achieve the appropriate amount of daylight in a workspace and view the outside with minimal glare issues. Jamrozik et al. (2019) concluded no significant differences from using dynamic tint or motorized mesh shades based on occupant perception. Their study demonstrates how different shading systems can improve occupant well-being by improving performance and reducing eye strain in office environments by providing access to daylight and outside views. Boubekri et al. (2020) implemented an experiment using two different shading systems in two separate office environments. The first room had an electrochromic glass that acted as a shading device. The other room used a traditional blind. To measure sleep quality improvement, Boubekri et al. (2020) used a wrist-worn actigraph device, which contained a light sensor that measures light exposure (lux) at the wrists of each participant and the duration of time asleep. Their experiment concluded that achieving optimal daylight and outside views can improve occupant well-being by increasing sleep

time by 37 min. The review also found a different approach to improving occupant health and well-being by simultaneously focusing on achieving better daylight conditions and outside view quality. This was based on a verbal questionnaire administered to occupants to rank different outside view scenes based on their feelings (see Table 3).

Table 3: Themes of well-being identified across the sample—assessing non-visual effects

No.	Studies	Methods	Shading potential (found/not found)	Daylight metric	Themes of well-being
1	Altomonte (2009)	Experimental (HDR analysis)	Found	Daylight levels/intensity (illuminance levels) lux/glare (visual comfort)	Not found
2	Elzeyadi (2011)	Questionnaire and survey methods	Not found	Glare index	Satisfaction with access to the outside view content
3	Sherif et al. (2015)	Computational methods using simulation	Found	Daylight levels/intensity (illuminance levels) lux	Satisfaction with daylight quality (daylight distribution ratio)
4	Amundadottir et al. (2017)	Computational simulation and experimental validation	Not found	Daylight exposure, daylight distribution patterns (uniformity)	Improve sleep comfort/visual interests and impressions in space
5	Acosta et al. (2019)	Questionnaire and survey methods	Found	Daylight levels/intensity (illuminance levels) lux, daylight distribution patterns (uniformity)	Circadian rhythm
6	Jamrozik et al. (2019)	Questionnaire and experimental validation	Found	Daylight levels/intensity (illuminance levels) lux	Satisfaction with view access
7	Boubekri et al. (2020)	Questionnaire and survey methods	Found	Daylight levels/intensity (illuminance levels) lux	View clarity effect, sleep quality and productivity
8	Pesenti et al. (2015)	Computational methods using simulation	Found	Daylight levels/intensity (illuminance levels) lux (visual comfort)	Not found
9	Sheikh and Asghar (2019)	Computational methods using simulation	Found	Daylight levels/intensity (illuminance levels) lux (visual comfort)	Not found
10	Jayathissa et al. (2018)	Computational methods using simulation	Found	Daylight levels/intensity (illuminance levels) lux (reduce solar heat gain)	Not found
11	Mahmoud and Elghazi (2016)	Computational methods using simulation	Found	Glare index (visual comfort)	Not found
12	Tabadkani et al. (2018)	Computational methods using simulation	Found	Daylight distribution patterns (uniformity) (visual comfort)	Not found

Source: Authors' own.

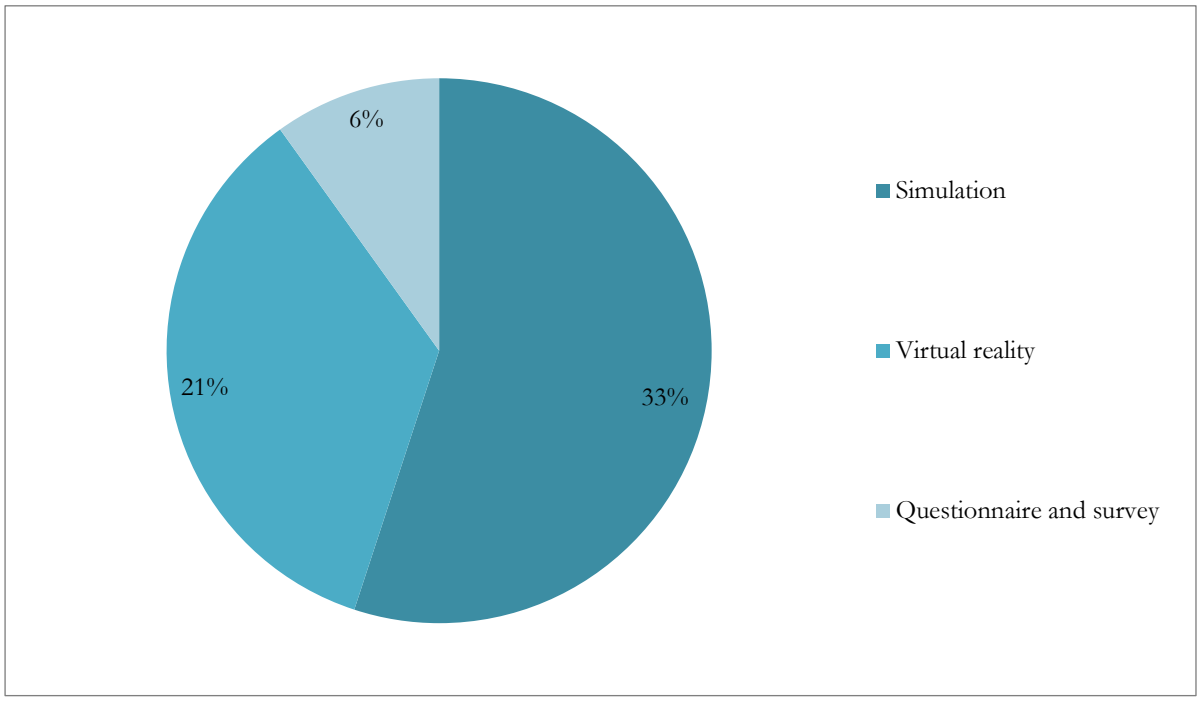
5 Analysis of the literature review

To identify gaps in the studies on daylighting and shading systems, an analysis of the literature review was organized into three categories: (i) methodological approaches, (ii) shading potential, and (iii) daylight metric. The following sections discuss these categories.

5.1 Methodological approaches

Various methodological approaches were used across the sample to quantify the non-visual effects of daylighting. The most common methodological approach was based on quantifying daylighting visual effects by using questionnaire and survey methods. These measurements indicate the health and well-being potential (Elzeyadi, 2011; Acosta et al., 2019; Jamrozik et al., 2019; Boubekri et al., 2020) (Figure 1).

Figure 1: Methodological approaches across the study sample



Source: Authors' own.

Although computational methods were used less to assess the theme of well-being associated with daylighting conditions (Sherif et al., 2015; Amundadottir et al., 2017), the sample shows that improving daylighting conditions without referring to the health and well-being potential of this improvement was the most useful for these methods (Pesenti et al., 2015; Sheikh & Asghar, 2019; Jayathissa et al., 2018; Mahmoud & Elghazi, 2016; Tabadkani et al., 2018).

5.2 Shading potential

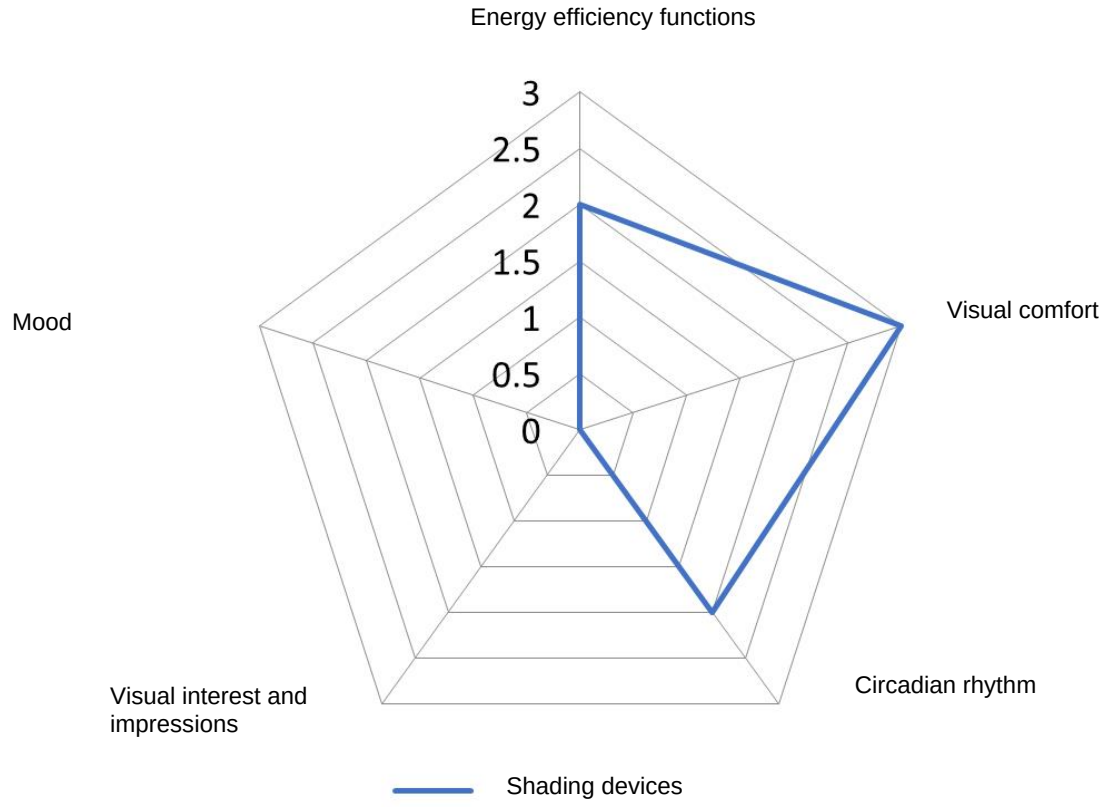
Across the selected papers, in many cases daylighting quality was integrated using a shading system. This integration has many objectives based on the shading function, such as energy efficiency functions (Sheikh & Asghar, 2019; Jayathissa et al., 2018) and visual comfort (Pesenti et al., 2015; Tabadkani et al., 2018; Mahmoud & Elghazi, 2016). For example, Sheikh and Asghar (2019) and Jayathissa et al. (2018) investigated the design of an adaptive biomimetic façade system based on energy efficiency functions. The building façade was divided into four shading panels that can be

deformed by folding forces to horizontal and vertical axes. The authors designed these shading panels to reduce energy consumption inside a workspace without blocking visibility to the outside environment (Figure 2).

Visual comfort is usually defined through criteria based on the light level in a room, the balance of contrasts, the colour temperature, and the absence or presence of glare. Using this function, Pesenti et al. (2015) optimized a shading system's functions to improve occupant visual comfort in office spaces, adapting to daylight performance and reducing glare issues. Mahmoud and Elghazi (2016) and Tabadkani et al. (2018) also investigated the possibility of improving daylight performance and reducing glare by using a kinetic shading system.

The selected sample in this study includes two papers presenting the shading system's role in improving the well-being potential. Jamrozik et al. (2019) conducted an experiment to show the impact of daylighting and views of the outside environment on occupant satisfaction. Another experiment was implemented by Boubekri et al. (2020) using electrochromic glass that acted as a shading device to assess the impact of daylighting colour temperature on occupant productivity by improving the occupant's circadian rhythm.

Figure 2: Trends in the themes of well-being



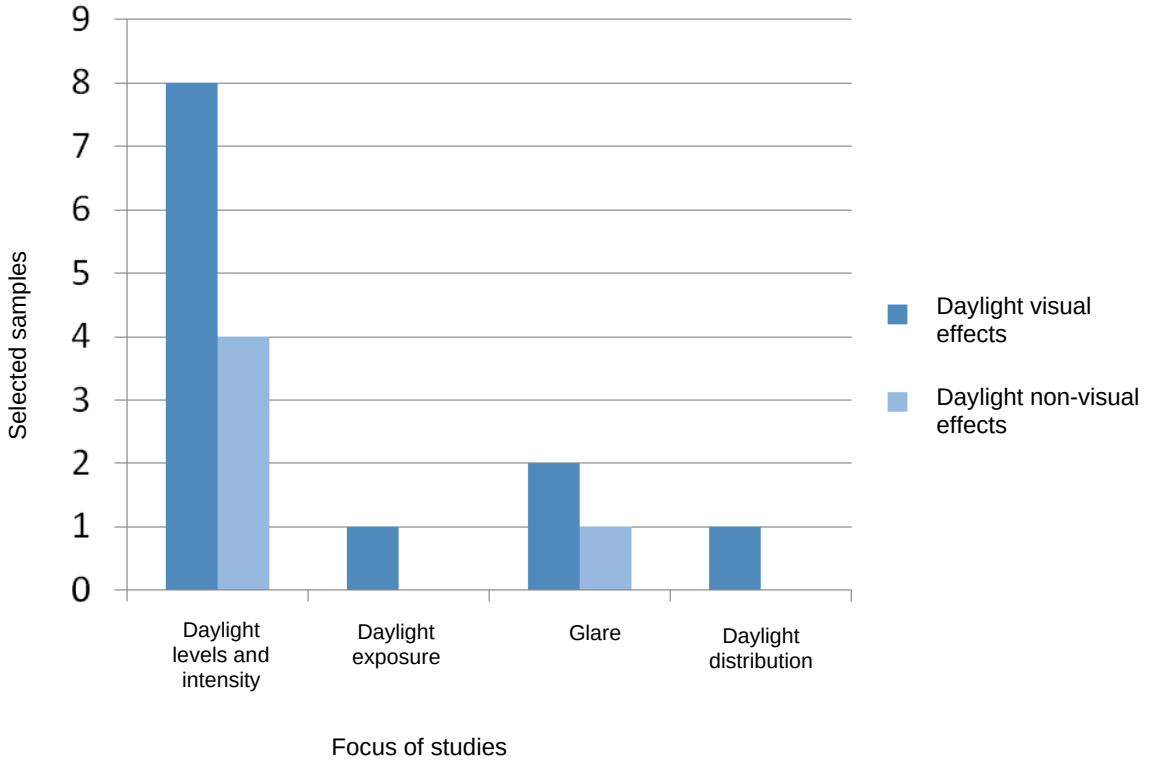
Source: Authors' own.

5.3 Daylight metric

Daylighting visual metrics indices that measure daylight levels/intensity were the most used metrics to assess themes of well-being (Sherif et al., 2015; Acosta et al., 2019; Jamrozik et al., 2019; Boubekri et al., 2020). Although the WELLv2 building standard recommends daylight exposure and states that the exposure for 1 hour or more in the early morning is enough to stimulate employees' circadian rhythm, the study sample shows that only one study conducted by

Amundadottir et al. (2017) used daylight exposure to assess the well-being and health potential. However, the glare index is considered one of the measurable metrics to quantify the visual discomfort potential, but only one study was conducted to assess satisfaction with daylight quality inside the working environment by measuring the glare index (Elzeyadi, 2011) (see Figure 3).

Figure 3: Daylighting metrics used to assess well-being



Source: Authors' own.

6 Discussion and conclusions

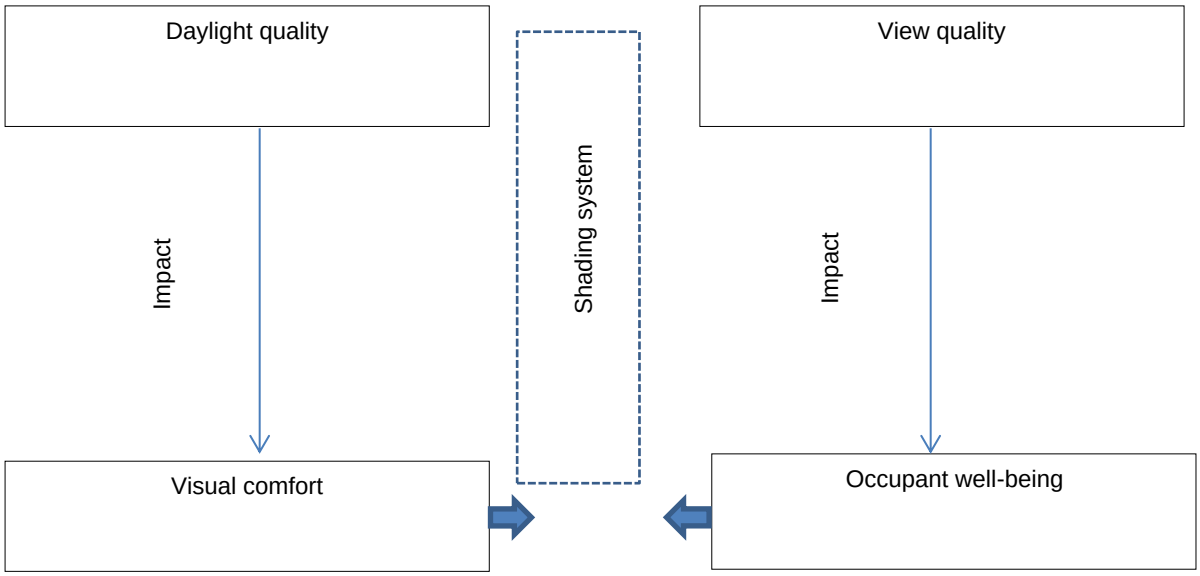
6.1 Gaps in holistic perspective

The WELLv2 building standard recommends that an occupant's ability to interact with the outside view through windows is linked to psychological advantages such as daylight. This connection can improve occupant comfort and well-being because this interaction reduces stress and improves worker performance (Schweizer et al., 2007).

Therefore, a holistic approach is needed to better understand the non-visual effects of daylighting inside the working environment. This environment consists of three mandatory factors: (i) daylight conditions inside, (ii) outside view quality, and (iii) the layer found between them, which refers to the shading systems (Figure 4). The non-visual effects of daylighting are considered 'well-being subjective' and include the circadian rhythm, alertness, and mood. The visual effects of daylighting are considered 'visual comfort objectives' and include glare and illuminance. The effects of daylighting are both visual and non-visual; the link between these opposing paths has remained unclear, especially when using a shading system, which may prevent the outside view potential from achieving the desired luminance and avoid glare issues. The visual effects of daylight and occupant well-being have been the subject of several studies that discuss their impact on occupant

perception (Sherif et al., 2015; Elzeyadi, 2011; Jamrozik et al., 2019; Boubekri et al., 2020). The present literature review shows that most researchers who want to evaluate the impact of daylighting quality on occupant perception aim to quantify visual comfort impressions such as glare. In addition, little attention is given to assessing satisfaction with outside view quality.

Figure 4: The holistic approach



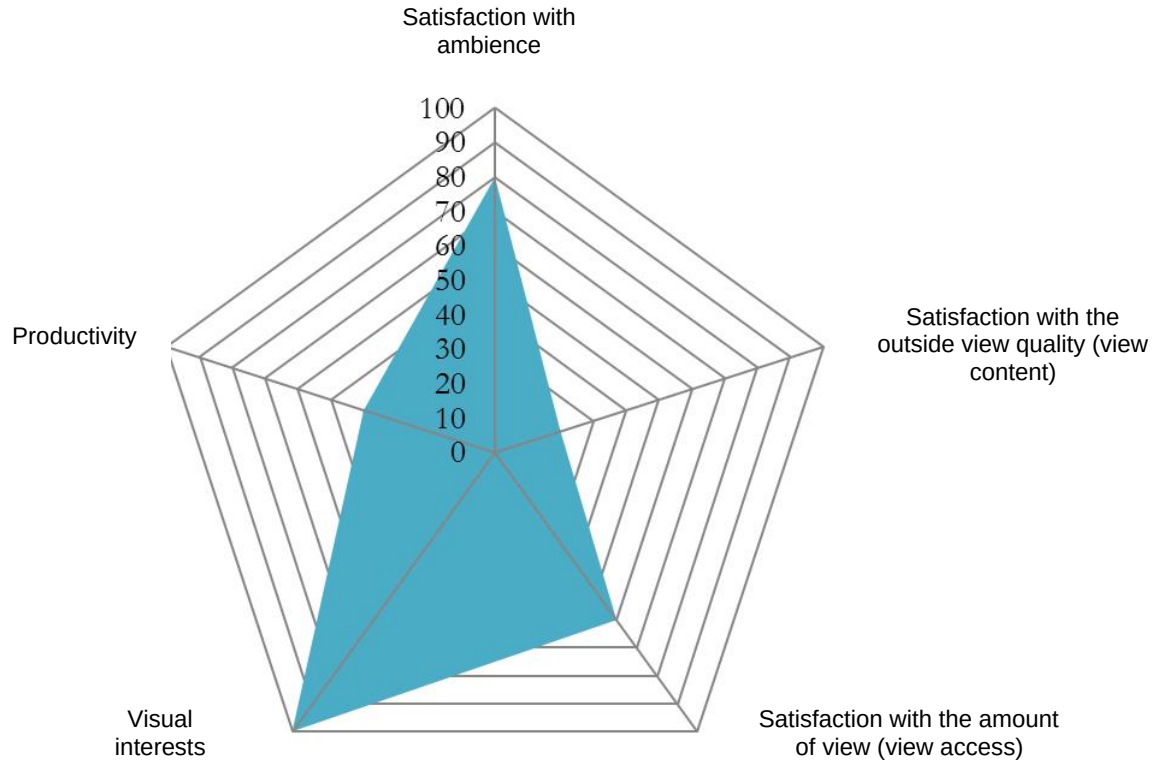
Source: Authors' own.

6.2 Gaps in methods

Satisfaction with outside view quality is considered a subjective aspect that may differ from one person to another one. Most researchers used printed-out pictures to ask participants about their feelings. However, this method did not take into consideration the outside view visible from inside the workspace. To the best of our knowledge, there is no study yet that assesses outside view quality and its impact on occupant well-being based on a computational calculation of the outside view elements visible from a viewpoint in a space that achieves the optimum daylight condition by installing shading systems. In addition, the literature shows an interest in studying shading devices to improve occupant well-being. However, most papers analysed focused on shading devices and daylight improvement simultaneously. Only two papers discussed how shading devices could affect occupant well-being by improving visual interest or satisfaction with ambience, or the amount of outside view. Very little attention was given to outside view quality (see Figure 5).

In conclusion, studies on occupant well-being and daylight in the workspace show a strong relationship between daylighting illuminance received and outside view quality. Daylight quality for visual efficiency is determined by how it is delivered and how it is integrated with other conflicting issues such as view to the outside. Therefore, shading systems should work to not obscure the view clarity value. Most researchers evaluated the impact of daylighting on view quality and on well-being separately; moreover, the method of evaluation of the outside view quality is often based on questionnaire results. In some cases, these questionnaires were administered by asking participants to rank some pictures with different outside views from most favourite to least favourite outside view content. In other cases, an indicator was assigned to each natural element and each outside view composition took an overall indicator that showed the amount of sky, green, water, etc., as observed by the surveyors or researcher.

Figure 5: Gaps in themes of well-being across the study sample



Source: Authors' own.

Daylight, comfort, and well-being have been the subject of several studies to discuss their impact on occupant perceptions. The literature indicates that shading devices are being studied in order to enhance well-being of occupants. The majority of studies analysed focused on both shading devices and daylight improvement at the same time, but little attention was given to discussing the effect of shading devices or outside view quality on occupant well-being. Shading devices can improve visual interest or satisfaction with ambience. Therefore, there is a need to define a new holistic system to investigate the possibilities of using shading systems to improve daylight quality and outside view quality inside the working environment.

7 References

Acosta, I., Campano, M. A., Leslie, R., & Radetsky, L. (2019). Daylighting design for healthy environments: Analysis of educational spaces for optimal circadian stimulus. *Solar Energy*, *193*, 584–596. https://doi.org/10.1016/j.solener.2019.10.004

Altomonte, S. (2009, June 22–24). *Daylight and the occupant: Visual and physio-psychological well-being in built environments* [Conference session]. PLEA2009 – 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada.

American Psychological Association. (2013). *Stress in America: 2013* [Press releases]. https://www.apa.org/news/press/releases/stress/2013/default

Amundadottir, M. L., Rockcastle, S., Sarey Khanie, M., & Andersen, M. (2017). A human-centric approach to assess daylight in buildings for nonvisual health potential visual interest and gaze behaviour. *Building and Environment*, *113*, 5–21. https://doi.org/10.1016/j.buildenv.2016.09.033

Andrews, F. M., & McKennell, A. C. (1982). *Response to Guttman & Levy's article 'on the definition and varieties of attitude and wellbeing'. Social Indicators Research*, *10*(2), 175–185. https://doi.org/10.1007/BF00302509

Berson, D. M., Dunn, F. A., Takao, M. (2002). Phototransduction by retinal ganglion cells that set the circadian clock. *Science*, *295*(5557): 1070–1073. https://doi.org/10.1126/science.1067262

Boubekri, M., Lee, J., MacNaughton, P., Woo, M., Schuyler, L., Tinianov, B., & Satish, U. (2020). The impact of optimized daylight and views on the sleep duration and cognitive performance of office workers. *International Journal of Environmental Research and Public Health*, *17*(9), Article 3219. https://doi.org/10.3390/ijerph17093219

Brainard, G. C., Hanifin, J. P., Greeson, J. M., Byrne, B., Glickman, G., Gerner, E., & Rollag, M. D. (2001). Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. *Journal of Neuroscience 21*(16), 6405–6412. https://doi.org/10.1523/JNEUROSCI.21-16-06405.2001

Canada Standards Association. (2013). *Psychological health and safety in the workplace: Prevention, promotion, and guidance to staged implementation* [National Standard of Canada annual report]. https://www.canada.ca/en/employment-social-development/services/health-safety/reports/psychological-health.html

Couvelas, M., Phocas, C., Maden, F ., Matheou, M., & Ölmez, D. (2018). Daylight performance of an adaptive façade shading system integrated on a multi-storey office building. In *Proceedings of the 13th Conference on Advanced Building Skins* (pp. 433–42), Bern, Switzerland.

Crisp, R. (2020). Well-being. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2020 edition). Metaphysics Research Lab, Stanford University.

Dewa, C., S. D., & McDaid, D. (2011). Investing in the mental health of the labour force: Epidemiological and economic impact of mental health disabilities in the workplace. In I. Z. Schultz & E. S. Rogers (Eds.) *Work accommodation and retention in mental health* (pp. 33–52). Springer. https://doi.org/10.1007/978-1-4419-0428-7_2

Dobrica, S. (2020). COVID-19 and work from home: Digital transformation of the workforce. *The Grey Journal*, *16*(2), 101–104.

Elkadi, H., & Al-Maiyah, S. (2021). *Daylight, design and place-making.* Routledge. https://doi.org/10.4324/9781315575896

Elzeyadi, I M. K. (2011, July). Workplace design: Health and healing impacts of daylight in the workplace. *World Health Design*, 60–67.

Fletcher, G. (ed.). (2016). *The Routledge handbook of philosophy of well-being.* Routledge. https://doi.org/10.4324/9781315745329

Gill, H., & Butler, D. (2020). *Mental health and wellbeing in the workplace: A practical guide for employers and employees* [Audiobook]. Gildan Media.

Hellinga, H., & Hordijk, T. (2014). The D&V analysis method: A method for the analysis of daylight access and view quality. *Building and Environment*, *79*, 101–114. https://doi.org/10.1016/j.buildenv.2014.04.032

Hui, X., Huiling, C., Li, X. (2021). Non-visual effects of indoor light environment on humans: A review. *Physiology & Behavior*, *228*, Article 113195. https://doi.org/10.1016/j.physbeh.2020.113195

International Commission on Illumination. (2008). *4th Conference of computer science, mathematics and logic.* University of Athens, Athens, Greece.

International Commission on Illumination. (2016). *Research roadmap for healthful interior lighting applications*. CIE Technical Report No. 218:2016. CIE Central Bureau. https://cie.co.at/publications/research-roadmap-healthful-interior-lighting-applications

Jamrozik, A., Clements, N., Hasan, S. S., Zhao, J., Zhang, R., Campanella, C., Loftness, V., Porter, P., Ly, S., Wang, S., & Bauer, B. (2019). Access to daylight and view in an office improves cognitive performance and satisfaction and reduces eyestrain: A controlled crossover study. *Building and Environment*, *165*, Article 106379. https://doi.org/10.1016/j.buildenv.2019.106379

Jayathissa, P., Caranovic, S., Hofer, J., Nagy, Z., & Schlueter, A. (2018). Performative design environment for kinetic photovoltaic architecture. *Automation in Construction*, *93*, 339–347. https://doi.org/10.1016/j.autcon.2018.05.013

Kelloway, E. K., & Cooper, C. (2021). *A research agenda for workplace stress and wellbeing*. Edward Elgar. https://doi.org/10.4337/9781789905021

Khademagha, P., Aries, M. B., Rosemann, A., van Loenen, E. J. (2016). Implementing non-image-forming effects of light in the built environment: A review on what we need. *Building and Environment*, *108*, 263–272. https://doi.org/10.1016/j.buildenv.2016.08.035

Kirimtat, A., Kundakci Koyunbaba, B., Chatzikonstantinou, L., & Sariyildiz, S. (2016). Review of simulation modeling for shading devices in buildings. *Building and Environment*, *53*, 23–49. https://doi.org/10.1016/j.rser.2015.08.020

Klein, T. (2021). *Integral façade construction: Towards a new product architecture for curtain walls*. TU Delft.

Mahmoud, A. H. A., & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. *Solar Energy*, *126*, 111–127. https://doi.org/10.1016/j.solener.2015.12.039

McArthur, J. J., & Powell, C. (2020). Health and wellness in commercial buildings: Systematic review of sustainable building rating systems and alignment with contemporary research. *Building and Environment*, *171*, Article 106635. https://doi.org/10.1016/j.buildenv.2019.106635

Mental Health Commission of Canada. (2022). *Changing directions, changing lives: The mental health strategy for Canada.* https://www.mentalhealthcommission.ca/wp-content/uploads/drupal/MHStrategy_Strategy_ENG.pdf

Newsham, G. R., Cetegen, D., Veitch., J. A., & Whitehead, L. A. (2010). Comparing lighting quality evaluations of real scenes with those from high dynamic range and conventional images. *ACM Transactions on Applied Perception*, *7*(2), 1–25. https://doi.org/10.1145/1670671.1670677

National Alliance on Mental Illness (NAMI). (2022). *NAMI 2019 Annual report.* https://www.nami.org/NAMI/media/NAMI-Media/PDFs/Financials/2019NAM-AnnualReport-web.pdf

Owl Labs. (2021). *State of remote work 2021* (5th ed.). https://owllabs.com/state-of-remote-work/2021

Pesenti, M., Masera, G., & Fiorito, F. (2015). Shaping an origami shading device through visual and thermal simulations. 6th International Building Physics Conference (IBPC). *Energy Procedia*, *78*, 346–351. https://doi.org/10.1016/j.egypro.2015.11.663

Rea, M. S. (2005). *IESNA Lighting Handbook* (9th ed.). Illuminating Engineering Society of North America.

Schweizer, C., Edwards, R. D., Bayer-Oglesby, L., Gauderman, W.J., Ilacqua, V., Juhani Jantunen, M., Lai, H. K., Nieuwenhuijsen, M., & Künzli, N. (2007). Indoor time–microenvironment–activity patterns in seven regions of Europe. *Journal of Exposure Science & Environmental Epidemiology*, *17*, 170–181. https://doi.org/10.1038/sj.jes.7500490

Sheikh, W. T., & Asghar, Q. (2019). Adaptive biomimetic facades: Enhancing energy efficiency of highly glazed buildings. *Frontiers of Architectural Research*, *8*, 319–331. https://doi.org/10.1016/j.foar.2019.06.001

Sherif, A., Sabry, H., Wagdy, A., & Arafa, R. (2015, December 7–9). Daylighting in hospital patient rooms: Parametric workflow and genetic algorithms for an optimum façade design. In *Proceedings of the 14th Conference of International Building Performance Simulation Association* (pp. 1383–1388), Hyderabad, India. https://doi.org/10.26868/25222708.2015.2775

Steemers, K. (2021). Architecture for well-being and health. *VELUX Commercial Blog.* https://commercial.velux.co.uk/blog/daylight/architecture-for-well-being-and-health

Tabadkani, A., Banihashemi, S., Reza Hosseini, M. (2018). Daylighting and visual comfort of oriental sun responsive skins: A parametric analysis. *Building Simulation*, 11(4), 663–676. https://doi.org/10.1007/s12273-018-0433-0

The WELL Building Standard. (2021). The WELL Building Standard™ version 2 (WELL v2™). https://v2.wellcertified.com/en/wellv2/overview; https://www.wellcertified.com/certification/v2/

Thapan, K., Arendt, J., & Skene, D. J. (2001). An action spectrum for melatonin suppression: Evidence for a novel non-rod, non-cone photoreceptor system in humans. *The Journal of Physiology*, *535*, 261–267. https://doi.org/10.1111/j.1469-7793.2001.t01-1-00261.x

Ticleanu, C., (2021). Impacts of home lighting on human health. *Lighting Research & Technology*, *53*(5), 453–475. https://doi.org/10.1177/14771535211021064

Valente, T. W. (2010). *Social networks and health: Models, methods, and applications*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195301014.001.0001

World Health Organization. (2022). *Mental health: Fact sheet*. https://www.euro.who.int/__data/assets/pdf_file/0004/404851/MNH_FactSheet_ENG.pdf

Zhou, P., Yang, X. L., Wang, X. G., Hu, B., Zhang, L., Zhang, W., Si, H.-R., Zhu, Y., Li, B., Huang, C.-L., Chen, H.-D., Chen, J., Luo, Y., Guo, H., Jiang, R.-D., Liu, M.-Q., Chen, Y., Shen, X.-R., Wang, X., . . . Li-Shi, Z. (2020). A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*, *579*, 270–273. https://doi.org/10.1038/s41586-020-2012-7

The state of immersive technology application in construction safety training

A systematic literature review

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Abstract: One of the main contributing factors to high fatality and injury rates is inadequate safety training. Safety training is typically delivered in a classroom or on-site. It has been criticized for needing more engagement between trainers and trainees and for insufficient opportunities to practice at actual construction sites. The application of immersive technology (ImT), such as virtual reality, augmented reality, and mixed reality, in safety training seems promising for overcoming the limitations of traditional training approaches because such technologies can provide trainees with an interactive and engaging way to learn how to identify and prevent hazards as well as experience the impact of risks in virtual and risk-free environments. Against this backdrop, researchers have attempted to develop various ImT-enabled training systems or approaches to enhance training effectiveness. However, there needs to be a more systematic review of what and how ImT has been used to improve safety training in the construction industry. To narrow this knowledge gap, we examined the results of 95 papers to systematically assess the state of ImT as applied in occupational health and safety training. The study was guided by the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' statement. We found that Unity 3D, head-mounted display, and computer-aided virtual environment are the most widely used ImT in safety training. In addition, most of the studies examined were published between 2020 and 2021 and are from the United States, China, and South Korea.

Keywords: construction, health and safety, training, intervention, immersive technologies

Acknowledgements: Sincere appreciation to Majlis Amanah Rakyat (MARA) Malaysia for partially funding this research studentship.

1 Introduction

The construction sector in the United Kingdom (UK) is recognized worldwide for its high-quality operations, but it remains one of the country's most dangerous industries. According to a recent report (2022) on construction statistics in Great Britain, 1.62% and 2.9% of workers on construction sites suffered from fatal and non-fatal injuries (Health and Safety Executive, 2022). Although the rate of fatal injuries has exhibited a downward trend, about 50% of deaths recorded have been due to falls from height. In June 2000, the UK government partnered with the Health and Safety Commission to launch the 'Revitalizing Health and Safety' campaign. Since this launch, the construction sector has developed targets to reduce the number of major and critical injuries among workers (see Department of the Environment, Transport and the Regions, 2000).

Numerous studies show that risky behaviours and actions are prior elements that increase safety hazards (Anderson, 2005), while research also shows safety training could help prevent those undesirable behaviours and actions (Fleming & Lardner, 2002). However, traditional classroom-based training has long been criticized for its effectiveness because of the low level of engagement and lack of opportunities to practice in a real-site scenario (Zhang et al., 2019). Traditional training usually refers to safety training programmes (e.g. OSHA 10-hour and 30-hour training modules) that include workers' rights and Occupational Safety and Health Administration (OSHA) protections, as well as how to identify, avoid, and prevent workplace hazards (US Department of Labor, 2016). Typically, those training programmes are provided in a classroom setting or on-site via PowerPoint presentations (Greene & Marcham, 2019). As a result, there is limited opportunity for workers to practise and gain direct experience, especially in high-risk scenarios like falling from a height. Wang et al. (2018) concluded that traditional training courses failed to equip construction workers with the knowledge needed to make decisions or handle a variety of hazard scenarios effectively. This is because the safety information provided within the presentations and instructional videos often does not reflect real-world construction site situations (Li et al., 2018; Wang et al., 2018), which leads to trainees failing to recognize hazards in the first place. These findings were supported by Chen et al. (2014) who concluded that most construction workers find it challenging to foresee hazards because they are hard to prevent and have the potential to undermine safety systems.

To improve safety training practices, construction workers could be developed through many ways, such as interactive and personalized training and applying various training methods (Choi et al., 2020). Specifically, immersive technology (ImT) is an emerging method to deliver interactive and personalized training to enhance safety training results for construction workers (Jeelani et al., 2017; Noghabaei & Han, 2020). ImT, epitomized in virtual reality (VR), augmented reality (AR), and mixed reality (MR), has enabled a very interactive approach to train and has proven to deliver safety training courses in a much safer way. ImT has been created in such a way for architecture, engineering, and construction to help professionals and construction workers make better judgements and to improve cross-discipline collaboration in occupational safety and health (OSH) training (Heydarian et al., 2015; Khan et al., 2021; Wen & Gheisari, 2020). This training is essential to keep learners' safety knowledge and skills up to date so they can handle complex or new hazards. For example, VR systems have conventionally concentrated on boosting the sense of vision, but recently VR technology has expanded to encompass wearable headset technologies that are putting a greater emphasis on audio feedback using headphones (e.g. demolition sounds) and on physical simulations for materials (e.g. rigid bodies, joints, characters, robots) (Grassini & Laumann, 2020). Trainees can obtain knowledge-based safety training through a gamified scenario that includes active exploration and human–computer interaction (Gavish et al., 2013; Moore& Gheisari, 2019). This gamification also allows trainees to experience the entire project, including its interior and outside locations, with a much greater realism (Ahmed 2019). For example, users can see the

position of columns behind a finished façade or the placement of rebar inside a column using AR (Feiner et al., 1997).

While ImT is expensive to implement, it could improve knowledge retention and affect construction workers' behaviour to respond in a way that can reduce risk and correct them in a way that is appropriate to handle hazards on construction sites, which is much more essential to enhance effectiveness in safety performance among construction workers.

1.1 Point of departure

The recent efforts to promote and apply ImT in OSH training in the construction industry have generated a lot of studies in the field. As a result, there are several literature reviews on the application of ImT and these reviews concentrate on certain technological applications such as VR in a specific training content. For example, Teizer et al. (2013) and Xu et al. (2019) did a review on VR applications in crane operator safety training. Other reviews focused on identifying methods to build VR applications in construction engineering education and training (Wang et al., 2018) and design a taxonomy of VR/AR technology for safety management (Li et al., 2018). Newaz et al. (2022) have assessed VR technology to address the risk of falling from a height. To conclude, there is limited study on reviewing the ImT applications that comprehensively include VR, AR, and MR in the construction industry in all different types of OSH trainings. This could hinder researchers and practitioners from understanding the development trends of ImT applications in OSH training, and thus prevent them from identifying the opportunities for future research and development work in this field.

2 Review methodology

Based on a clearly stated research question, a systematic review discovers relevant papers and articles, assesses their quality, and analyses the data using defined procedures (Khan et al., 2003). It is distinguished from traditional typical reviews and comments by its explicit and systematic methodology. This research was designed following the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) statement, which provides guidelines to help improve the reporting of systematic reviews. Although PRISMA is not an evaluation tool for determining the quality of a systematic review, it can be used to measure the validity of published systematic reviews (Liberati et al., 2009).

2.1 Construction of a research question

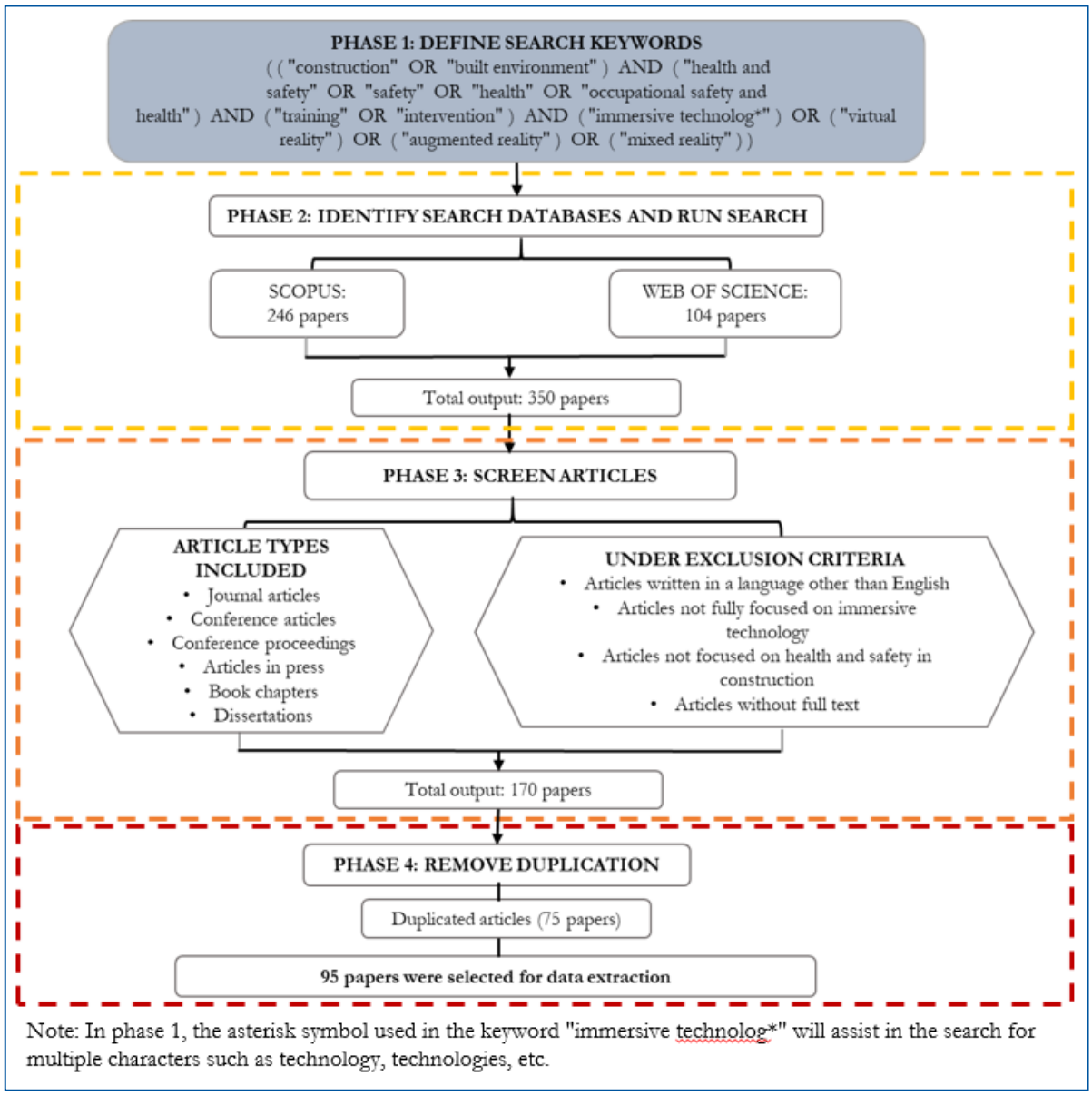
Before beginning the review, the concerns to be addressed should be clearly outlined, with unambiguous and structured questions also known as research questions (Khan et al., 2003). It is important to construct a question that can be answered objectively through use of evidence rather than subjectively. Developing research questions can help a research project focus on a specific issue or problem, which in this study reviews the extant research on the feasibility of integrating ImT into safety training. Most research focuses on a single or a combination of application features for a specific learning outcome. A research question was established and applied to each article discovered to address the following concerns:

- What is the status of ImT application in OSH training in the construction industry?
- What is the future road map of ImT application in OSH training in the construction industry?

2.2 Identification of relevant studies

A variety of activities is performed in the area of construction operations and numerous training programmes are available under the general category of health and safety management. To discover publications related to ImT that may be particularly suitable for application in construction safety training, specific keywords were used for searching the selected literature electronic database systems (Web of Science and Scopus), obtaining relevant publications, and excluding all irrelevant results. The main reason for choosing these databases is that Scopus has a large number of journal indexes, whereas Web of Science covers older publications and archived records dating back to 1900 (Falagas et al., 2008). The keywords were derived from the research question. It may also be found in the titles and abstracts of the papers, which were used to generate the filters. Figure 1 depicts the combination of keywords used in this systematic review. The filters helped identify relevant publications from a large number of sources. A thorough review of the literature on ImT in the construction industry, which included journal papers, conference papers, newspapers, books, and electronic media, was conducted to meet the research objectives.

Figure 1: Four-stage systematic literature review process



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2.3 Study selection

Figure 1 summarizes the four stages of the systematic literature review process used in this study. A paper retrieval process related to ImT in construction safety training research was filtered according to exclusion criteria. All articles were analysed based on the ImT used in construction safety training. Through this process, a plethora of ImT products available on the market was identified. The keyword strings assisted in identifying 95 relevant papers retrieved from the Scopus and Web of Science databases. An unconstrained and unconstructed search was initially performed to find relevant publications within the scope of health, safety, and training in the construction industry. Relevant keywords were extracted based on the main topics explored in related publications and author experience, followed by a literature search (i.e. a database search). After acquiring keywords from unconstrained and unconstructed searches, Scopus provided a larger selection of relevant journals and articles than the Web of Science database.

Using the search string formations from these two databases, 350 items published from 1996 to February 2022 were retrieved. In the screening process, an additional filtration method was used to guarantee that all of the papers found were relevant to the study's objective. However, the articles from 1996 to 2001 were excluded at this stage because they either did not mention ImT or were not related to OSH training, which did not cover the main research subject. Figure 1 depicts the key inclusion criteria for this systematic review. Those publications that met these criteria were further processed with Mendeley reference management software to identify duplicate results. Out of 170 publications, 75 duplicates were detected, and 95 publications were identified for evaluation and analysis. At this stage, table outlines were created to identify the data captured. Designing simple forms and collecting sufficient unambiguous data can help to capture essential data in a structured and organized way (Li et al., 2022).

2.4 Bibliometrics method

The bibliometrics analysis of the data set used two database publication resources, Scopus and Web of Science. The science mapping VOSviewer software tool was used to construct and visualize bibliometric networks from journals, researchers, or individual publications based on citation, bibliographic coupling, co-citation, or co-authorship relation indicators across the selected subject. This technique enables researchers to recognize specific issues and topics in a given field, whether there are numerous or few relevant studies, revealing the co-occurrence of keywords and thus helping to identify major research streams and future research directions. Due to a limitation in VOSviewer functionality, such that it can only generate a visualization from one database at a time, Scopus was chosen for the visualization of this study's bibliometrics analysis because of the wider range of journal and article contributions available through Scopus. The data from Web of Science were manually collected in a spreadsheet. The analysis identifies keywords, data set topics, country contributions, and prominent institutions.

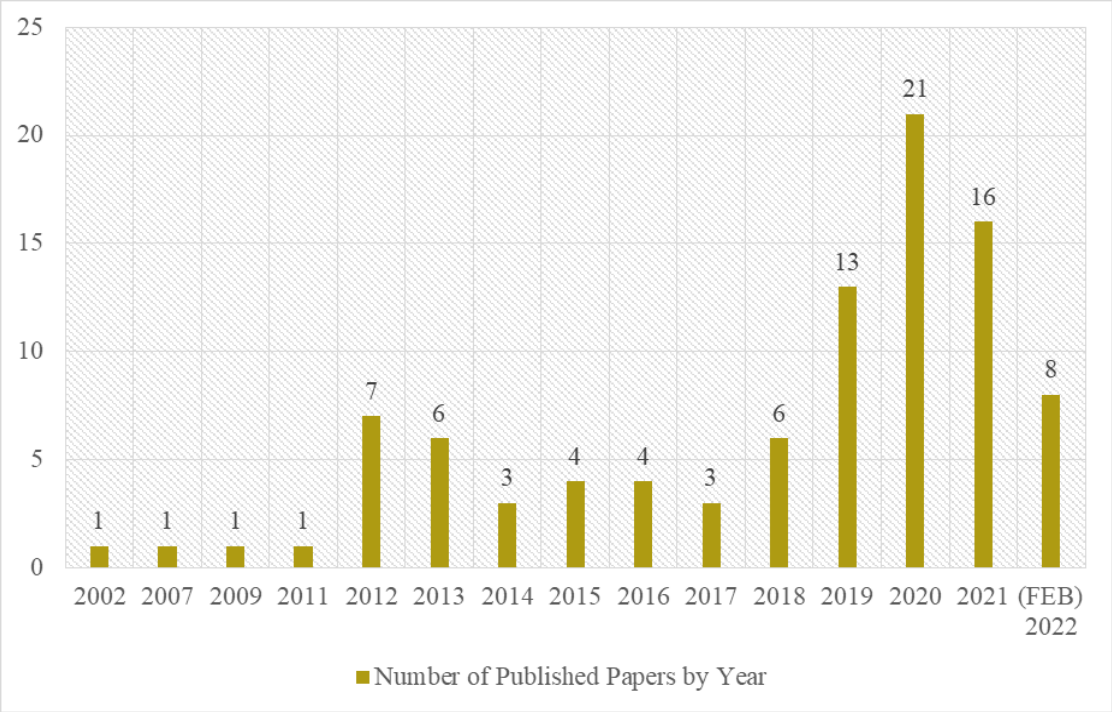
3 Results and discussion

3.1 Overview of the current state of ImT application in construction safety training

A total of 95 ImT papers, retrieved from two research databases, were analysed to understand the present status of ImT application in construction safety training. The number of publications by year as illustrated in Figure 2 indicates that researchers became interested in ImT in construction safety and health training in 2002 and continued to demonstrate interest through February 2022. The number of publications per year has changed throughout the last decade. Given the exclusion

criteria of this review, only a small number of qualifying articles were present between the years 2002 and 2011, and no publications qualified in particular years (2003, 2004, 2005, 2006, and 2008).

Figure 2: Number of published papers by year linked to ImT for construction safety training based on the systematic literature review



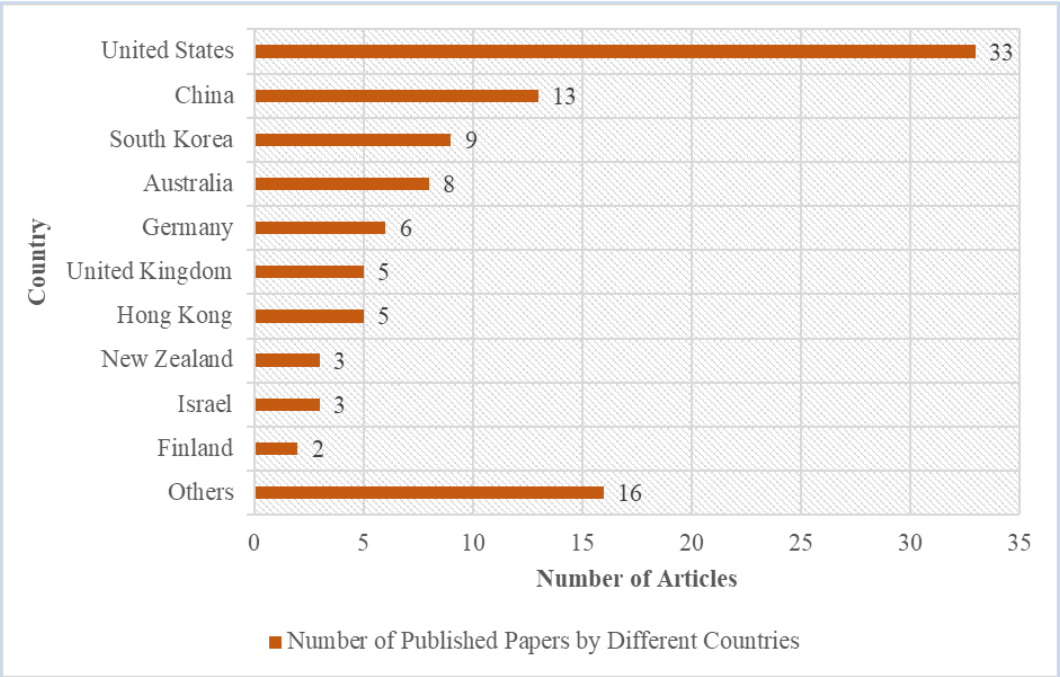
Source: Authors' own.

The distribution of the 95 publications can be divided into two distinct phases. During the 'domain formation' phase, which lasted until 2011, one article was consistently released yearly. One of the reasons for this underrepresentation is that the concept of ImT was still undergoing notable development, with education and training as the main area of application (Mencke et al., 2017). From 2012 onwards, the 'emerging' phase began, with an exponential increase in the number of publications, showing a growing interest in ImT research in the construction sector. The highest number of papers published in a year rose from 13 to 21 in 2019 and 2020, with almost half of the articles coming from the United States during this time frame. However, the epic boom ended the following year, with only 16 publications issued in 2021.

Some of the notable publications from the United States in the year 2020 mentioned 360° panoramas, and the use of head-mounted display (HMD) devices was featured as an alternative, low cost, and easy-to-access solution to the cost barrier problem in adopting safety training (Eiris et al., 2020). A virtual learning environment was presented in other publications to support training in worker–robot interaction on construction sites (e.g. Adami et al., 2020). Another study described the real-time location-tracking sensors to track participants' movement, risk-taking behaviour, and risk perception (Hasanzadeh & de La Garza 2020).

These 95 publications were also analysed according to the journal country of origin, with the results shown in Figure 3. With 33 publications, the United States takes the top spot, followed by China (13), South Korea (9), and Australia (7) and Germany (6). Other countries also made significant contributions such as the United Kingdom and Hong Kong, where efforts have been made to provide training in realistic, challenging settings while mitigating OSH risks (Bosché et al., 2016).

Figure 3: Number of published papers on ImT for construction safety training, sorted by country of origin



Source: Authors' own.

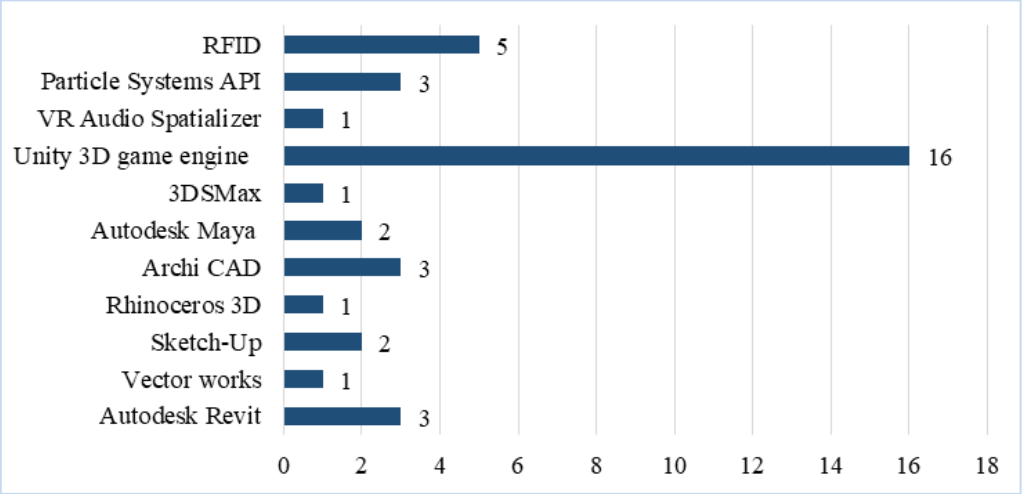
3.2 Types of ImT that are commercially applied in OSH training

Based on the 95 publications selected for data extraction, the software and hardware categories for health and safety training and related ImT were identified. Figure 4 shows a graph of the most prominent software programs and the frequency of their appearance in the review. The most widely used software programs in ImT are the Unity 3D game engine and radio frequency identification device (RFID), which were examined in 16 and 5 papers, respectively. One main feature of Unity 3D noted in the research is how it enables users to explore an immersive environment through transforming equirectangular photos into spherical coordinates (Eiris et al., 2020). Unity 3D can seamlessly integrate with hardware such as the six degrees of freedom head-tracking system, enabling broad application and scalability across a range of different training contexts and diverse construction trades (Bosché et al., 2016). This head-tracking system provides programmers with a variety of additional features, such as collision detection and physical handling (Golovina et al., 2019) and the ability to track construction resources (people, equipment, materials, etc.), as well as real-time feedback and post-event visualization analysis in a virtual environment for safety training (Kassem et al., 2017). Four publications focused on RFID technology, which is primarily used for tracking materials across an entire supply chain (Teizer et al., 2013). This technology also identifies worker locations and provides an immediate warning signal for nearby hazards to them during construction site operations (Park & Kim, 2013).

The hardware serves as the primary interface between the user and the virtual or augmented world supported by the software. ImT hardware can be categorized according to various shapes and sizes, each of which offers a unique set of features. Figure 5 shows a graph of the most popular ImT hardware used in construction safety training. Remarkably, about a quarter of the articles in this systematic review have explored HMD equipment in depth, making HMD the most frequently researched hardware in this space. An HMD device enables the wearer to interact with VR using hand-held controllers. HMD hardware often uses Oculus Rift (a non-see-through HMD), which provides an immersive experience with a 110° field of view (Bosché et al., 2016), making it the third most popular ImT for construction safety training. Computer-aided virtual environment

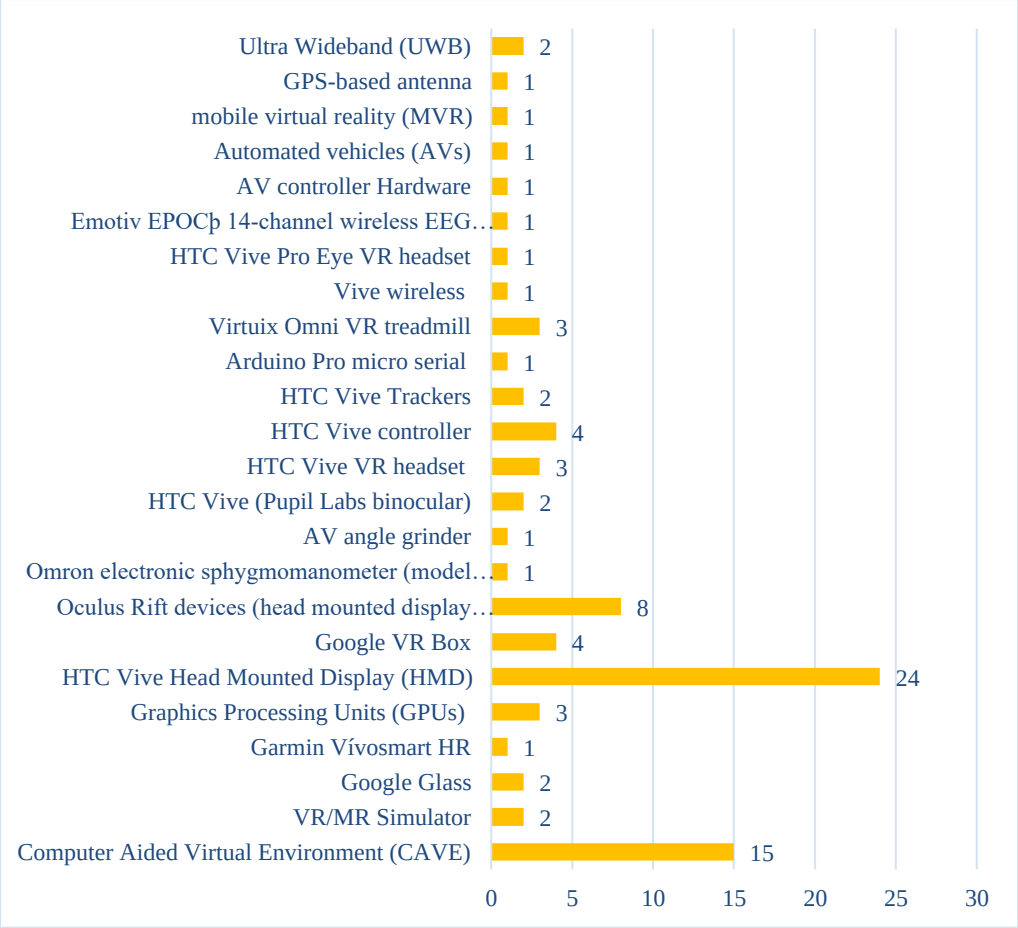
(CAVE) is the second most frequently researched hardware identified in the review. Fifteen articles discussed changing the CAVE projector settings to improve the virtual environment's compatibility with analogous physical objects. One popular VR display technique is using a VR treadmill with CAVE to simulate walking locomotion in an immersive environment (Sloot et al., 2014).

Figure 4: Prominent ImT software used for construction safety training



Source: Authors' own.

Figure 5: Prominent ImT hardware used for construction safety training



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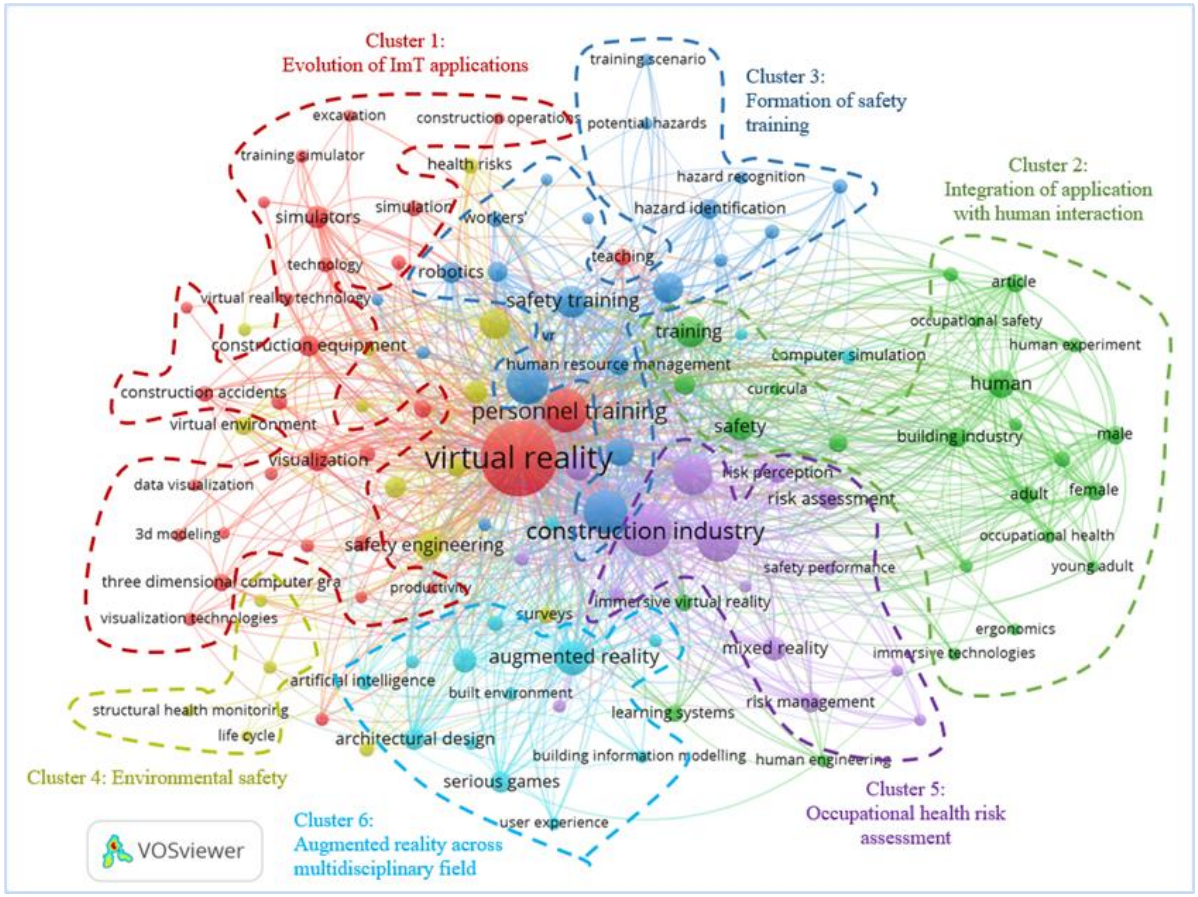
3.3 Emerging ImT trends in OSH training using bibliometric analysis

Bibliometrics analysis was utilized to map scientifically retrieved data in large amounts and highlight features of the data used in research papers (Khan et al., 2021). VOSviewer visuals were used throughout this study to analyse bibliometric data by determining how different items are connected. Closely linked sets of items create colour-coded clusters, and connections among these clusters form networks. The colour code of keywords indicates their similarity and linkages, and the size of the circle suggests its weight depending on the number of documents, citations, or occurrences (Jan van Eck & Waltman, 2022). The colour of a cluster also reflects the aggregation and segmentation of articles that belong to a specific field, with each group based on similarity of ideas. When examining keyword co-occurrence, for example, the link strength reflects the number of publications in which two terms appeared. The distance attribute demonstrates how the keywords are related in terms of co-occurrence. As a result, the link between two keywords is more robust the closer together they are. Figure 6 portrays an overview of the data gathered from the retrieved articles and the most critical keywords in the literature review that were generated by the VOSviewer software.

Figure 6: Thematic networks based on the 134 most common keywords under six clusters from our research using VOSviewer software



Source: Authors' own.

Based on the results of the VOSviewer software, the research dimension of ImT in OSH training has been coloured to correspond with their research theme for better understanding. We can see that the ImT in OSH training is highly diversified and widely explored throughout the construction industry. The research dimension can be identified through six major clusters of research themes. In the first cluster, 'virtual reality', there were 30 items including a training simulator, construction equipment, data visualization, and construction operation. The second cluster, 'construction

industry', included 24 items such as human experiment, ergonomics, learning systems, and procedures. The third cluster, 'personnel training', contained 22 items including training scenario, hazard identification, robotics, and training methods. The fourth cluster, 'accident prevention', had 16 items including information management, safety education, project management, and surveys. The fifth cluster, 'construction safety', contained 15 items such as accident prevention, risk assessment, risk-taking behaviour, and wearable technology. The sixth cluster, 'occupational risks', had 16 items including AR, artificial intelligence, built environment, and user experience. Based on the initial search strings from Phase 1 of the systematic literature review, VOSviewer identified 2,283 interrelated keywords. The single-use keywords are not depicted on our map because we chose to depict only the 134 most often occurring keywords for visual clarity. The less frequent the phrase, the smaller the nodes, most of which are not easily visible on the VOSviewer map or at all.

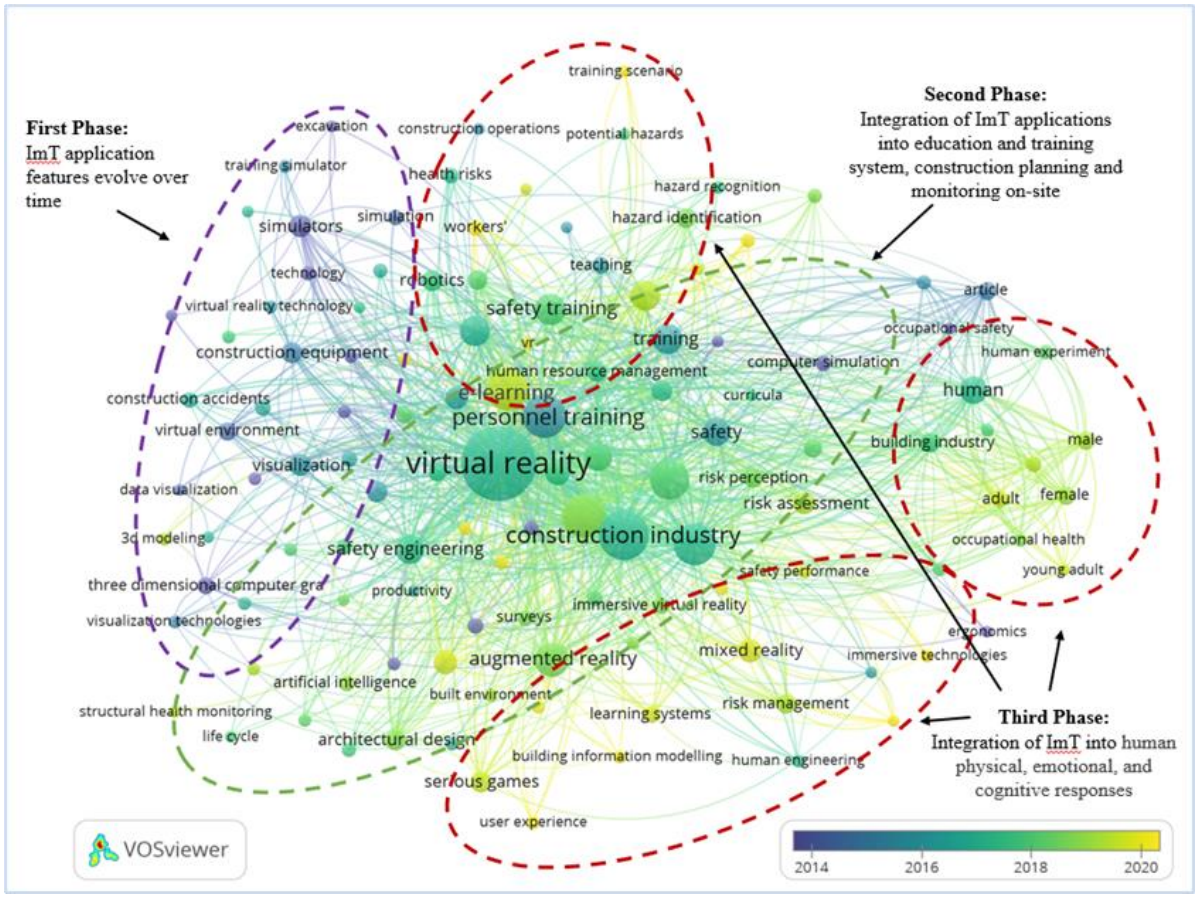
The keyword 'virtual reality' had the strongest connections with the six other main research themes featured in our saved list. The VR cluster covers the largest number of journals and the distance among nodes is small, which implies that all of the journals have very similar research topics or research fields. The VR topic is related to several different disciplines such as technology features (e.g. three-dimensional modelling, simulators, visualization, and construction equipment), application integration (e.g. construction safety, artificial intelligence, AR, and architectural design), and human management. Most of the papers in this cluster also concentrate on occupational safety and human behaviour problems in relation to safety training programmes. The cluster around the keywords 'construction safety' includes 'augmented reality', which is used in architectural design and structural health monitoring. Papers on AR tend to pay more attention to sustainable strategy and planning problems. It should be noted that there may be overlap between two journal clusters. For example, it is clear that there is a significant overlap between the 'virtual reality' and 'construction safety' clusters, which is due to the interdisciplinary nature of the issues investigated.

In contrast, the overlay visualization performed via VOSviewer is chosen to demonstrate the verification of research trends in the academic field by classifying the keywords using timescale, which provided more function than network visualization. Figure 7 demonstrates the time periods since before 2014 until 2020 in which particular keywords are more or less prominent in the literature. It could be useful to survey the evolution of ImT keywords in the construction industry over the last decade, which could assist researchers in identifying major research trends that are significant in a specified year. The keywords are coloured differently based on the year of publication, which explains the function of the colour bar in the map's corner. Each circle's colour represents when the keywords are most frequently used, with a range of colour from darker to yellowish indicating earlier to recent periods of use. For example, darker circles represent the keywords used in the prior approach in the construction activity. In this case, the selection is dark around 'construction equipment', which indicates that the keywords present were more significant to research-related activities since before 2014–15, in turn implying that researchers paid more attention to these topics during that time. The three red dotted lines mark off the more recent evolution of high-frequency keywords. Similarly, highlighted keywords such as 'workers', 'young adult', and 'risk management' appear between 2018 and 2020, signalling new directions in researcher focus.

The map in Figure 7 reveals that the ImT has so far developed in three stages. During the first phase between 2014 and 2016, many publications focused more on the technology features. From 2016 to 2018, the topics explored by the majority of papers shifted towards how to diversify and integrate technology into education and training systems. A detailed review of papers published from 2018 to 2020 reveals that the majority of them focus on integrating ImT with human physical, emotional, and cognitive responses (e.g. behaviours, pleasure, anxiety, and expectations) towards training outcomes. In particular, the keyword 'young learner' signals a growing interest in the

relationship between ImT and younger generations who are especially receptive towards using ImT (Noghabaei & Han, 2020).

Figure 7: An overlay visualization map of high-frequency keywords used over time generate by VOSviewer software



Source: Authors' own.

4 Conclusion and future research

This literature review study provides a survey of research trends on the use of ImT in safety training that has been commercially demonstrated for OSH purposes in the construction industry. This area of research, which includes VR, AR, and MR, has demonstrated enormous benefits for creating scenarios that help draw attention to hazards.

Based on the review and bibliometrics analysis of 95 publications, ImT has been investigated according to six main themes: VR, construction industry, personnel training, accident prevention, construction safety, and occupational risks. The present study also found that the most commonly used ImT software for safety training is Unity 3D, which is a free game engine. Researchers also exhibited a particular interest in HMD and CAVE hardware to create simulated environments for safety training.

We suggest there are additional questions in need of further investigation. This review covers only the state of ImT application in safety training, but does not centre the financial challenges associated with expanding such application, which is a major topic needing further study. In addition, the long-term effectiveness of the use of ImT in safety training has yet to be determined.

Given the computational cost and development time that remain barriers to expanding ImT for safety training in the construction sector, solutions addressing these challenges need to be researched and developed.

5 References

Adami, P., Rodrigues, P. B., Woods, P. J., Becerik-Gerber, B., Soibelman, L., Copur-Gencturk, Y., & Lucas, G. (2021). Effectiveness of VR-based training on improving construction workers' knowledge, skills, and safety behavior in robotic teleoperation. *Advanced Engineering Informatics*, *50*, Article 101431. https://doi.org/10.1016/j.aei.2021.101431

Ahmed, S. (2019). A review on using opportunities of augmented reality and virtual reality in construction project management. *Organisation, Technology and Management in Construction: An International Journal*, *11*(1): 1839–1852. https://doi.org/10.2478/otmcj-2018-0012

Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., & Golparvar-Fard, M. (2014, July). Enhancing construction hazard recognition with high-fidelity augmented virtuality. *Journal of Construction Engineering and Management*, 140(7). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000860

Anderson, M. (2005). Behavioural safety and major accident hazards: Magic bullet or shot in the dark? *Process Safety and Environmental Protection*, *83*(B2), 109–116. https://doi.org/10.1205/psep.04230

Bosché, F., Abdel-Wahab, M., & Carozza, L. (2016). Towards a mixed reality system for construction trade training. *Journal of Computing in Civil Engineering*, *30*(2), 1–38. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000479

Choi, M., Ahn, S., & Seo, J. (2020). VR-based investigation of forklift operator situation awareness for preventing collision accidents. *Accident Analysis and Prevention*, *136*, Article 105404. https://doi.org/10.1016/j.aap.2019.105404

Department of the Environment, Transport and the Regions. (2000). *Revitalising health and safety: Strategy statement.* https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/policy/wcms_212111.pdf

Eiris, R., Jain, A., Gheisari, M., & Wehle, A. (2020). Safety immersive storytelling using narrated 360-degree panoramas: A fall hazard training within the electrical trade context. *Safety Science*, *127*, Article 104703. https://doi.org/10.1016/j.ssci.2020.104703

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. *The FASEB Journal*, *22*(2), 338–342. https://doi.org/10.1096/FJ.07-9492LSF

Feiner, S., MacIntyre, B., Höllerer, T., and Webster, A. (1997). A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. *Personal Technologies*, *1*(4), 208–217. https://doi.org/10.1007/BF01682023

Fleming, M., & Lardner, R. (2002). *Strategies to promote safe behaviour as part of a health and safety management system.* Contract Research Report 430/2002. Health and Safety Executive.

Gavish, N., Gutiérrez, T., Webel, S., Rodríguez, J., Peveri, M., Bockholt, U., & Tecchia, F. (2013). Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments*, *23*(6), 778–798. https://doi.org/10.1080/10494820.2013.815221

Golovina, O., Kazanci, C., Teizer, J., & König, M. (2019, May 21–24). Using serious games in virtual reality for automated close call and contact collision analysis in construction safety. In *The 36th International Symposium on Automation and Robotics in Construction (ISARC 2019)* (pp. 967–974), Banff, Alberta, Canada. https://doi.org/10.22260/ISARC2019/0129

Grassini, S., & Laumann, K. (2020, November 1–5). Evaluating the use of virtual reality in work safety: A literature review. In *30th European Safety and Reliability Conference (ESREL 2020) and 15th Probabilistic*

Safety Assessment and Management Conference (PSAM 2020) (pp. 4964–4971). https://doi.org/10.3850/978-981-14-8593-0_3975-cd

Greene, H. E. T., & Marcham, C. L. (2019). Online vs. conventional safety training approaches. *Professional Safety*, *64*(1), 26–31.

Hasanzadeh, S., & de La Garza, J. M. (2020). Productivity-safety model: Debunking the myth of the productivity-safety divide through a mixed-reality residential roofing task. *Journal of Construction Engineering and Management*, *146*(11). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001916

Health and Safety Executive. (2022). *Construction statistics in Great Britain, 2022*. https://www.hse.gov.uk/statistics/industry/construction.pdf

Heydarian, A., Carneiro, J. P., Gerber, D., Becerik-Gerber, B., Hayes, T., & Wood, W. (2015). Immersive virtual environments versus physical built environments: A benchmarking study for building design and user-built environment explorations. *Automation in Construction*, *54*, 116–126. https://doi.org/10.1016/j.autcon.2015.03.020

Jan van Eck, N., & Waltman, L. (2022, January 24). *VOSviewer Manual* (Version 1.6.18). https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.18.pdf

Jeelani, I., Han, K., & Albert, A. (2017, June 25–27). Development of immersive personalized training environment for construction workers. In *Proceedings of the Congress on Computing in Civil Engineering*, Seattle, Washington, DC (pp. 407–415). https://doi.org/10.1061/9780784480830.050

Kassem, M., Benomran, L., & Teizer, J. (2017). Virtual environments for safety learning in construction and engineering: Seeking evidence and identifying gaps for future research. *Visualisation in Engineering*, *5*(1), Article 16. https://doi.org/10.1186/s40327-017-0054-1

Khan, A., Sepasgozar, S. Liu, T. T., & Yu, R. R. (2021). Integration of BIM and ImT for AEC: A scientometric–SWOT analysis and critical content review. *Buildings*, *11*(3), Article 126.

Khan, K. S., Kunz, R., Kleijnen, J., & Antes, G. (2003). Five steps to conducting a systematic review. *Journal of the Royal Society of Medicine*, *96*(3), Article 118. https://doi.org/10.1177/014107680309600304

Li, T., Higgins, J. P. T., & Deeks, J. J. (2022). Chapter 5: Collecting data. In Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (eds), *Cochrane handbook for systematic reviews of interventions* (Version 6.3, updated February 2022). Cochrane Training. https://training.cochrane.org/handbook/current/chapter-05

Li, X., Yi, W., Chi, H. L., Wang, X. and Chan, A. P. C. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, *86*, 150–162. https://doi.org/10.1016/j.autcon.2017.11.003

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *Journal of Clinical Epidemiology*, *62*(10), e1–e34. https://doi.org/10.1016/j.jclinepi.2009.06.006

Mencke, N., Winge, A., & Lombardi, P. A. (2017). Towards the application of virtual reality technologies for the training on major construction sites. *INTED2017 Proceedings*, *1*, 7215–7220. https://doi.org/10.21125/inted.2017.1671

Moore, H. F., & Gheisari, M. (2019). A review of virtual and mixed reality applications in construction safety literature. *Safety*, *5*(3), 51. https://doi.org/10.3390/safety5030051

Newaz, M. T., Ershadi, M., Carothers, L., Jefferies, M., & Davis, P. (2022). A review and assessment of technologies for addressing the risk of falling from height on construction sites. *Safety Science*, *147*, Article 105618. https://doi.org/10.1016/j.ssci.2021.105618

Noghabaei, M., & Han, K. (2020). Hazard recognition in an immersive virtual environment: Framework for the simultaneous analysis of visual search and EEG patterns. In P. Tang, D. Grau, & M. El Asmar

(Eds.), *Construction Research Congress 2020: Computer Applications* (pp. 934–943). https://doi.org/10.1061/9780784482865.099

Park, C. S., & Kim, H. J. (2013). A framework for construction safety management and visualization system. *Automation in Construction*, 33, 95–103. https://doi.org/10.1016/j.autcon.2012.09.012

Sloot, L. H., van der Krogt, M. M., & Harlaar, J. (2014). Self-paced versus fixed speed treadmill walking. *Gait & Posture*, *39*(1), 478–484. https://doi.org/10.1016/j.gaitpost.2013.08.022

Teizer, J., Cheng, T., & Fang, Y. (2013). Location tracking and data visualization technology to advance construction ironworkers' education and training in safety and productivity. *Automation in Construction*, *35*, 53–68. https://doi.org/10.1016/j.autcon.2013.03.004

US Department of Labor. (2016, January 14). *OSHA to release more durable and secure outreach trainer and student cards* [OSHA trade release]. https://www.osha.gov/news/newsreleases/trade/01142016-0

Wang, P, Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International Journal of Environmental Research and Public Health*, 15(6), Article 1204. https://doi.org/10.3390/ijerph15061204Wen, J., & Gheisari, M. (2020). Using virtual reality to facilitate communication in the AEC domain: A systematic review. *Construction Innovation*, *20*(3), 509–542. https://doi.org/10.1108/CI-11-2019-0122

Xu, S., Ni, Q., & Du, Q. (2019, May 21–24). The effectiveness of virtual reality in safety training: measurement of emotional arousal with electromyography. In *Proceedings of the 36th International Symposium on Automation and Robotics in Construction (ISARC 2019)* (pp. 20–25), Banff, Alberta, Canada.

Zhang, P., Cheung, C., & Hou, L. (2019, September 2–4). Applications of visualisation technology in construction safety training: A preliminary review. In *Proceedings of the 35th Conference and Annual General Meeting (ARCOM 2019)* (pp. 396–405), Association of Researchers in Construction Management, Leeds, United Kingdom. https://researchrepository.rmit.edu.au/esploro/outputs/conferenceProceeding/Applications-of-Visualisation-Technology-in-Construction-Safety-Training-A-Preliminary-Review/9921860929401341

A text mining approach to performance enhancement in building information modelling-pervasive major project delivery

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Abstract: This study proposes the use of text mining techniques to address challenges in building information modelling (BIM)-pervasive major project delivery, such as budget, quality, and schedule. It includes a bibliometric analysis to highlight the need for text analysis, a generic text mining process framework, and a structured discussion of findings from a text mining experiment to demonstrate its efficacy. The study aims to inform both academic research and professional practice in the built environment, offering a new process framework for theoretical development and a novel technical solution for performance enhancement in BIM project delivery.

Keywords: Bibliometrix, BIM, construction management, data, major project, text mining

Acknowledgements: The research presented in this publication is based on an ongoing PhD study. Any observations, findings, recommendations, or conclusions presented in this publication are those of the authors and do not necessarily reflect the views of the supporting institution or organization.

1 Introduction

Although building information modelling (BIM) technology has seen a large growth in use, teething problems such as performance enhancement, insufficient training optimization, platform interoperability, and the absence of rigorous standards for use in some architecture, engineering, and construction organizations persist today (Chen et al., 2020; Criminale and Langar, 2017). Chen et al. (2020) posit that challenges associated with major construction projects can be placed into three categories: (i) workforce/people, (ii) production, and (iii) processes.

Although BIM has been widely adopted across work stages in major construction project delivery, professional expertise and competence required for a systematic BIM execution in large-scale project engineering and management still pose a challenge. According to Retzlaff (2018), the goals of BIM are attainable if optimal approaches through cross-party co-operation and technical integration are used.

According to the Royal Society's report *Dynamics of Data Science Skills* (Blake, 2019), the UK government policy paper 'National Data Strategy' (Dowden, 2020), and current BIM research and practice, BIM underpinned digital transformation in the construction sector and big lessons were learnt from practices in major construction project delivery.

The purpose of this study is to present a new evidence-based learning experiment using text mining techniques to inform both research and practice in the process of adapting to uncertainty, error, and the unexpected in BIM-pervasive major project delivery. The approach is completed by linking bibliometric analysis, text mining, and data science to provide evidence on the practice of BIM in major project delivery. The areas are chosen because they offer insightful information on the evidence of BIM use in major pervasive projects.

This study is important as it focuses on a crucial aspect of text mining in improving the performance of BIM in large-scale projects. It creates an opportunity to use research findings to inform evidence-based practices and demonstrates how text mining techniques can be used to solve problems and improve the research process through bibliometric analysis and text mining. The results of the study are based on evidence-based data, which is crucial for making informed decisions about the performance of BIM in large-scale projects.

2 Literature review

2.1 Data science skill dynamics

According to Blake (2019) and Dowden (2020), the United Kingdom has the potential to become a leading data science research nation through the development of collaborative and sustainable methods for data scientists to work across different sectors. Blake (2019) identified four main areas for action to address the data science talent pipeline, whereas Dowden (2020) stressed the importance of using data to improve efficiency, productivity, and competitiveness in the digital economy. The benefits of data skills are not limited to a specific group, but instead can benefit everyone, as businesses that effectively use data will have a competitive advantage.

A review of the data science skills dynamics for BIM execution (Oti-Sarpong et al., 2021) shows the need for skills improvement in digital transformation in construction project delivery. The review suggests that improving data science skills can result in improved project quality, reduced time, increased efficiency, and optimized processes. Furthermore, the review highlights that the

use of data science skills can lead to better decision-making, aimed at achieving the best quality outcomes in major project delivery.

2.2 Bibliometrics and text mining analysis

Knowledge can be discovered in a variety of ways, including mathematical, non-mathematical, or inductive. Information management, query optimization, decision assistance, and data maintenance can all benefit from the knowledge that was uncovered in this research. When a user interacts with a group of documents, they use various analysis tools to uncover and explore the patterns that interest them (Feldman & Sanger, 2006). Text mining, as opposed to generalized data mining, focuses on analysing and modelling unstructured natural language text, such as news articles, scientific research papers, and medical documents. Natural language processing and pattern categorization, machine learning, and statistics are all used in this technology, making it a full-fledged solution in and of itself (Grobelnik et al., 2002).

Jones et al. (2004) highlighted the difficulty on high-quality information extracted from big data (Cai & Zhu, 2015), including web data (Li & Wu, 2010), which are continuously generated across the connected world. Although bibliometric studies are conducted for the use of the text mining technique in various fields (Wen et al., 2021) for its usefulness for management processes and activities, the use of text mining for BIM-pervasive major project delivery is still at the starting point at the time of writing.

The review of bibliometrics and text mining analysis indicates that there is a need to maximize the value of data, information, and knowledge to improve the performance of major project delivery.

2.3 Incorporating BIM into policy and practice

Some industry policymakers and governments, particularly in some regions of the developing globe, are still behind in embracing BIM as a standardized platform for enhanced building practice. Despite certain national governments' enthusiasm for adopting BIM (Jamal et al., 2019; Rahim and Zakaria, 2017), there are still numerous obstacles preventing BIM from being a useful tool in the building industry. Governments must play a role in facilitating BIM technology and platform usage. The sector may significantly increase sustainability and efficiency by implementing practicable and realistic policies.

Global organizations, such as the Royal Institution of Chartered Surveyors (RICS), and the International Organization for Standardization (ISO), have developed BIM guides and standards. The international BIM implementation guide was designed by the RICS, and ISO developed the ISO 29461 standard. The national BIM standard and the BIM guide are designed for use in the construction industry in the United States. The UK government developed BIM protocols in 2015 (Kumar, 2015) to be used by contractual partners and units. The goal is to create frameworks that make BIM adoption beneficial for cultural and environmental needs. The BIM standard will impact industry techniques (Mayouf et al., 2019) and the standardization of cost planning formats, and it has already had an impact on the industry's operational procedures and processes.

Despite challenges in the widespread adoption of BIM, it is becoming more commonly used in major construction projects owing to its potential for increased efficiency and profitability (Chen et al., 2020). To support successful BIM delivery, a formal information analysis process is necessary to manage and analyse the large amounts of information generated through BIM technology.

3 Research methodology

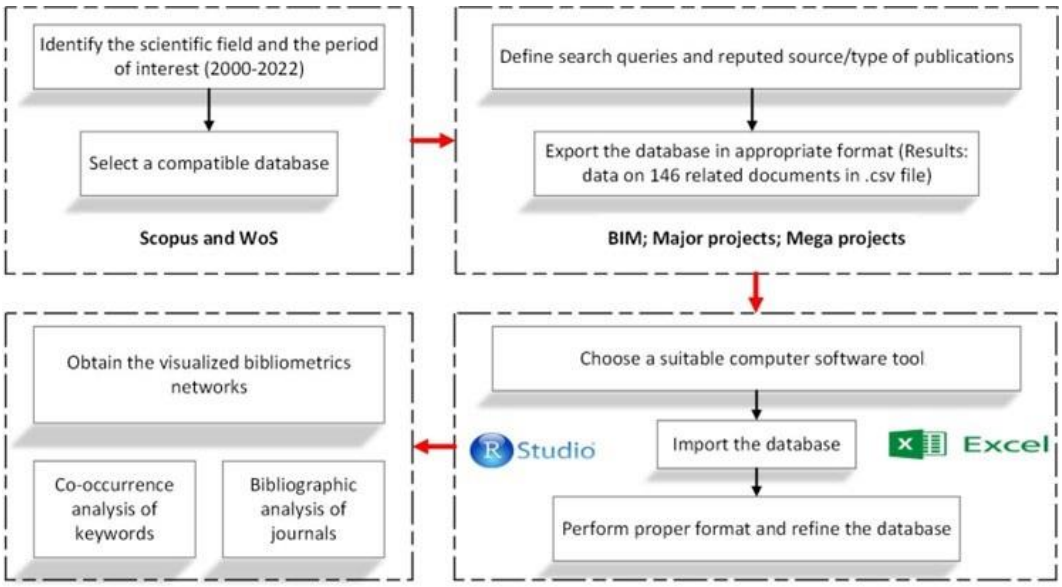
3.1 Detailed bibliometric analysis

Metric studies is a field that uses standardized measurement techniques to analyse various forms of information and communication media, such as documents, books, and texts (Chellappandi and Vijayakumar, 2018). Bibliometrics is a subfield of metric studies that uses mathematical and statistical approaches to study the features of information and communication media (Pritchard, 1969). Over time, the field of metric studies has expanded to include various disciplines, including altmetrics, scientometrics, cybermetrics/webometrics, and informetrics. These studies are used not just in information sciences and libraries but also in a variety of other fields to examine research trends and implications.

Sajovic et al. (2018) discovered that bibliometric studies analyse the visual aspects of similarities and differences in data from one or more sources to express relationships such as bibliographic coupling, co-authors, citations, and publication timelines through techniques and science mapping algorithms. The following approaches were used in the present study to evaluate research trends in BIM for major project delivery, with the goal of creating research timelines and benchmarks for future studies:

- Analyses of publication frequency by authors, region/country, sources, publication type, and organizations from 2000 to 2022, as illustrated in Figure 1.
- Co-authorship analyses of the study's corpus, which include evidence of author co-operation networks and co-occurrences.
- Interrelationships and correlation between trends and relevant terms in BIM-pervasive major project delivery literature, discovered through the co-occurrence of keywords analysis. The co-occurrence of terms was limited to the years 2014–22 to uncover recent trends and other related exclusion criteria.
- Using the full text of research documents acquired from the Scopus and Web of Science databases, the content of the research body reported in the articles can be mapped and mined.

Figure 1: Process of bibliometric analysis



Source: Authors' own based on Wrigley et al. (2019).

3.2 Text mining

Text mining involves the process of extracting information from large amounts of unstructured text data (Hotho et al., 2005; Weiss et al., 2010). It uses algorithms to determine the significance of text words and nouns to uncover patterns and insights in the data. Text mining has been applied in a variety of fields (Zhang et al., 2019), including construction management and oil and gas project bidding processes, as a powerful tool for gaining valuable insights from large datasets (Son and Lee, 2019).

3.3 Data collection

The Scopus and Web of Science core collections were searched and retrieved online using a robust and broad search approach. A two-step filtering process was used to select only the most relevant results, while excluding documents such as conference papers, book chapters, editorials, and textbooks from the screening process. Initial search results revealed 601 items covering 22 years from 2000. Search strings (Tables 1 and 2) were used to obtain relevant documents from the Scopus and Web of Science databases, respectively. In decreasing order, most journal sources were identified in construction and building technology, environmental engineering, civil engineering, multi-disciplinary engineering, industrial engineering, and computer science. To conduct a more in-depth and extensive evaluation of BIM-pervasive project delivery-related themes, it became more convenient to narrow the search to reflect the focus. After removing book chapters and summaries from the extracted articles from the Scopus and Web of Science collections, a new set of filtering criteria was used to sort the 601 papers that remained. When these criteria were applied, it was found that no paper had been published before 2014. Hence, to uncover research trends, it was necessary to maintain the study's time span. Other filter criteria used in the final selection of the extracted documents included the following:

- Research published in English and focused on recent work from 2014 to 2022 was considered.
- Articles from computing and mathematical journals were not included in the final set of research results.
- Articles with fewer than five distinct keywords were excluded manually by the researcher as they were deemed not valuable to the field of BIM.

Table 1: Search results from the Scopus database (as of 18 February 2022)

Integrated search query	Records
TITLE-ABS-KEY ((‘Building Information Modelling’ OR ‘Building Information Modeling’ OR ‘Building Information Model’ OR ‘BIM’) AND (‘Bridge’ OR ‘Dam’ OR ‘Highway’ OR ‘Major construction project’ OR ‘Major project’ OR ‘Railway’ OR ‘Megaproject delivery’ OR ‘Mega construction project’ OR ‘Mega project’ OR ‘Megaproject’ OR ‘Airport’ OR ‘Underground’ OR ‘Tube’ OR ‘High Speed Rail’ OR ‘Olympics’ OR ‘Olympic stadium’ OR ‘National stadium’ OR ‘Urban regeneration’ OR ‘Urban redevelopment’ OR ‘Transit’ OR ‘Water infrastructure’ OR ‘Waste water infrastructure’)) AND (LIMIT-TO (DOCTYPE, ‘ar’)) AND (EXCLUDE (PUBYEAR,1992)) AND (LIMIT-TO (LANGUAGE, ‘English’)) AND (LIMIT-TO (SUBJAREA, ‘ENGL’) OR LIMIT-TO (SUBJAREA, ‘BUSI’) OR LIMIT-TO (SUBJAREA, ‘ENVI’) OR LIMIT-TO (SUBJAREA, ‘COMP’) OR LIMIT-TO (SUBJAREA, ‘ENER’) OR LIMIT-TO (SUBJAREA, ‘MULT’))	412

Source: Authors’ own based on study data.

Table 2: Search results from the Web of Science database (as of 18 February 2022).

Integrated search query	Records
('building information modelling' OR 'building information modeling' OR 'building information model' OR 'BIM') AND ('Bridge' OR 'Dam' OR 'Highway' OR 'Major construction project' OR 'Major project' OR 'Railway' OR 'Megaproject delivery' OR 'Mega construction project' OR 'Mega project' OR 'Megaproject' OR 'Airport' OR 'Underground' OR 'Tube' OR 'High Speed Rail' OR 'Olympics' OR 'Olympic stadium' OR 'National stadium' OR 'Urban regeneration' OR 'Urban redevelopment' OR 'Transit' OR 'Water infrastructure' OR 'Waste water infrastructure') (Topic) and Review Articles (Exclude – Document Types) and Articles (Document Types) and Engineering Civil OR Construction Building Technology OR Engineering Industrial OR Engineering Multidisciplinary OR Management OR Architecture (Web of Science categories) and Science Citation Index Expanded (SCI-EXPANDED) OR Social Sciences Citation Index (SSCI) (Web of Science index) and English (Languages)	189

Source: Authors' own based on study data.

Once the '.bib' files for each database search had been retrieved, they were transformed into Bibliometrix format. RStudio's 'Biblioshiny()' command, available through the Bibliometrix package's 'Biblioshiny()' command, was used by the researcher in this instance (Aria and Cuccurullo 2017; RStudio Team, 2020). Biblioshiny makes it possible for researchers unfamiliar with RStudio to complete the bibliometric analysis stage. The process involves converting the '.bib' file into Bibliometrix by importing it through the 'Import raw files' option in the 'Import or Load files' menu under 'Data'. The file is then saved as an Excel file through the same menu. To simplify the process, each file is saved as Scopus.xlsx and WoS.xlsx. This results in two Excel files with the same tag fields in the first row but with information organized in different columns. Once the datasets were in the same format, they were merged. This was done by opening both Excel files, arranging the windows side by side for simultaneous viewing, and using Excel's 'Remove duplicates' function to eliminate duplicates in the data.

3.4 Trend analysis

After removing duplicates, the refined result underwent co-occurrence and frequency analysis. This analysis used information such as the number of publications linked to an author, publication dates, publication type, journal source, country, and other relevant details. To identify research trends, directions, and knowledge gaps, keyword co-occurrence analyses were conducted to evaluate BIM research in the context of major project delivery.

3.4.1 Choosing the analytical tool

Visualization and network analysis was facilitated by various tools such as Biblioshiny, VOSviewer, Pajek, Citespace, Gephi, and nodeXL. This study used the 'Biblioshiny()' command in RStudio, available through the Bibliometrix package (Aria and Cuccurullo 2017). RStudio software is increasingly being recognized and used in the industry, especially for graphical and metadata metric studies (Aria and Cuccurullo 2017). The data used in this study was sourced from the Scopus and Web of Science databases, and the research focused on keyword co-occurrence and co-authorship analysis, which was carried out using the 'Biblioshiny()' command in RStudio.

3.5 Frequency analysis

3.5.1 Journal publications

Following the implementation of the filtration criteria, a total of 146 bibliographic documents were found to be fit for further examination. From 2014 to 2022, 100% of the materials were articles that were used in this study (see Table 5). Only the relevant publications and co-occurrence criteria were used in the second step of filtering.

The Scopus and Web of Science databases yielded 146 different publications. Table 3 lists the 10 most frequently cited publications, the number of published documents, and the number of recorded citations. According to Guo et al. (2019), high impact on the scientific community is indicated by multiple citations of an article or document. There were sixteen papers published in the journal *Automation in Construction*, with a total of 548 citations, and one paper in the journal *Advanced Engineering Informatics* with 73 citations. The journal *Engineering Construction and Architectural Management* had the least number of articles (five) and citations (four).

Table 3: Top 10 most often cited journals

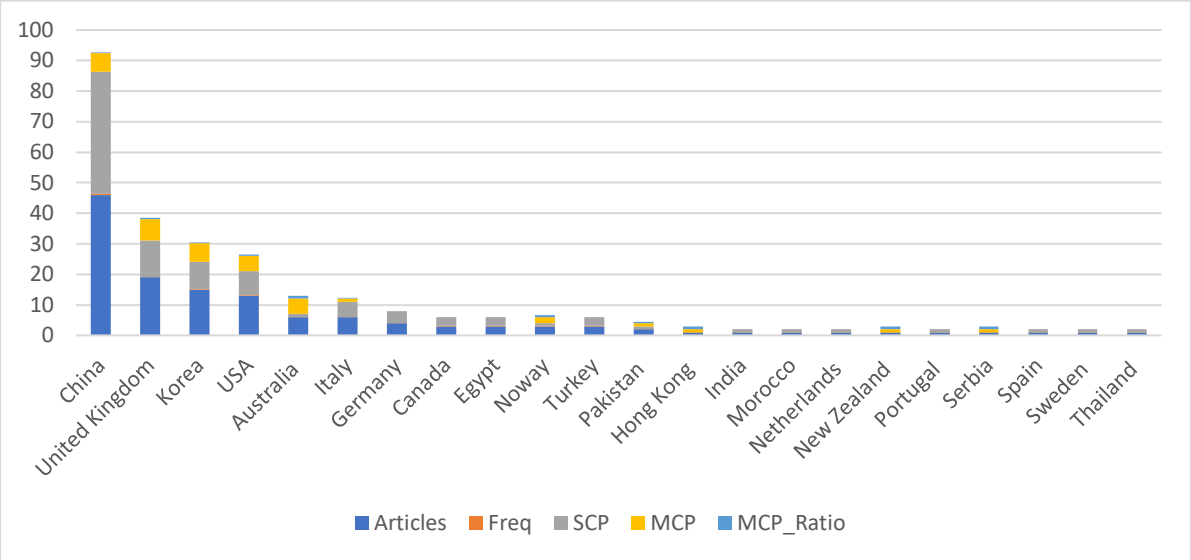
No.	Journal name	Documents	Citations
1	*Automation in Construction*	16	548
2	*Sustainability*	9	34
3	*Tunnelling and Underground Space Technology*	9	70
4	*Advances in Civil Engineering*	8	5
5	*Journal of Computing in Civil Engineering*	6	67
6	*Applied Sciences*	5	25
7	*Engineering Construction and Architectural Management*	5	4
8	*KSCE Journal of Civil Engineering*	5	26
9	*Advanced Engineering Informatics*	1	73
10	*Journal of Construction Engineering and Management*	4	31

Source: Authors' own, generated using RStudio software.

3.5.2 Distribution across regions and countries

The distribution of countries' publication activity for BIM research in major project delivery is demonstrated in Figure 2. This study found that there were 146 published documents on BIM research in major project delivery from five continents. Asia had the most publications with 67 articles, followed by Europe with 37, North America with 16, Australia with 6, and New Zealand with 1. South America was not represented. In Africa, BIM research in major project delivery was only found in Egypt and Morocco. The countries in North America, Europe, Asia, New Zealand, and Australia accounted for the majority of published BIM research for major project delivery worldwide. Saka and Chan (2019, 2020) stated that BIM adoption and usage challenges still persist in Africa, but its paradigms for adaptation are divided into three stages: improvement, awareness, and implementation (Mtya and Windapo, 2019; Nasila and Cloete, 2018; Hamma-adama and Kouider, 2019; Olanrewaju et al., 2020) (see also Figure 3).

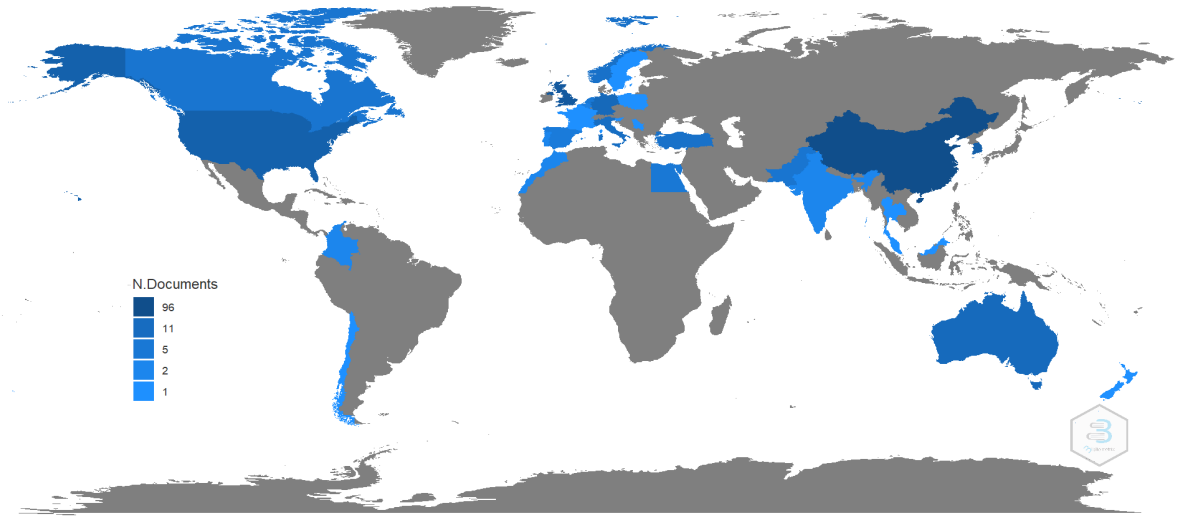
Figure 2: The distribution of publication activity by country



Notes: Freq, frequency; SCP, single country publication; MCP, multiple country publication. Some typographic errors in labelling remain from original data input.

Source: Authors' own, generated using 'Biblioshiny' in RStudio software.

Figure 3: Distribution of globally published studies on BIM for major project delivery research

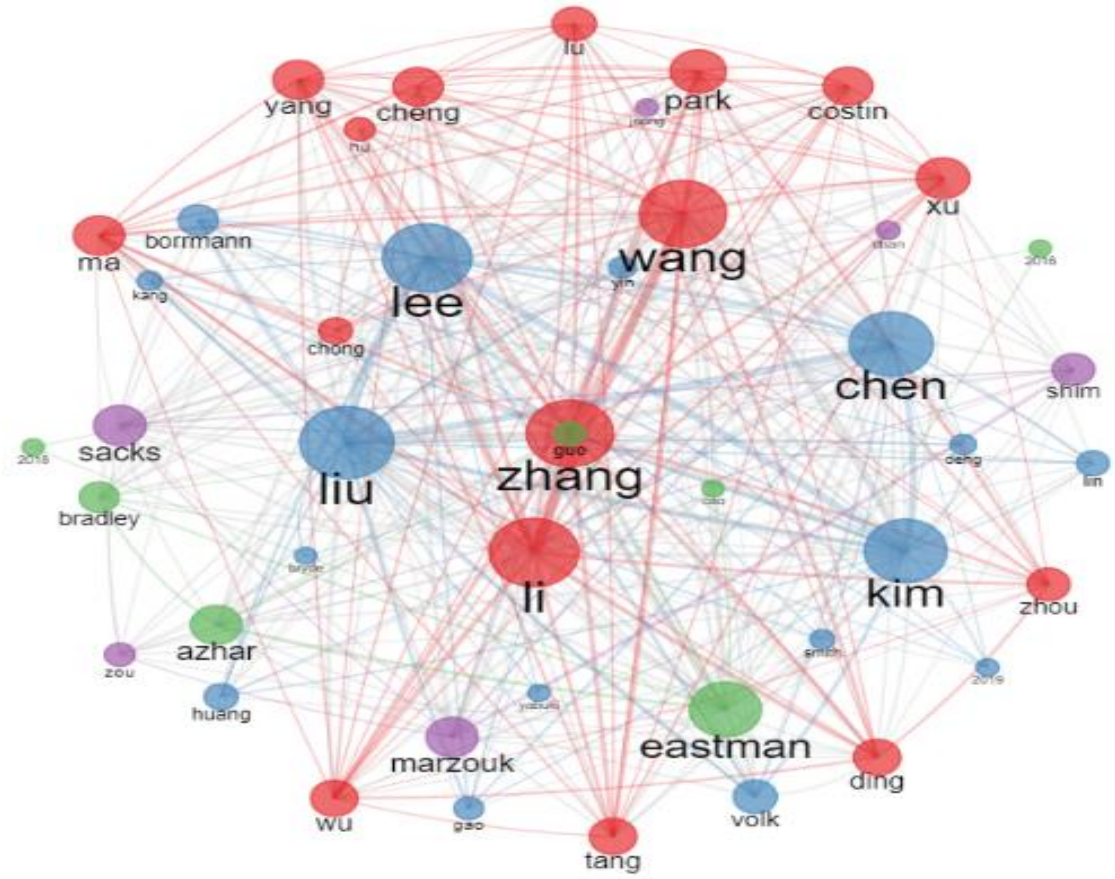


Source: Authors' own, generated using 'Biblioshiny' in RStudio software.

3.5.3 Co-authorship network and publication per author

According to the information presented in the text, a co-authorship network (de Paula Fonseca e Fonseca et al., 2016) was created to analyse the collaboration trends among authors in the field of BIM-pervasive major project delivery. The network was created using the software function with a minimum requirement of five documents with at least 10 citations. The authors were then ranked based on their total citation (TC) scores, TC per year, and normalized TC to determine their research impact. Figure 4 shows the network of the 20 most prolific authors.

Figure 4: A network of authors who have made major contributions to research and trends on BIM



Source: Authors' own, generated using 'Biblioshiny' in RStudio software.

From the 146 documents, 442 authors met the threshold, including contributing and lead authors. The Biblioshiny command in RStudio software's analytical algorithms required a minimum of five documents and 10 citations per author; 67 writers met this requirement. The top 20 researchers who have made scientific contributions and have had the greatest influence on BIM-pervasive major project delivery research are listed in Table 4. The first authors of the following studies were found to be the most prolific in the research topic under investigation:

- Marzouk and Abdelaty (2014) (74 TC, 8.22, TC per year, 2.84 normalized TC),
- Mcguire et al. (2016) (61 TC, 8.71 TC per year, 2.62 normalized TC),
- Zhang et al. (2016) (60 TC, 8.57 TC per year, 2.58 normalized TC),
- Fanning et al. (2014) (49 TC, 6.12 TC per year, 2.25 normalized TC),
- Kaewunruen and Lian (2019) (45 TC, 11.25 TC per year, 3.46 normalized TC), and
- Tang et al. (2020) (40 TC, 13.33 TC per year, 4.94 normalized TC).
- Using the extensive collection of linkages and link strengths that were previously determined, the overlay and network representations in Figure 4 are explored. A connection in this category refers to co-operation between writers, whereas the overall link strength (Van Eck and Waltman, 2010) of the co-authorship networks indicates the relationship between sources.

Table 4: Studies with the 20 most prolific first authors in this research domain

No	Author(s) (Year)	Total citations (TCs)	TCs per year	Normalized TC
1	Marzouk and Abdelaty (2014)	74	8.22	2.8462
2	Mcguire et al. (2016)	61	8.71	2.6237
3	Zhang et al. (2016)	60	8.571	2.5806
4	Fanning et al. (2014)	49	6.125	2.2529
5	Kaewunruen and Lian (2019)	45	11.25	3.4615
6	Tang et al. (2020)	40	13.333	4.9485
7	Lee et al. (2018)	36	7.2	1.9412
8	Zou et al. (2016)	35	5	1.5054
9	Wang et al. (2018)	34	6.8	1.8333
10	Love et al. (2017)	32	5.333	1.8462
11	Tang et al. (2020)	32	10.667	3.9588
12	Hu et al. (2016)	31	4.429	1.3333
13	Li et al. (2018)	31	6.2	1.6716
14	Wang et al. (2019)	30	7.5	2.3077
15	Shim et al. (2017)	28	4.667	1.6154
16	Yin et al. (2020)	28	9.333	3.4639
17	Aziz et al. (2017)	27	4.5	1.5577
18	Delgado et al. (2018)	26	5.2	1.402
19	Liu et al. (2020)	25	8.333	3.0928
20	Marzouk and Abdelaty (2014)	24	2.667	0.9231

Source**:** Authors' own, generated using RStudio software.

Figure 4 represents the network visualization in which 20 clusters of co-authorship were detected, with 45 network objects and a total connection strength of 218 produced among the authors. Twenty-nine connections between authors in the research field were found.

In particular, the clusters of primary authors in studies like Tang et al. (2020), Marzouk and Abdelaty (2014), Mcguire et al. (2016), Fanning et al. (2014), and Kaewunruen and Lian (2019) show active research collaboration. There has been a gradual increase in research production from 2014 to 2022, as seen by publication outputs in Table 5.

Table 5: Publications from 2014 to 2022

Description	Results
Main information about data	
Timespan	2014–22
Sources (journals and books)	66
Documents	146
Average years from publication	2.79
Average citations per document	10.23
Average citations per year per document	2.289
References	6,123
Document types	
Article	146
Document contents	
Keywords plus (ID)	996
Author keywords (DE)	475
Authors	
Authors	442
Author appearances	541
Authors of single-authored documents	6

Authors of multi-authored documents	436
Author collaborations	
Single-authored documents	6
Documents per author	0.33
Authors per document	3.03
Co-authors per document	3.71
Collaboration index	3.11

Source: Authors' own, generated using RStudio software.

3.5.4 Affiliations of publications

This section also looks at the scope of university- and organization-level research projects and publications. The selection was based on the criteria of the research. A total of 197 organizations/universities were found, and the 20 documents released by various organizations and universities since 2014 are listed in Table 6.

Table 6: Affiliations of publications

Affiliations	Documents
Southeast University	6
University of Birmingham	6
Chung-ang University	4
Colorado State University	4
Shanghai University	4
Southeast University	4
Tianjin University	4
University of Liverpool	4
University of Twente	4
Xian University Architecture and Technology	4
Yonsei University	4
Bauhaus-University Weimar	3
Beijing University of Technology	3
Central South University	3
China University of Mining and Technology	3
Chongqing Jiaotong University	3
Curtin University	3
Hanyang University	3
Harbin Institute of Technology	3
Huazhong University of Science and Technology	3
Newcastle University	3
Syracuse University	3
Hong Kong University of Science and Technology	3
University of Nottingham	3
Tongji University	3

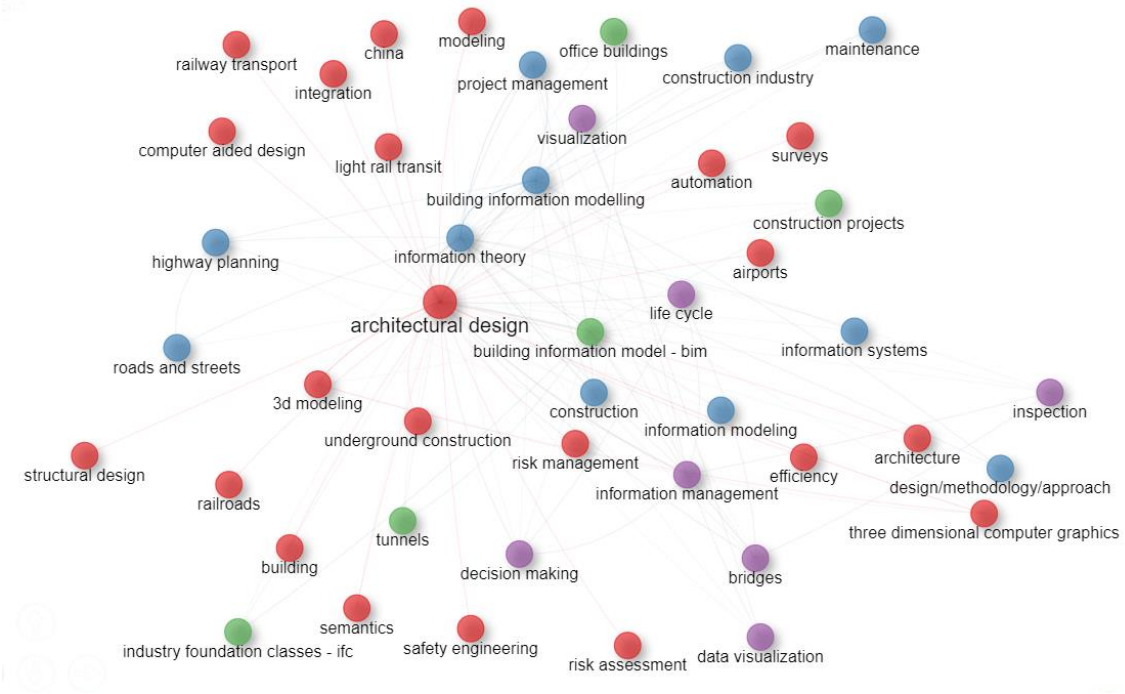
Source: Authors' own, generated using RStudio software.

3.5.5 Keyword network formed by co-occurrences

The keywords in a publication reflect the content of the publication (Xiang et al., 2017). Co-occurrence refers to the proximity or presence of similar keywords. In the study by Lozano et al. (2019), the closer the keywords are in proximity, the more likely they are to appear together. The RStudio software was used to build a co-occurrence network from 730 significant keywords using the Biblioshiny command. A minimum inclusion criterion of five was used to select keywords, and

45 of the 730 key terms met this standard, resulting in the identification of four clusters. These clusters are depicted in Figure 5. The discussions and study will now focus on the trends and innovations represented by these clustered keywords, rather than the previously popular words associated with BIM.

Figure 5: A co-occurrence network of keywords



Source: Authors' own, generated using 'Biblioshiny' in RStudio software.

- *Cluster 1:* Figure 5 shows that this cluster, represented in red, contains 22 terms. The keywords in this cluster include architectural design, automation, three-dimensional computer graphics, risk assessment, safety engineering, railroads, efficiency, integration, light rail transit, structural design, and underground construction. These keywords are related to pre-design considerations for BIM and provide optimization plans for proposed projects. As a result, this cluster can also be referred to as BIM performance indicators or 'BIM PI'.
- *Cluster 2:* This cluster, highlighted in blue, is associated with 11 keywords including information theory, maintenance, information systems, roads, and streets. The focus of this cluster is on information systems and can be summarized as 'BIM IS'.
- *Cluster 3*: This cluster, highlighted in green, contains five keywords including industry foundation classes (IFCs), office buildings, and tunnels. This cluster can be summarized as 'BIM IFC' and focuses on BIM industry foundation classes.
- *Cluster 4:* This cluster, highlighted in a soft yellow, contains seven different terms including information management, decision-making, life cycle, visualization, data visualization, and inspection. The cluster focuses on BIM solution content and applications and can be summarized as 'BIM SCA'.

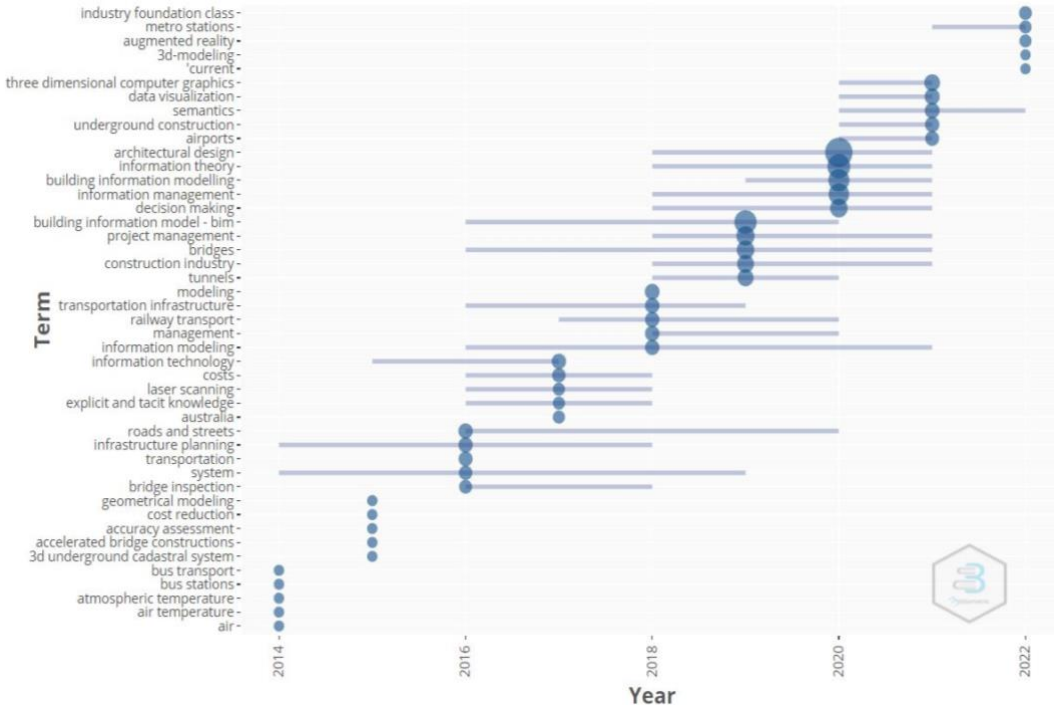
The results of the co-occurrence analysis indicate the need for further research in these areas, especially in the implementation and integration of BIM into the construction industry. The findings also suggest that there is room for improvement in information systems, information management, and decision-making processes related to BIM. Standardization of BIM across different projects and industries will also be an important aspect to consider in future studies.

3.6 Trends in BIM-pervasive major project delivery

Studies on BIM have significantly improved in scope, focus, and quantity between 2014 and 2022. Visualizing the subjects of research from the start year of 2014 reveals an interesting evolution. The initial focus was on exploratory topics such as infrastructure planning, air temperature, and atmospheric temperature, but the number of publications increased and the focus shifted to more specific issues like three-dimensional underground cadastral systems, accuracy assessment, cost reduction, geometrical modelling, and information technology in 2015. The interest in transportation, roads and streets, bridge inspection, laser scanning, transportation infrastructure, and explicit and tacit knowledge increased in 2016. Modelling, management, railway transport, information theory, information management, and decision-making saw a rise in popularity between 2017 and 2018. Figure 6 shows an increase in the usage of BIM in three-dimensional computer graphics, data visualization, underground construction, and airports towards the start of 2020. Metro stations, IFCs, and augmented reality also gained popularity in the years 2021–22. The trend analysis results demonstrate the progression of research and its connection to BIM's pervasive use in major project delivery.

According to the findings of this research, there has been a dramatic shift in the study of BIM. However, it should be emphasized that BIM for performance enhancement, improving productivity, and for governance has not been fully tackled.

Figure 6: Trend analysis results



Source: Authors' own, generated using 'Biblioshiny' in RStudio software.

3.7 Analysis of articles using text mining

For text mapping, RStudio software was used to scan the full text of the 146 documents and extract the text from the corpus using the occurrences and importance of active nouns. The software determined the relevance of terms with at least 20 occurrences. There were 808 words in the 52,065-word list that matched the criterion. Filtering choices, such as removing word texts and their acronyms, were used to determine relevance. The 20 most frequent words in analysed full-text articles are presented in Table 7.

Table 7: The 20 most frequent words in analysed full-text articles

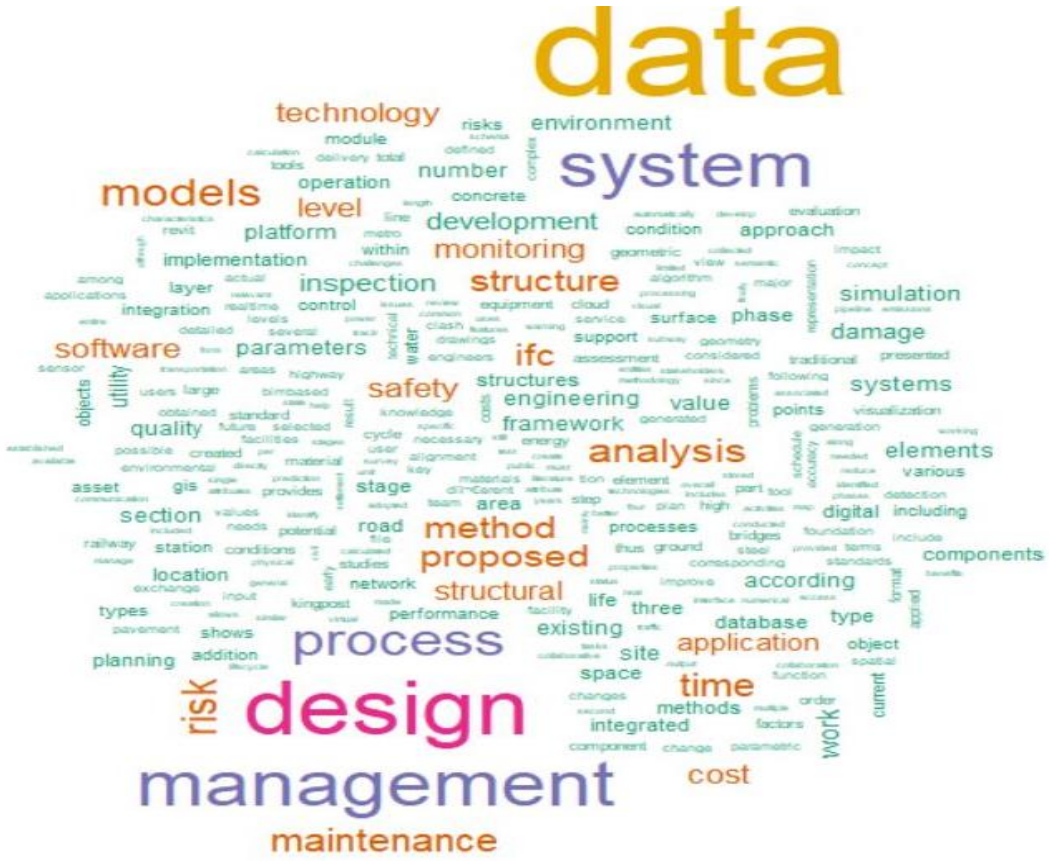
No.	Term	Frequency	No.	Term	Frequency
1	Data	6,224	11	Structure	1,374
2	Design	3,618	12	Proposed	1,328
3	System	2,956	13	IFCs	1,325
4	Management	2,929	14	Method	1,313
5	Process	2,178	15	Cost	1,276
6	Models	1,815	16	Safety	1,240
7	Risk	1,689	17	Software	1,212
8	Analysis	1,608	18	Technology	1,203
9	time	1,472	19	Level	1,160
10	Maintenance	1,429	20	Structural	1,151

Note: IFCs, industry foundation classes.

Source: Authors' own, generated using RStudio software.

The word cloud in Figure 7 shows the most relevant words related to text mining in the construction sector, generated by a software program. The 200 words are grouped into different categories based on their meaning. The words in orange relate to technology, software, data, monitoring, IFCs, and maintenance. The words in red highlight design aspects, whereas the words in blue focus on system, process, and management. The most frequent words are highlighted in green and pertain to the usage of BIM in major project delivery, including performance, risks, environment, simulation, development, operation, implementation, and scheduling.

Figure 7: A word cloud depiction of the most active words



Source: Authors' own, generated using 'Biblioshiny' in RStudio software.

4 Discussion and outcomes

This study found that new BIM publications and research trends are coming from Asia, the United States of America, Europe, New Zealand, and Australia. Regarding BIM trends in Africa, they do not appear in the research corpus, which lists words. This is in line with the findings of Saka and Chan (2020) and Olawumi et al. (2017), who say that African countries still have difficulty getting people to use BIM. Nevertheless, the present study reveals that the construction sector is changing, and BIM is being adopted into policy and practice across the globe. The trend is driven by the need for environmentally friendly and efficient construction practices.

The bibliometric data analysis of public journals in this study reveals that government bodies are creating realistic and practicable policies that need to be implemented in the construction sector to increase efficiency and sustainability. These approaches are being undertaken because of the realization of the potential of BIM in supporting pervasive major project delivery. The wide adoption and support of BIM are based on the benefits of supporting real-time management decisions in the construction sector, including conducting the anticipated simulation approaches for the projects. The findings indicate that BIM needs interoperability, which rules out the need for consensus.

This study shows that recent advancements in text mining and data science research are driving the field of BIM forward, helping to clarify technical terms and patterns in BIM research. The close relationship between energy management, performance, and BIM also underscores the importance of considering energy-efficient design and construction practices in the implementation of BIM. The use of model view definitions and IFC subsets to facilitate data communication and iterative workflows is a key aspect of BIM that can support effective governance and improve project outcomes.

5 Conclusion

The results of this study provide valuable information for researchers, practitioners, and policymakers in the construction industry. The study highlights the key trends and developments in BIM research and offers insights into the current state of BIM adoption and implementation in major construction projects. It concludes that BIM has the potential to improve the efficiency and sustainability of construction projects, but for it to be effectively adopted, there must be a focus on interoperability and integration with other software tools. Future research should aim to further understand the impact of BIM on the construction industry and explore ways to overcome barriers to its widespread adoption and implementation. The analysis of a wider range of sources would allow for a more thorough understanding of the impact of BIM on the construction industry and the various challenges and opportunities it presents. In addition, incorporating real-time case studies would provide practical insights into the actual use and effectiveness of BIM in construction projects.

6 References

Aria, M., & Cuccurullo, C. (2017). A brief introduction to Bibliometrix. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Aziz, Z., Riaz, Z., & Arslan, M. (2017). Leveraging BIM and big data to deliver well maintained highways. *Facilities*, *35*(13/14). 818–832. https://doi.org/10.1108/F-02-2016-0021

Blake, A. (2019). *Dynamics of data science skills: How can all sectors benefit from data science talent?* Royal Society [Online]. https://royalsociety.org/-/media/policy/projects/dynamics-of-data-science/dynamics-of-data-science-skills-report.pdf

Cai, L., & Zhu, Y. (2015). The challenges of data quality and data quality assessment in the big data era. *Data Science Journal*, *14*, Article 2. https://doi.org/10.5334/dsj-2015-002

Chellappandi, P., & Vijayakumar, C. S. (2018). Bibliometrics, scientometrics, webometrics/cybermetrics, informetrics and altmetrics–: An emerging field in library and information science research. *Shanlax International Journal of Education*, *7*(1), 5–8.

Chen, Z., Agapiou, A., & Li, H. (2020). A benefits prioritization analysis on adopting BIM systems against major challenges in megaproject delivery. *Frontiers in Built Environment*, 6, Article 26. https://doi.org/10.3389/fbuil.2020.00026

Criminale, A., & Langar, S. (2017). Challenges with BIM implementation: A review of literature. In *53rd ASC Annual International Conference Proceedings* (pp. 329–335). Associated Schools of Construction. http://ascpro0.ascweb.org/archives/cd/2017/paper/CPGT224002017.pdf

de Paula Fonseca e Fonseca, B., Sampaio, R. B., de Araújo Fonseca, M. V., & Zicker, F. (2016). Co-authorship network analysis in health research: Method and potential use. *Health Research Policy and Systems*, *14*, Article 34. https://doi.org/10.1186/s12961-016-0104-5

Delgado, J. M., Butler, L. J., Brilakis, I. K., Elshafie, M. Z., & Middleton, C. R. (2018). Structural performance monitoring using a dynamic data-driven BIM environment. *Journal of Computing in Civil Engineering*, *32*, Article 04018009. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000749

Dowden, O. (2020, December 9). *National data strategy* [Policy paper, Online]. HM Government. https://www.gov.uk/government/publications/uk-national-data-strategy/national-data-strategy

Fanning, B., Clevenger, C., Ozbek, M., & Mahmoud, H. (2014). Implementing BIM on infrastructure: Comparison of two bridge construction projects. *Practice Periodical on Structural Design and Construction*, *20*, Article 04014044. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000239

Feldman, R., & Sanger, J. (2006). *The text mining handbook: Advanced approaches in analyzing unstructured data*. Cambridge University Press. https://doi.org/10.1017/CBO9780511546914

Grobelnik, M., Mladenic, D., & Jermol, M. (2002, April). Exploiting text mining in publishing and education. In *Proceedings of the ICML 2002 Workshop on Data Mining Lessons Learned* (pp. 34–39), Ljubljana, Slovenia.

Guo, Y., Huang, Z.-L., Guo, J., Li, H., Guo, X.-R., & Nkeli, M. J. (2019). Bibliometric analysis on smart cities research. *Sustainability*, *11*(13), Article 3606. https://doi.org/10.3390/su11133606

Hamma-adama, M., & Kouider, T. (2019). Comparative analysis of BIM adoption efforts by developed countries as precedent for new adopter countries. *Current Journal of Applied Science and Technology*, *36*(2), 1–15. https://doi.org/10.9734/cjast/2019/v36i230224

Hotho, A., Nürnberger, A., & Paass, G. (2005). A brief survey of text mining. *LDV Forum*, *20*, 19–62. https://doi.org/10.1007/s11192-009-0146-3

Hu, Z-Z., Zhang, J.-P., Yu, F.-Q., Tian, P.-L., & Xiang, X.-S. (2016). Construction and facility management of large MEP projects using a multi-scale building information model. *Advances in Engineering Software*, *100*, 215–230. https://doi.org/10.1016/j.advengsoft.2016.07.006

Jamal, K. A. A., Mohammad, M. F., Hashim, N., Mohamed, M. R., & Ramli, M. A. (2019). Challenges of building information modelling (BIM) from the Malaysian architects perspective. *MATEC Web of Conferences*, *266*, Article 05003. https://doi.org/10.1051/matecconf/201926605003

Jones, Q., Ravid, G., & Rafaeli, S. (2004). Information overload and the message dynamics of online interaction spaces: A theoretical model and empirical exploration. *Information Systems Research*, *15*(2), 194–210. https://doi.org/10.1287/isre.1040.0023

Kaewunruen, S., & Lian, Q., (2019). Digital twin aided sustainability-based lifecycle management for railway turnout systems. *Journal of Cleaner Production*, *228*, 1537–1551. https://doi.org/10.1016/j.jclepro.2019.04.156

Kumar, B. (2015). *A practical guide to adopting BIM in construction projects*. Whittles Publishing.

Lee, C.-Y., Chong, H.-Y., Liao, P.-C., & Wang, X. (2018). Critical review of social network analysis applications in complex project management. *Journal of Management in Engineering*, 34(2), Article 04017061. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000579

Li, M., Yu, H., & Liu, P. (2018). An automated safety risk recognition mechanism for underground construction at the pre-construction stage based on BIM. *Automation in Construction*, *91*, 284–292. https://doi.org/10.1016/j.autcon.2018.03.013

Li, N., & Wu, D. D. (2010). Using text mining and sentiment analysis for online forums hotspot detection and forecast. *Decision Support Systems*, *48*(2), 354–368. https://doi.org/10.1016/j.dss.2009.09.003

Liu, Y., Cheng, J., & Wang, Q. (2020). Semi-automated generation of parametric BIM for steel structures based on terrestrial laser scanning data. *Automation in Construction*, *112*, Article 103037. https://doi.org/10.1016/j.autcon.2019.103037

Love, P. E., Zhou, J., Edwards, D. J., Irani, Z., & Sing, C. P. (2017). Off the rails: The cost performance of infrastructure rail projects. *Transportation Research Part A: Policy and Practice*, *99*, 14–29. https://doi.org/10.1016/j.tra.2017.02.008

Lozano, S., Calzada-Infante, L., Adenso-Díaz, B., & Carbajal, S. G. (2019). Complex network analysis of keywords co-occurrence in the recent efficiency analysis literature. *Scientometrics*, *120*(2), 609–629. https://doi.org/10.1007/s11192-019-03132-w

Marzouk, M., & Abdelaty, A. (2014). Monitoring thermal comfort in subways using building information modeling. *Energy and Buildings*, *84*, 252–257. https://doi.org/10.1016/j.enbuild.2014.08.006

Mayouf, M., Gerges, M., & Cox, S. (2019). 5D BIM: An investigation into the integration of quantity surveyors within the BIM process. *Journal of Engineering, Design and Technology*, *17*(3), 537–553. https://doi.org/10.1108/JEDT-05-2018-0080

McGuire, B., Atadero, R., Clevenger, C., & Ozbek, M. (2016). Bridge information modeling for inspection and evaluation. *Journal of Bridge Engineering*, *21*, Article 04015076. https://doi.org/10.1061/(ASCE)BE.1943-5592.0000850

Mtya, A., & Windapo, A. O. (2019). Drivers and barriers to the adoption of building information modelling (BIM) by construction firms in South Africa. In P. Wu & X. Wang (Eds.), *Innovative production and construction: Transforming construction through emerging technologies* (pp. 215–223). World Scientific. https://doi.org/10.1142/9789813272491_0013

Nasila, M., & Cloete, C. E. (2018). Adoption of building information modelling in the construction industry in Kenya. *Acta Structilia*, *25*(2), 1–38. https://doi.org/10.18820/24150487/as25i2.1

Olanrewaju, O. I., Chileshe, N., Babarinde, S. A., & Sandanayake, M. (2020). Investigating the barriers to building information modeling (BIM) implementation within the Nigerian construction industry. *Engineering, Construction and Architectural Management*, *27*, 2931–2958. https://doi.org/10.1108/ECAM-01-2020-0042

Olawumi, T. O., Chan, D. W. M., & Wong, J. S. (2017). Evolution in the intellectual structure of BIM research: A bibliometric analysis. *Journal of Civil Engineering and Management*, *23*, 1060–1081. https://doi.org/10.3846/13923730.2017.1374301

Oti-Sarpong, K., Pärn, E. A., Burgess, G., & Zaki, M. (2021). Transforming the construction sector: an institutional complexity perspective. *Construction Innovation*, *22*(2), 361–387. https://doi.org/10.1108/CI-04-2021-0071

Pritchard, A. (1969). Statistical bibliography or bibliometrics. *Journal of Documentation*, *25*(4), 348–349. https://doi.org/10.1108/eb026482

Rahim, N. S. A., & Zakaria, S. A. S. (2017). The framework of building information modeling (BIM) implementation stages for Malaysian construction industry. *IPTEK Journal of Proceedings*, *6*, 62–68.

Retzlaff, T. (2018). Stufen der BIM-Modellierung im Infrastrukturbereich. *Bautechnik*, *95*(7), 512–517. https://doi.org/10.1002/bate.201800045

RStudio Team. (2020). *RStudio: Integrated Development for R*. RStudio, PBC, Boston, MA. http://www.rstudio.com/

Sajovic, I., Tomc, H. G., & Podgornik, B. (2018). Bibliometric study and mapping of a journal in the field of visualization and computer graphics. *COLLNET Journal of Scientometrics and Information Management*, *12*, 263–287. https://doi.org/10.1080/09737766.2018.1453677

Saka, A. B., & Chan, D. W. M. (2019). A scientometric review and metasynthesis of building information modelling (BIM) research in Africa. *Buildings*, *9*(4), Article 85. https://doi.org/10.3390/buildings9040085

Saka, A. B., & Chan, D. W. M. (2020). Profound barriers to building information modelling (BIM) adoption in construction small and medium-sized enterprises (SMEs). *Construction Innovation: Information, Process, Management*, *20*, 261–284. https://doi.org/10.1108/CI-09-2019-0087

Shim, C., Kang, H., Dang, S., & Lee, D. (2017). Development of BIM-based bridge maintenance system for cable-stayed bridges. *Smart Structures and Systems*, *20*, 697–708.

Son, B.-Y., & Lee, E.-B. (2019). Using text mining to estimate schedule delay risk of 13 offshore oil and gas EPC case studies during the bidding process. *Energies*, *12*(10), Article 1956. https://doi.org/10.3390/en12101956

Tang, F., Ma, T., Zhang, J., Guan, Y., & Chen, L. (2020). Integrating three-dimensional road design and pavement structure analysis based on BIM. *Automation in Construction*, *113*, Article 103152. https://doi.org/10.1016/j.autcon.2020.103152

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*, 523–538. https://doi.org/10.1007/s11192-009-0146-3

Wang, M., Deng, Y., Won, J., & Cheng, J. (2019). An integrated underground utility management and decision support based on BIM and GIS. *Automation in Construction*, *107*, Article 102931. https://doi.org/10.1016/j.autcon.2019.102931

Wang, Q., Xue, X., Zhang, X., Wang, L., & Skitmore, M. (2018). Analyzing collaborative relationships among industrialized construction technology innovation organizations: A combined SNA and SEM approach. *Journal of Cleaner Production*, *173*, 265–277. https://doi.org/10.1016/j.jclepro.2017.01.009

Weiss, S. M., Indurkhya, N., Zhang, T., & Damerau, F. J. (2010). *Text mining: Predictive methods for analyzing unstructured information*. Springer.

Wen, Q.-J., Ren, Z.-J., Lu, H., & Wu, J.-F. (2021). The progress and trend of BIM research: A bibliometrics-based visualization analysis. *Automation in Construction*, *124*, Article 103558. https://doi.org/10.1016/j.autcon.2021.103558.

Wrigley, J., Carden, V., & von Isenburg, M. (2019). Bibliometric mapping for current and potential collaboration detection. *Journal of the Medical Library Association*, *107*(4), Article 597. https://doi.org/10.5195/jmla.2019.764

Xiang, C., Wang, Y. B., & Liu, H. (2017). A scientometrics review on nonpoint source pollution research. *Ecological Engineering*, *99*, 400–408. https://doi.org/10.1016/j.ecoleng.2016.11.028

Yin, X., Liu, H., Chen, Y., Wang, Y., & Al-Hussein, M. (2020). A BIM-based framework for operation and maintenance of utility tunnels. *Tunnelling and Underground Space Technology*, *97*, Article 103252. https://doi.org/10.1016/j.tust.2019.103252

Zhang, F., Fleyeh, H., Wang, X., & Lu, M. (2019). Construction site accident analysis using text mining and natural language processing techniques. *Automation in Construction*, *99*, 238–248. https://doi.org/10.1016/j.autcon.2018.12.016

Zhang, L., Wu, X., Ding, L., Skibniewski, M. J., & Lu, Y. (2016). BIM-based risk identification system in tunnel construction. *Journal of Civil Engineering and Management*, *22*(4), 529–539. https://doi.org/10.3846/13923730.2015.1023348

Zou, Y., Kiviniemi, A., Jones, S. W. (2016). Developing a tailored RBS linking to BIM for risk management of bridge projects. *Engineering, Construction and Architectural Management*, *23*, 727–750. https://doi.org/10.1108/ECAM-01-2016-0009

An ontological risk management model for adopting the modern methods of construction through agile lean construction

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Abstract: This study aims to present a new generic ontological model for risk management in adopting the modern methods of construction (MMC) via a methodological integration of agile project management and lean construction in housing projects. This study consists of three interconnected parts: (i) a systematic literature review to clarify the need for agile lean construction (ALC) and risk management in practices driven by the MMC; (ii) an ontological model for risk management in adopting the MMC under ALC-oriented controls on people, product, and process in housing projects; and (iii) a structured discussion on technical essentials of this ALC-oriented risk management ontology for practical enhancement in adopting the MMC. It is expected that this study can inform both academic research and professional practice in adopting and developing the MMC in housing project delivery across key work stages, which cover design, construction, and operation. For academic research into the MMC, this study initiates the use of ontological approach to risk management by integrating ALC controls. For professional practice in housing development, this study puts forward an ontological risk management model that can not only enable ALC-integrated project delivery that adopts the MMC but also reflect the need for professional competence enhancement in construction risk management and lean construction.

Keywords: agile project management, lean construction, modern methods of construction, ontological model, risk management

Acknowledgements: This research was funded by the Government of National Unity, Libya, and conducted in the Department of Architecture at the University of Strathclyde in Glasgow, United Kingdom.

1 Introduction

Construction projects often face significant challenges that can negatively affect their long-term viability and value, including low productivity, inadequate safety, poor working conditions, and issues related to quality, time, and cost overruns (Nikakhtar et al., 2015; Alarcón, 1997; Sohi et al., 2016). Inappropriately, project management often fails to achieve the highest level of project objectives because of erroneous or complex decision-making procedures, which result in decreased efficiency and more time and cost overruns (Jensen, 2014). These projects are typically complex, unique, and dynamic, and require an original design that includes multiple sub-assemblies with diverse requirements (Bertelsen, 2003). Due to the on-site nature of construction projects, the installation of these sub-assemblies is often delayed by overlapping and interacting operations of multiple contractors, making it more challenging to adhere to the specified timeline (Salem et al., 2006).

Effective decision-making that takes into account risk management is a crucial aspect of construction project management, and the success or failure of a project is ultimately determined by it. However, interdisciplinary and iterative risk management is often not given adequate attention, even as the management of construction projects becomes increasingly integrated. With the dynamic nature of construction project development and management, a traditional approach to project management may not be able to keep up because of the slow process of adapting to changes and other challenges. As such, several researchers, including Demir (2013) and Sohi et al. (2016), have called for new methodologies that can accommodate changes and respond to the current requirements of the project.

According to Farmer (2016), the construction industry and housing market could potentially experience significant gains in productivity through a coordinated effort to promote research, development, and innovation within the framework of a new tripartite covenant. This could involve implementing techniques such as the 'design for manufacture and assembly' approach, standardizing products, and pre-manufacturing components. Additionally, it is crucial to evaluate the capabilities and scalability of emerging technologies, like three-dimensional printing, drones, and on-site robotics, as well as consider the long-term effects of recent advances in materials science. Farmer (2016) emphasized the need to give serious consideration to these strategies and technologies for increasing productivity in the construction industry and housing market.

1.1 Research background

For decades, the housing sector in the United Kingdom has struggled to produce an adequate number of homes, despite various efforts to address the issue. In fact, the total number of houses constructed fell by more than 40%, from 251,820 in 1980 to 152,380 in 2015 (Davies et al., 2018, p. 8). According to Davies et al. (2018), the majority of house-building still relies on traditional construction methods that are unable to meet the required housing demand. In project management, risk management involves a systematic approach to identifying, assessing, and responding to risks that may arise throughout a project's life cycle, with the goal of achieving an acceptable level of risk reduction or control. According to Fidan et al. (2011), effective risk assessment and response planning during the bidding stage of a construction project can significantly affect a company's competitiveness and profit potential.

The objective of many risk management research projects has been to create methods that depend on knowledge and experience. Some studies have looked at risk management for knowledge repositories, and ontologies have been used to represent, share, and manage domain knowledge through a system of concept hierarchies, associative relations, and axioms that allow for semantic

reasoning (Tserng et al., 2009). According to Ahmed and Mohammed (2019), ontologies function as a framework for managing, sharing, and representing domain knowledge, and El-Diraby et al. (2005) noted that critical construction concepts can be formalized by converting ontological entities into extensible concept trees.

The Project Management Body of Knowledge (PMBOK) guide offers comprehensive knowledge of project management, including tools, methods, and processes (Project Management Institute [PMI], 2008, 2013). Brioso (2015) and Hodgson and Cicmil (2006) asserted that the primary aim of PMBOK is to create a globally recognized language and ontology for the project management field. The body of knowledge represents the ontology of the profession, which is composed of a set of concepts, relationships, and definitions that constitute the philosophy of project management. PMBOK is based on the answer to the fundamental question, 'what is a project?'.

Bazán et al. (2019) and Hong et al. (2014) highlighted that the lean philosophy emphasizes the systematic reduction of operational waste in an organization by implementing a set of complementary practices in the workplace. This approach aims to produce quality goods and services within specified delivery timeframes and enhance overall efficiency by reducing waste. In light of this, a research question was formulated to explore the feasibility of integrating modern methods of construction (MMC), agile project management, and lean construction as a means of achieving effective risk management in housing projects.

1.2 Research aim and objectives

The aim of this study is to introduce a novel comprehensive ontological model for risk management by integrating MMC with agile project management and lean construction in housing projects. The proposed agile lean construction (ALC) model can aid project managers in making informed decisions, improving project performance, and achieving project objectives.

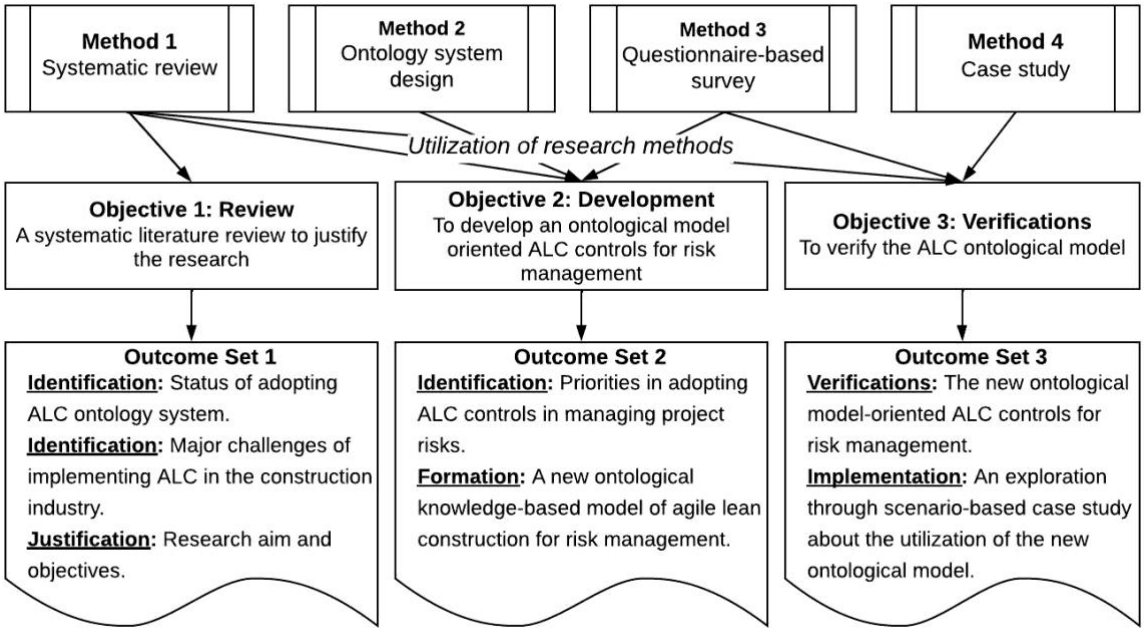
The study has the following three objectives:

- *Objective 1:* A systematic literature review to justify the research.
- *Objective 2:* A knowledge-based system design and analysis for the development of an ALC ontological model for risk management.
- *Objective 3:* An empirical validation of the ALC ontological model.

2 Systematic review

The research project utilized a mixed method technique that combines qualitative and quantitative methods to gain a better understanding of the topic under study. This approach is a strategy for collecting, interpreting, and integrating qualitative and quantitative data (Hennink et al., 2020). The selection of this research technique was based on the belief that combining qualitative and quantitative methodologies leads to a more comprehensive response to the studied situation (Bryman, 2016). The present study used several methods, including a systematic literature review, knowledge-based system design approach, questionnaire-based survey, and case study. To provide a clear understanding of the research study, a research roadmap was developed. Figure 1 illustrates the four approaches used to achieve the study's objectives.

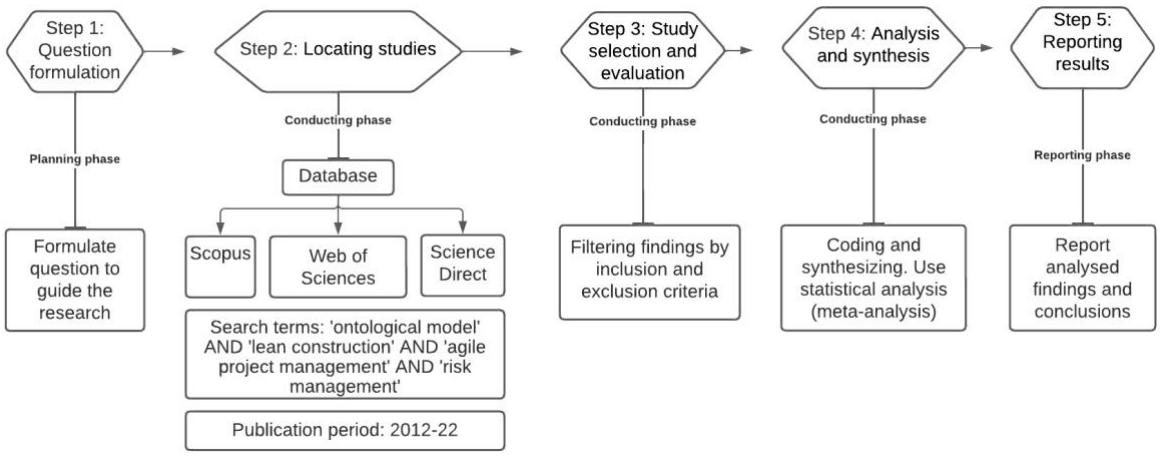
Figure 1: Research roadmap



Source: Authors' own.

An initial examination of relevant literature confirmed that adopting a systematic review would be a constructive strategy to develop a general ALC ontological model approach, and further investigation can be carried out using this approach. To validate the current research, a specified systematic literature review was conducted in five primary steps, which is illustrated in Figure 2. This methodology has been recommended by Denyer and Tranfield (2009) and has been implemented by Ten Ham-Baloyi and Jordan (2016). To ensure a more focused and selective set of outcomes, the results of database searches were screened utilizing a predetermined set of inclusion and exclusion criteria that correspond with the content of each publication (Abdirad and Dossick, 2016).

Figure 2: Steps and procedures for systematic review



Source: Authors' own.

According to Tserng et al. (2009), effective knowledge management requires managing the knowledge flow that an organization needs. To improve knowledge processing and workflow, a combination of knowledge management and information technology tools can be used. Process-oriented knowledge management (POKM) takes a process-oriented approach, which studies the workflow activities and knowledge requirements to incorporate knowledge management into the workflow. By facilitating information flow across an organization's workflow, the POKM strategy has the potential to improve work performance.

In the construction industry, the search for alternative management approaches to manage construction projects has led to the promotion of two different management paradigms, which are still in their infancy. Lean construction is an excellent choice for dealing with predictable or static settings, whereas agile project management is geared towards handling dynamic and uncertain situations (Burlereaux et al., 2013; Demir, 2013; Sheffield & Lemétayer, 2013).

3 ALC ontological model for risk management

To provide direction for the research, it is necessary to establish a preliminary model of the ALC ontology. The objective of this investigation is to combine the concepts and applications of agile project management and lean construction by examining their possible linkages and exploring measures to achieve a unified implementation. The central hypothesis is that the integration of these two methods can enhance construction practices and tackle real-world challenges by proficiently leveraging principles and techniques from both (Raedemaecker et al., 2020).

3.1 Previous studies on ontological models

Tserng et al. (2009) highlighted that an ontology serves as a precise and explicit representation of shared knowledge in a particular field. It offers a comprehensive and structured description of concepts and their interactions within the domain, consisting of two primary components: ideas and relationships. A formalized ontology can be useful in several areas, including machine learning, knowledge representation, semantic web, system integration, and problem-solving techniques. As the construction industry involves extensive and intricate project data, the effectiveness of knowledge distribution and information-sharing functions within an organization can significantly affect its overall performance (Eshaq & Karboulonis, 2003; Tserng et al., 2009). According to El-Diraby et al. (2005), ontologies fall into two broad categories.

- *Domain ontologies*: These are specialized terminologies that pertain to a particular subject matter and consist of conceptual elements and their interconnections. The primary goal of these ontologies is to define the relationships between concepts within the given domain. For instance, an engineering design ontology for construction planning could feature concepts such as the critical path method, planner, and schedule, along with their respective connections.
- *Upper-level ontologies*: The concept of generic knowledge involves defining and applying knowledge that can be used across a wide range of subjects. The Institute of Electrical and Electronics Engineers conducted a study to establish a standard higher ontology in this field, which is known as the Cyc Project (El-Diraby et al., 2005).

Ontologies play a crucial role in establishing a standardized and interoperable model for enterprises operating in virtual environments. Fox and Grüninger (1998) defined enterprise models as computational representations of different aspects of an organization, such as its structure, activities, processes, information, resources, people, behaviour, goals, and limitations (El-Diraby

et al., 2005). Fidan et al. (2011) noted an increase in ontology engineering education in construction literature, likely due to the growing awareness of the benefits of ontologies for collaborative work.

Moreover, Tzortzopoulos et al. (2020) highlighted that the two different aspects of process ontology are incorporated into the lean methodology. The strategy of continuous improvement can be understood as a methodical management action that focuses on making small but consistent adjustments. The significant emphasis that is placed on collaboration within the lean methodology is supported by process ontology. This allows for the elimination of the numerous dependencies that exist between the various tasks involved in design and production, which are frequently difficult to discern in advance.

3.2 Ontological approach to risk management

This study found that the proposed ontological risk management technique could be beneficial to project managers in conducting project risk management, particularly in risk assessment, analysis, and response planning. The study also demonstrated that the project risk ontology could be established through the acquisition of tacit knowledge and the extraction of explicit knowledge from organizations. By improving the effectiveness of risk management, this ontological approach could ultimately enhance the workflow of risk management based on knowledge management implementation, providing potential benefits to managers (Tserng et al., 2009).

According to Fidan et al. (2011), ontology development involves the five stages of specification, conceptualization, formalization, implementation, and evaluation. As a result, there is a growing need for efficient ways to reuse existing information, which has become a research topic of interest. In response to this challenge, several studies proposed different models to extract building knowledge and these studies highlight the importance of knowledge extraction in enabling effective information reuse, as pointed out by Tserng et al. (2009).

The present study aimed to create an ontology-based risk management model for construction project managers. The researchers conducted a review of ontology development research and, based on findings, a six-step process was considered: (i) defining the scope, (ii) reviewing domain authorities, (iii) extracting essential concepts, (iv) organizing concepts into hierarchies, (v) defining concept properties, and (vi) validating the ontology. To validate the ontology, the following three approaches were substantial: competency questions, expert survey, and case study. The literature suggests that these validation techniques are crucial for ontology validation (Pandit & Zhu, 2007; El-Diraby & Zhang, 2006; El-Diraby, 2006).

3.3 Risk management process

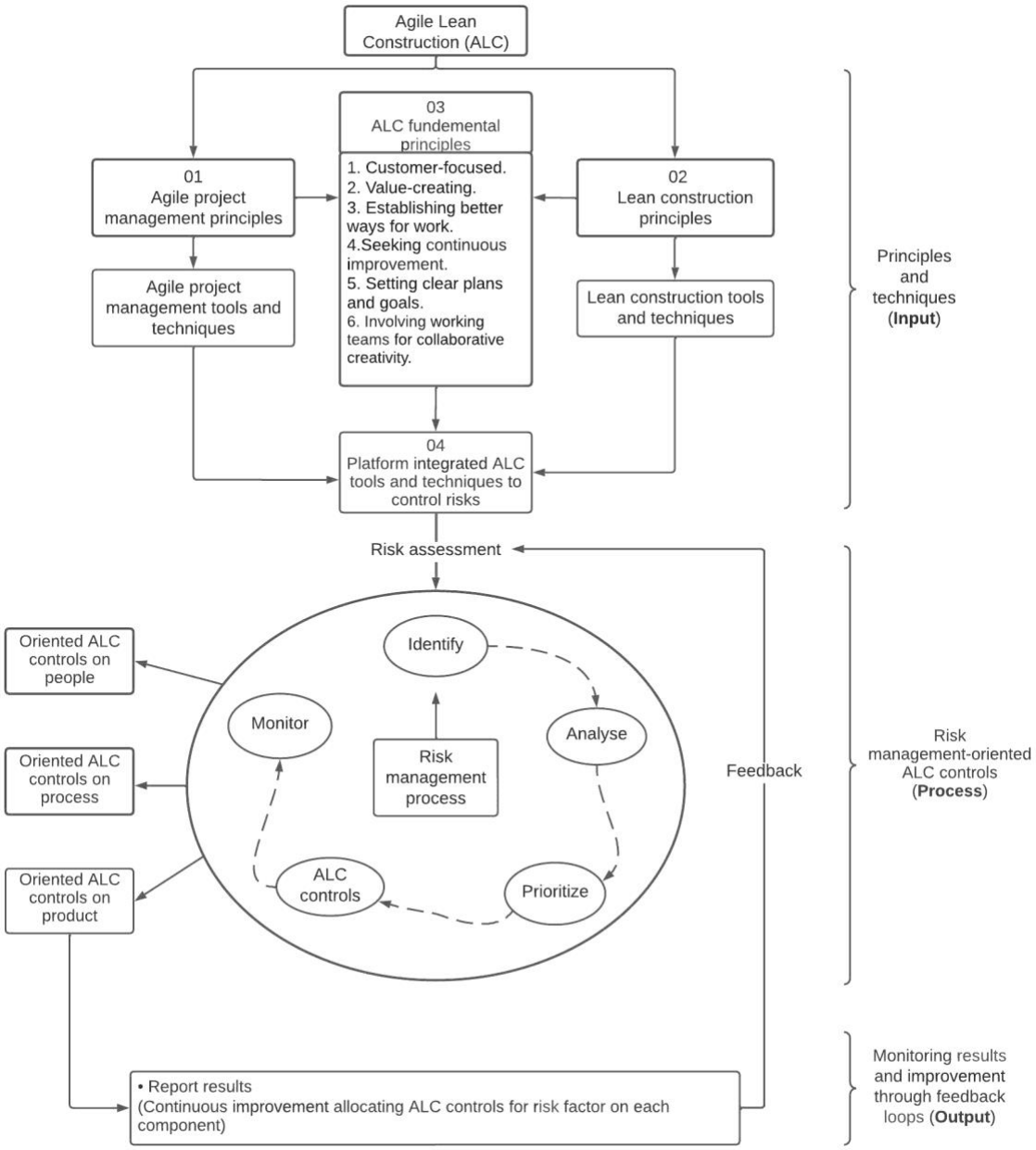
Risk management is a critical aspect of project success, as it involves recognizing possible risks, assessing their consequences, and creating plans to reduce their impact. Many experts, such as Fidan et al. (2011), believe that the occurrence of risks and how they are managed during a project are the primary factors that differentiate anticipated and actual project outcomes (Klakegg et al., 2020).

Additionally, Tserng et al. (2009) highlighted the significance of activity analysis in ontology construction to define the scope of work. The construction industry accepts risk management as a structured and systematic process that involves risk planning, identification, analysis, response, risk monitoring, and feedback. The ontology was developed based on this approach to offer a more general solution to construction practitioners. The literature on construction risk management provides general risk checklists and breakdown structures to enhance the effectiveness and efficiency of the initial stage of risk modelling, which is risk identification. It is

advisable to group risk variables into categories based on their foundations or controllability level while creating a checklist (Fidan et al., 2011).

Raedemaecker et al. (2020) stated that both agile project management and lean construction share similar concepts and fundamental principles, such as customer focus, value creation, the establishment of improved work practices, continuous improvement, the development of clear plans and objectives, and the involvement of teams for creativity. Therefore, an initial model, as shown in Figure 3, was further enhanced by joining ISO:31000 (see International Organization for Standardization [ISO] 2009–11, 2018–20) and other relevant studies, such as PMI (2008, 2013).

Figure 3: Agile lean construction (ALC) ontological model for risk management



Source: Authors' own.

Ontologies offer several advantages, including the ability to clarify information structure and facilitate knowledge sharing. They also allow for a more robust integration of technological and organizational aspects, while addressing the challenge of converting tacit knowledge to explicit knowledge (El-Diraby et al., 2005). Nevertheless, the ALC ontological model will undergo validation and refinement through various methods, such as a questionnaire-based survey and a case study.

4 Findings and discussion

The construction industry is marked by heightened levels of risk and uncertainty in project settings. This generates ambiguity for engineers and project managers during decision-making, resulting in risk factors affecting project performance without adequate mitigation. Specifically, contractors face risks during the construction phase not only due to their own limited experience but also due to limitations imposed by the owner or design firm. For this reason, the success of the contractor relies critically on implementing effective risk management strategies (Tserng et al., 2009).

Tah and Carr (2001) conducted a study that revealed the importance of the risk management process to participants and their study showed how the development of a well-designed approach allows for the systematic and consistent implementation of risk management. According to Tah and Carr (2001), several studies have evaluated the effectiveness of the risk management procedure. Since risk management is critical to project performance, it has been integrated into the PMBOK framework produced by PMI (2008). Tserng et al. (2009) demonstrated through case studies that the methodology and tools outlined in the PMBOK framework are advantageous to the overall project performance.

4.1 Construction risk management

According to Fidan et al. (2011), risks in construction projects can be managed through different frames of reference, but a major obstacle is the lack of consistent language used for risk-related concepts. The accuracy of risk definitions and communication throughout a project affects the reliability of risk models used to predict project outcomes under different risk scenarios. In addition, Tserng et al. (2009) found that inadequate risk identification was a prevalent issue during construction projects, leading to ineffective risk management during project execution.

A study conducted by Akintoye and MacLeod (1997) in the British construction industry revealed that many companies relied on their past experiences to carry out risk management instead of utilizing official risk analysis methodologies. Similar conclusions were drawn in subsequent studies, indicating that the major challenge in risk management involved the complexity of the risk analysis process, which was often not properly implemented because of time constraints and a lack of training in the techniques (Kartam and Kartam, 2001).

Zimina et al. (2012) argued that the risk allocation balance tilts further towards the contractor in guaranteed maximum price agreements used in target cost contracts, which are risk management strategies that aim to allocate risks optimally among various stakeholders. In contrast, subcontractors tend to pass on risks to lower levels in the supply chain without hesitation. However, this 'risk shifting' approach is deceptive as ultimately it is the customer who bears the consequences if issues arise. This can result in delayed project delivery, reduced specifications, increased lifecycle costs, and poorer quality, all of which can significantly affect the client's business.

4.2 Practical enhancement in adopting MMC

It is widely recognized in the literature that risks associated with construction projects can have a negative impact on project delivery in terms of cost and time overruns. Therefore, it is important to develop new techniques to address this issue (Issa, 2013; Lewis et al., 2014). Additionally, Zimina et al. (2012) suggested that implementing lean concepts in project management philosophy, such as 'work on demand' and 'just-in-time' production, can significantly reduce or eliminate risks associated with cost, quality, schedule, and safety. This study proposes an innovative solution for effective risk management in construction projects by integrating agile project management and lean construction techniques.

Cho and Ballard (2011) highlighted that the last planner system (LPS) is used as a production planning and control system to enhance planning and production efficiency in construction projects. LPS consists of four main components: the master schedule, phase schedule, look-ahead plan, and weekly plan. Meanwhile, Amade et al. (2019) acknowledged that the LPS, introduced by Glen Ballard in 1992, is a production control method that establishes a workflow system emphasizing the relationship between scheduling, planning, and production management to achieve predictability. However, it should be stressed that there are other tools available for this purpose besides LPS.

The implementation of LPS has a significant impact on a project's overall performance, which can be measured by the total percentage of time and cost savings (Cho & Ballard, 2011). Furthermore, Brioso (2015) emphasized that integrated project delivery is an approach to project completion that integrates people, systems, business structures, and practices into a cohesive process. This method leverages the skills and knowledge of all participants to eliminate waste and increase productivity throughout the entire design and construction stages.

According to Cho and Ballard (2011), the Construction Management Association of America recognizes that the construction industry suffers from problems such as low productivity, inefficiency, rework, conflicts, high costs, and lengthy project durations. These problems are caused by organizational, commercial, and operational issues inherent in the current project delivery systems. The integrated project delivery method was designed to address these issues.

To achieve the goals of lean management, the strategic project delivery method also incorporates target value delivery, which is a collection of interrelated tools used in an ongoing process (Zimina et al., 2012). Brioso (2015) described target value delivery as a structured management approach implemented throughout a project to ensure that the facility meets the users' operational values, remains within the estimated budget, and fosters improvement to generate value and reduce waste.

In addition, target value delivery is a construction management method that prioritizes clients' value in the design process while minimizing waste and ensuring that the overall cost of planning and constructing a facility remains within a predetermined budget. It is an expanded version of target costing developed specifically for the construction industry. The aim of target value delivery and similar business arrangements is not to transfer risk, but rather to understand and share it, with techniques for risk reduction embedded into the organization and operating system (Zimina et al., 2012; Dave et al., 2013).

Therefore, it is hypothesized that the two methods of agile project management and lean construction can work together to increase the potential of construction practices and address practical difficulties by demonstrating that the principles and techniques of both these methods can be more successfully utilized to each other's construction practices (Raedemaecker et al., 2020).

4.3 Modern methods of construction

Building information modelling (BIM) is rapidly being adopted by various businesses, and some of them have become proficient in using BIM to improve and collaborate on project processes. As a result, combining BIM with lean building practices leads to even greater benefits (Dave et al., 2013). To effectively manage construction risk, Tserng et al. (2009) suggested that construction must be conducted in a formal and systematic manner that aligns with a business's requirements. Audits and records can be utilized to update the knowledge database of risk management, resulting in improved resource management performance and the achievement of knowledge reuse objectives.

Dave et al. (2013) claimed that the integration of BIM and lean construction is a promising approach to improve productivity and diversity, as the lean methodology highlights the significance of continuous improvement and examination in production. However, any programme that involves changes in business practices, advanced tools, technologies, or processes, as well as the implementation of changed plans and obtaining support from employees and partners, carries inherent risks.

According to Raedemaecker et al. (2020), there is a common misconception that organizations must choose between agile and lean management methods, as these approaches are thought to have distinct ideas and practices. However, they argue that agile project management and lean management share the same basic principles and innovative concepts. These principles include a customer focus, value creation, efficient processes, continuous improvement, clear goals and plans, and collaborative innovation involving working teams.

5 Conclusion

The construction industry is facing critical challenges that need to be addressed, such as poor productivity and cost and time overruns due to inadequate risk management. This study proposes a new model for risk management in housing projects that integrates MMC with agile project management and lean construction. The adoption of this model can improve project performance and ensure successful completion of project objectives. A multidisciplinary approach, which includes a systematic literature review, knowledge-based system design, questionnaire-based surveys, and case studies using both qualitative and quantitative methods, has been used to achieve this goal. The ALC system aims to introduce innovation and excellence in construction project delivery by assisting project managers in making informed decisions regarding project risk management. By adopting the ALC system, project managers can effectively manage risks and enhance the overall efficiency of construction projects. It is anticipated that this research will contribute to the advancement of risk management practices in the building industry and promote the adoption of MMC to address the industry's challenges.

6 References

Abdirad, H., & Dossick, C. S. (2016). BIM curriculum design in architecture, engineering, and construction education: A systematic review. *Journal of Information Technology in Construction (ITcon)*, *21*(17), 250–271.

Ahmed, M. N., & Mohammed, S. R. (2019). Developing a risk management framework in construction project based on agile management approach. *Civil Engineering Journal*, *5*(3), 608–615. https://doi.org/10.28991/cej-2019-03091272

Alarcón, L. (Ed.) (1997). *Lean construction*. CRC Press. https://doi.org/10.1201/9781482287356

Amade, B., Ononuju, C. N., Obodoh, D., Okorie, C. E., & Tech, B. (2019). Barriers to lean adoption for construction projects. *Pacific Journal of Science and Technology*, *20*, 153–166.

Akintoye, A. S., & MacLeod, M. J. (1997). Risk analysis and management in construction. *International Journal of Project Management*, *15*(1), 31–38. https://doi.org/10.1016/S0263-7863(96)00035-X

Bazán, D., Pinedo, M., Rojas, J., & Raymundo, C. (2019, August, 22–24). Project planning methodology based on lean philosophy and PMBOK guidelines for SMEs in the electricity sector. In *Proceedings of the 1st International Conference on Human Interaction and Emerging Technologies (IHIET 2019)* (pp. 849–855), Nice, France. Springer. https://doi.org/10.1007/978-3-030-25629-6_133

Bertelsen, S. (2003, July). Construction as a complex system. In *Proceedings of the 11th Annual Conference of the International Group for Lean Construction* (pp. 11–23), Virginia. https://www.iglc.net/papers/details/231

Burlereaux, M., Gauthier, S., & Rieu, C. (2013). Agile: An iron fist in a velvet glove. *The Journal of Modern Project Management*, *1*(1), 56–69.

Brioso, X. (2015). Integrating ISO 21500 guidance on project management, lean construction and PMBOK. *Procedia Engineering*, *123*, 76–84. https://doi.org/10.1016/j.proeng.2015.10.060

Bryman, A. (2016). *Social research methods*. Oxford University Press.

Cho, S., & Ballard, G. (2011). Last planner and integrated project delivery. *Lean Construction Journal*, *2011*, 67–78.

Davies, A., Bagust, P., & Basquill, A. M. (2018). *Modern methods of construction: A forward-thinking solution to the housing crisis?* Royal Institution of Chartered Surveyors. https://www.buildoffsite.com/content/uploads/2019/04/modern-methods-of-construction-paper-rics.pdf

Dave, B., Koskela, L., Kiviniemi, A., Tzortzopoulos, P., & Owen, R. (2013). *Implementing lean in construction: Lean construction and BIM [CIRIA Guide C725]*. Construction Industry Research and Information Association. https://s3.eu-west-2.amazonaws.com/assets.highwaysengland.co.uk/specialist-information/knowledge-compendium/2011-13-knowledge-programme/Lean%20Construction%20and%20BIM.pdf

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. In D. A. Buchanan & A. Bryman (Eds.), *The SAGE handbook of organizational research methods* (pp. 671–689). SAGE Publications.

Demir, S. T. (2013). *'AgiLean PM': A unifying strategic framework to manage construction projects*. Liverpool John Moores University. https://researchonline.ljmu.ac.uk/id/eprint/4509/

El-Diraby, T. A., Lima, C., & Feis, B. (2005). Domain taxonomy for construction concepts: toward a formal ontology for construction knowledge. *Journal of Computing in Civil Engineering*, *19*(4), 394–406. https://doi.org/10.1061/(ASCE)0887-3801(2005)19:4(394)

El-Diraby, T. E. (2006). Web-services environment for collaborative management of product life-cycle costs. *Journal of Construction Engineering and Management*, *132*(3), 300–313. https://doi.org/10.1061/(ASCE)0733-9364(2006)132:3(300)

El-Diraby, T. E., & Zhang, J. (2006). A semantic framework to support corporate memory management in building construction. *Automation in Construction*, *15*(4), 504–521. https://doi.org/10.1016/j.autcon.2005.07.005

Eshaq, A. R. M., & Karboulonis, P. (2003). Design considerations for the design of an advanced VR interface for knowledge management and its relevance to CAD. *Automation in Construction*, *12*(5), 501–507. https://doi.org/10.1016/S0926-5805(03)00036-0

Farmer, M. (2016). *Modernise or die: Time to decide the industry's future. The farmer review of the UK construction labour model*. Construction Leadership Council. https://www.constructionleadershipcouncil.co.uk/wp-content/uploads/2016/10/Farmer-Review.pdf

Fidan, G., Dikmen, I., Tanyer, A. M., & Birgonul, M. T. (2011). Ontology for relating risk and vulnerability to cost overrun in international projects. *Journal of Computing in Civil Engineering*, *25*(4), 302–315. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000090

Fox, M. S., & Grüninger, M. (1998). Enterprise modeling. *AI magazine*, *19*(3), 109–109.

Hennink, M., Hutter, I., & Bailey, A. (2020). *Qualitative research methods*. SAGE Publications.

Hong, P., Yang, M. G. M., & Dobrzykowski, D. D. (2014). Strategic customer service orientation, lean manufacturing practices and performance outcomes: an empirical study. *Journal of Service Management*, *25*(5), 699–723. https://doi.org/10.1108/JOSM-12-2013-0355

Hodgson, D., & Cicmil, S. (2006). Are projects real? The PMBOK and the legitimation of project management knowledge. In *Making projects critical* (pp. 29–50). Palgrave MacMillan. https://doi.org/10.1007/978-0-230-20929-9_2

International Organization for Standardization. (2009–11). *ISO Guide 73:2009 Risk Management – Vocabulary*. ISO/TMBG. https://www.iso.org/standard/44651.html

International Organization for Standardization. (2018–20). *ISO 31000:2018 Risk Management – Guidelines*. ISO/TC. https://www.iso.org/iso-31000-risk-management.html

Issa, U. H. (2013). Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Engineering Journal*, *52*(4), 697–704. https://doi.org/10.1016/j.aej.2013.07.003

Jensen, C., (2014). *Risk analysis and management for projects* (3rd ed). Institution of Civil Engineers and Institute and Faculty of Actuaries.

Kartam, N. A., & Kartam, S. A. (2001). Risk and its management in the Kuwaiti construction industry: A contractors' perspective. *International Journal of Project Management*, *19*(6), 325–335. https://doi.org/10.1016/S0263-7863(00)00014-4

Klakegg, O. J., Torp, O., Kalsaas, B. T., Bølviken, T., & Hannås, G. (2020). Uncertainty management: A development area for lean construction. In *Lean construction: Core concepts and new frontiers* (pp. 361–386). Routledge. https://doi.org/10.1201/9780429203732-18

Lewis, H., Allan, N., Ellinas, C., & Godfrey, P. (2014) *Engaging with risk [CIRIA C747]*. Construction Industry Research and Information Association. https://www.ciria.org/CIRIA/CIRIA/Item_Detail.aspx?iProductCode=C747F&Category=FREEPUBS

Nikakhtar, A., Hosseini, A. A., Wong, K. Y., & Zavichi, A. (2015). Application of lean construction principles to reduce construction process waste using computer simulation: a case study. *International Journal of Services and Operations Management*, *20*(4), 461–480. https://doi.org/10.1504/IJSOM.2015.068528

Pandit, A., & Zhu, Y. (2007). An ontology-based approach to support decision-making for the design of ETO (engineer-to-order) products. *Automation in Construction*, *16*(6), 759–770. https://doi.org/10.1016/j.autcon.2007.02.003

Project Management Institute. (2008). *A guide to the project management body of knowledge* (4th ed.). https://www.pmi.org/pmbok-guide-standards/foundational/PMBOK

Project Management Institute. (2013). *A guide to the project management body of knowledge* (5th ed.). https://www.pmi.org/pmbok-guide-standards/foundational/PMBOK

Raedemaecker, S., Handscomb, C., Jautelat, S., Rodriguez, M., and Wienke, L. (2020). *Lean management or agile? The right answer maybe both*. McKinsey & Company.

Salem, O., Solomon, J., Genaidy, A., & Minkarah, I. (2006). Lean construction: From theory to implementation. *Journal of Management in Engineering*, *22*(4), 168–175. https://doi.org/10.1061/(ASCE)0742-597X(2006)22:4(168)

Sheffield, J., & Lemétayer, J. (2013). Factors associated with the software development agility of successful projects. *International Journal of Project Management*, *31*(3), 459–472. https://doi.org/10.1016/j.ijproman.2012.09.011

Sohi, A. J., Hertogh, M., Bosch-Rekveldt, M., & Blom, R. (2016). Does lean & agile project management help coping with project complexity? *Procedia Social and Behavioral Sciences*, *226*, 252–259. https://doi.org/10.1016/j.sbspro.2016.06.186

Ten Ham-Baloyi, W., & Jordan, P. (2016). Systematic review as a research method in postgraduate nursing education. *Health SA Gesondheid*, *21*(1), 120–128. https://doi.org/10.4102/hsag.v21i0.942

Tserng, H. P., Yin, S. Y., Dzeng, R. J., Wou, B., Tsai, M. D., & Chen, W. Y. (2009). A study of ontology-based risk management framework of construction projects through project life cycle. *Automation in Construction*, *18*(7), 994–1008. https://doi.org/10.1016/j.autcon.2009.05.005

Tah, J. H., & Carr, V. (2001). Knowledge-based approach to construction project risk management. *Journal of Computing in Civil Engineering*, *15*(3), 170–177. https://doi.org/10.1061/(ASCE)0887-3801(2001)15:3(170)

Tzortzopoulos, P., Kagioglou, M., & Koskela, L. (Eds.). (2020). *Lean construction: Core concepts and new frontiers*. Routledge. https://doi.org/10.1201/9780429203732

Zimina, D., Ballard, G., & Pasquire, C. (2012). Target value design: using collaboration and a lean approach to reduce construction cost. *Construction Management and Economics*, *30*(5), 383–398. https://doi.org/10.1080/01446193.2012.676658

Sustainable Developments

The role and feasibility of urban agriculture in addressing food insecurity challenges in Nigeria

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Abstract: Due to the rising population in urban areas worldwide and an estimated 10 billion people by the year 2050, there is a need to rethink our relationship with food. The prevalence of poverty and hunger is a major concern as food produced from rural areas is no longer enough to meet the needs of the increasing population. The effects of the coronavirus pandemic were evident on global food systems as the restrictions obstructed the ease of movement of people and products, resulting in reduced access to agricultural labour. Interest in urban agriculture (UA) has increased since the pandemic. The practice of UA has gained relative success in the Global North, but the same cannot be said of the Global South as there are limiting factors such as urban planning, land availability, and policy changes due to government administration. Generally, UA has a long history in Nigeria, but its formal practice has been limited and relatively scarce. This research appraises UA in Nigeria by exploring existing practices and its future and upscaling potential. This study adopts a qualitative research methodology to critically compare approaches to city food growing. Some clear indications demonstrate the lack of adequate enlightenment to new methods of UA, non-inclusion of UA in planning and zoning, and lack of favourable policies. Lack of innovative UA practices, education, planning and zoning exclusion, and supportive regulations and incentives are evident. Food insecurity has increased the government's and young people's interest in UA. This increased interest contradicts prior research and strongly indicates that UA has tremendous potential in Nigeria.

Keywords: food security, food sustainability, urban agriculture, urban farming

Acknowledgements: The first author expresses gratitude to their supervisors for consistent support to help professional growth. The range of Professor Michael Hardman and Andrew Clark's expertise and experience is invaluable to this study.

1 Introduction: Increased demand for food

Major stakeholders are driving the need for urban agriculture (UA) around the world (Tornaghi & Certomà, 2019; Hume et al., 2021). This increase is due to fast-growing population-related food security issues (Broom & Breene, 2020). The Food and Agricultural Organization (FAO, 2020) says there are significant challenges to addressing food insecurity and malnutrition and is looking for ways to end poverty and hunger. Population growth has increased competition for vital resources, especially in cities (Chipungu et al., 2015), prompting the need to produce food while promoting sustainable cities in urban areas (Dona et al., 2021). UA is the practise of producing food in urban spaces for human consumption, including crop production, animal husbandry, and crop-livestock combinations (Halvey et al., 2021). UA activities range in size and type, and can include individual households, community, and allotment gardens; urban farms, indoor, vertical, and rooftop farms; and hydroponics and aquaponics facilities (Dos Santos, 2016). This study explores UA practices and the potential for upscaling them in Nigeria. It reflects on data from case studies across a wide range of urban farm types and explores the opportunities and barriers to setting up large-scale city farms.

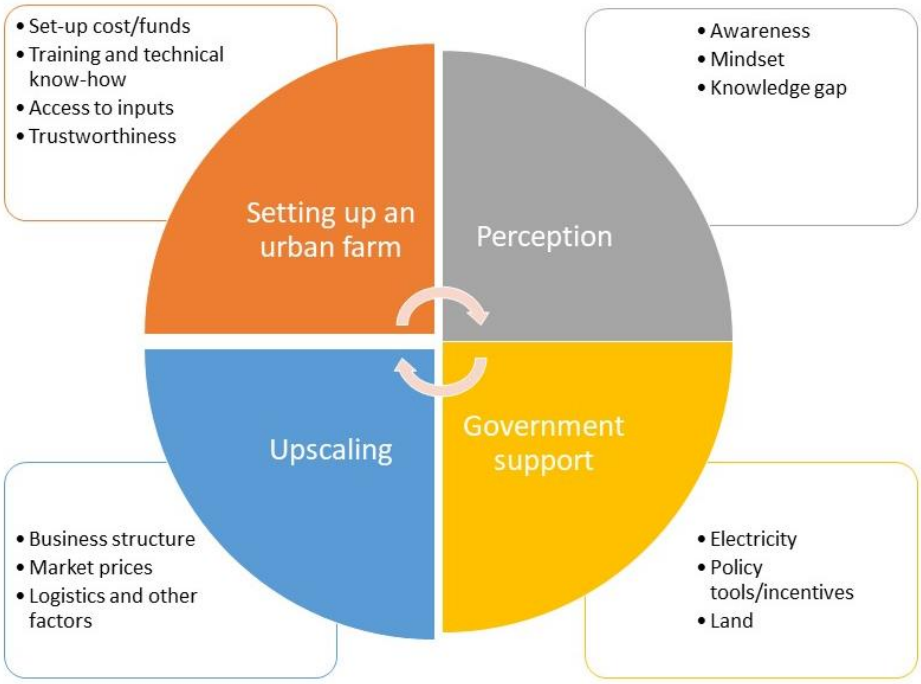
2 Need for UA

Due to the fast rate of urbanization and the impact it has on food security in cities, particularly in the Global South nations (Gwan & Kimengsi, 2020), some experts have urged additional study into the concept of UA for preserving food supply in urban areas (Diehl et al., 2020). Fruit and vegetable crops are grown through UA in the Global North on a variety of land types (Orsini et al., 2013), including plots that are allocated, home gardens, communal spaces, and gardens located in market spaces (Schmutz et al., 2018). Public and private land, as well as vacant lots, open fields, and greenhouses, are all used in the Global South for UA (Olumba et al., 2019). Furthermore, people across the world use UA for different reasons; unlike in the Global South, where UA is undertaken for food availability and alleviating poverty, it is more commonly engaged in by those in the Global North for leisure or social purposes (Zezza & Tasciotti, 2010).

Rapid urbanization is happening globally (Arbolino et al., 2018). The World Health Organization (WHO, 2015) forecasts that the mean annual growth rate in cities in the Global South is four times that in cities in the Global North. Sub-Saharan African cities are expected to grow at a pace of 4.1%, above the world average of 1.84%. (WHO, 2015). With an annual growth rate of 4.3%, Nigeria's urban population is expected to double by 2037 (United Nations – Department of Economic and Social Affairs [UN-DESA], 2018). Small to medium growing sites increased food production to meet demand during the pandemic and this brought more attention to UA (Schoen et al., 2021).

Academic literature has demonstrated UA's social, environmental, health, and economic advantages. UA leads to food sufficiency in households and enhanced nutritional variety (Alimba et al., 2018); Minimizing food miles between production and consumption may also help maintain food production and supply (Ackerman, 2012). It offers a means of livelihood for urban farmers and other service providers (Binns & Nel, 2019). UA reduces greenhouse gas emissions and energy consumption by reducing food miles; while trees enhance the urban environment and may mitigate climate change in certain agricultural systems (De Zeeuw et al., 2011). Despite a post-pandemic surge in UA practices in the Global South, the sector faces many constraints that limit upscaling. These include inadequate government support, setup costs, perception, and other factors affecting upscaling of UA practice (Figure 1).

Figure 1: Summary of barriers affecting UA practice in Nigeria



Source: Authors' own.

2.1 Background

Nigeria has the highest population in Africa, estimated at 215 million with 52% of the population residing in urban areas (UN-DESA, 2019). Lagos is the largest city in Nigeria and sub-Saharan Africa has an estimated population of about 9 million, justifying the need to upscale UA (Abou Kamer et al., 2022). This study provides a critical assessment of the potential for upscaling UA using Lagos, Nigeria, as a case study. It presents an analysis of qualitative data compiled from a wide range of UA sites, exploring stakeholders' opinion, opportunities, and barriers to setting up. The study contributes to the growing body of literature on UA in the Global South region and it is expected that the outcomes will be of interest to policy makers, consultants, and researchers exploring the prospect of UA in feeding the urban population.

3 Methodology

The aim of this study is to critically appraise UA activities and its upscaling future potential. The goal is to critically explore current UA practices while identifying enabling policy tools that supports UA's potential for upscaling. Furthermore, the research aims to characterize different stakeholders' perception towards UA, ascertain barriers affecting UA, and identify the impact of UA practices on food security. Data were collected anonymously because of the nature of the research that aims to explore the perception of stakeholders. The spectrum of sites captured shows a recent increase in the adoption of new farming urban methods and improved awareness about these new practices (Alimba et al., 2018). In addition to this, the research reflects on the barriers affecting attempts to upscale and the government's influence.

This study explores urban farming practices in Lagos, Nigeria, using a qualitative approach. The methodology used participant observation, online qualitative survey, and semi-structured interviews to garner a range of responses and insights into various areas of interest. The semi-structured interviews used a case study approach selected from each of the categories in Table 1. Four urban farmers were interviewed in each of these categories alongside other key stakeholders. These urban farms were majorly cultivated for food production and for individual household consumption needs (Caputo et al., 2020).

Table 1: The categories of urban farms explored

Size	Type of urban farm	Activities
Small	Informal growing	Backyard gardening, guerrilla gardening
Medium	Community growing	Crop farming such as vegetable and mushroom farming, livestock farming including snail, poultry, fish, piggery, and beekeeping
Large	Urban farms/high-tech growing sites	Hydroponics, aquaponics, aeroponics, vertical farming, greenhouses

Source: Authors' own.

3.1 Participant characteristics

A total of 20 participants were interviewed for this research; data collection and analysis stopped when no new information was discovered, and further data collection was unnecessary. The sample size of respondents was influenced by the grounded theory's principle of saturation, a concept that is commonly used in qualitative research for this purpose (Silverman, 2017). The sample was achieved using snowball sampling where research participants help to identify other potential subjects.

Semi-structured interviews were the main tool used to gather responses from stakeholders, building upon observations and themes from the objectives of the research. The main themes explored were centred around perception, barriers, and opportunities for improving awareness of UA practices. The variety of stakeholders ranged from urban farmers, urban residents, consumers, policymakers/government officials, and non-governmental organizations to private funders to enable an in-depth exploration of views. The participants' gender was mostly male (17 out of 20) with age ranges between 25 and 40 years, and all were resident in Lagos, Nigeria.

4 Results and discussion

This section analyses and discusses the core themes from the qualitative study before ascertaining the barriers, opportunities to upscale, and the future potential of UA. As emphasized earlier, the recent surge in interest in UA in Nigeria is largely linked to increased awareness of the state of food insecurity in the country (Houessou et al., 2020). This shows the need for more critical assessment in this region with emphasis on encouraging the use of the right practices that are best suited for upscaling, serving as a basis for further research in sub-Saharan Africa and the wider continent.

4.1 Increased interest in UA

The increased interest in the practice of UA in Nigeria is by the youths who also constitute a substantial percentage of the total population at approximately 53.77% (UN-DESA, 2019). These young people were initially not interested in traditional farming methods because these were deemed stressful as practising the techniques needed large expanses of land and travelling long distances to rural areas. However, there has been an increased awareness of the state of food insecurity in the country as well as an increased rate of migration of people from rural to urban areas (United Nations, 2016). This migration is caused by a myriad of factors including but not limited to banditry, increased rate of insurgency, kidnappings, killings, and farms being burnt down during feuds (Abagale et al., 2013; Johnson & Ifeoma, 2018). Another factor driving the interest in UA is the notion that the practice can be easily combined with other personal endeavours as it requires less time (Urban farmer).

Some participants indicated that by using greenhouses it is possible to overcome the problem of adverse weather conditions such as extreme drought or rainfall, which might help to enhance food security (Urban farmer). Furthermore, there is increased knowledge sharing as people learn more about alternative methods of farming that are feasible and result in healthier produce.

> [. . .] because people are more health conscious now and you know most of these new urban farming produce are organic. (Urban farmer)

It is notable that there has been an increased awareness of healthy eating in Nigeria as people are becoming more health conscious and most foods produced from UA are organic produce (Soper, 2021). This can only be possible with increased awareness and increased participation by all. Some people practice UA as a status symbol and have inadvertently raised awareness for the practice of UA because it piques people's interest in wanting something they do not have (Urban resident).

4.2 UA, food security, and sustainability

A good majority of the participants interviewed shared the view that UA has the immense potential to alleviate food insecurity in Nigeria (Urban farmers); however, the agricultural sector is currently burdened with the imposition of several government bans, which has a negative impact on the importation of materials needed for agricultural practice (Oyekanmi & Moliki, 2021). Most participants believe that UA can help achieve food sustainability as individuals can practise small-scale urban farming. This implies that individuals can sustain themselves by producing food for their families in a way that is not wasteful or detrimental to the environment. They believe UA can be practised in the safety of the home with little need for government support as a wide range of vegetables that can be consumed daily can be planted. This impact of UA might be noticeable even on a small scale as individual sustainability can be achieved if people are encouraged to embrace this practice (Aduloju et al., 2021).

> Yes, it has the potential to achieve food security. The impact might still be very little because of the scale that it is. (Hydroponics farmer)

> The impact on food security may not be on a large scale, but somehow it has an impact. If everyone is encouraged to plant one thing or the other, it would assist in food security. (Community farmer)

> Yes, it holds great potential, especially with the system that we've adopted. (Urban farmer)

Some other participants shared a dissenting view on the impact of the current state of UA. They suggested it will take a longer period for its impact to be truly felt because of the challenges being faced by the agricultural sector, such as the cost of start-up (Soil-less farmer). Furthermore, it is believed that a household cannot grow everything it needs within the urban space; food is perishable and can go bad within a short time if storing conditions are not maintained. These participants also opined that the number of farmers engaging in UA is too few to achieve food sustainability. Rural and urban spaces depend on each other to create a sustainable environment.

It is generally believed that the impact of UA in relation to dealing with food insecurity in the country can eventually be felt because Nigeria is a huge country with a lot of young people whose interest in UA practice is increasing. These young people are enthusiastic and believe that UA can help with the food insecurity situation in the country. They believe that UA helps with food production by producing quality food at a faster rate within a small space (McDougall et al., 2019). Narratives from the past have shown that if everyone embraced UA within the confines of their individual spaces, it would only be a matter of time before a significant impact can be felt (Wan et al., 2018). However, it is important to recognize that such benefits may be curtailed by factors such as limitations on supply of inputs. The government of Nigeria has noted recent increased interest in the practice of UA from the massive number of growers who were unable to access agriculture input in the last planting season.

> [. . .] the tonnes of seed sold this year alone—we have not sold that amount in more than two years. (Government official)

4.3 Limiting factors associated with UA practice

During this research, the most significant barrier that was conspicuously highlighted by the farmers was the prevailing incidence of poverty in the country.

> Another thing is the enabling environment; human beings are struggling to eat, and animals too are struggling for the same. (Small-scale urban farmer)

As reported by Nigeria's National Bureau of Statistics (2020), 40% of the total population lives below the country's poverty line of US$381.75 per year. In addition to this, the situation in Nigeria was classed as an area that does not necessarily provide an enabling environment for UA practice on a large scale, as there are several limiting factors (see Figure 1).

The practice of UA, therefore, is seen as a mode of promoting the survival of the person(s) rather than the production of food on a large economic and viable scale with the capacity to garner a boom in economic turnover. It is classed as UA in theory, bearing all UA's characteristics and semblance; however, reality suggests it is more subsistent in practice. It is apposite to note that the practice of UA in Nigeria is hampered by people farming to feed for calories as against feeding for nutritional value that is one of the biggest proponents of UA (Morgan & Fanzo, 2020).

> In this part of the world, we think calories over nutrition. One is just interested in filling up his stomach and doesn't care whether what he's eating has any benefits [to add] to his body. (Community farmer)

In Nigeria, there is a saying that implies people are more concerned with having eaten – mostly attributed to the high rate of poverty and malnutrition – than with the quality of what they have eaten. This readily denotes the extent of the limiting factors that invariably affect the quality of food produced and the scale within which it is produced.

4.3.1 Start-up cost

Setting up an urban farm is expensive since materials are mostly imported. The government provides funds for farmers, but they are lost in transit by intermediaries tasked with distributing them because they sometimes divert the funds for personal use. This leads to low-quality setups as the funds that reach the farmers are reduced. In addition, there is a lack of information about grants and their processes. Even when available, these grants have arduously complex and tedious processes that make accessing and utilizing them difficult for farmers.

> The major issue is that most people often get discouraged by the tedious processes involved in applying for a grant and some have short deadlines. (Soil-less farmer)

Inputs such as seeds and seedlings used in UA are usually exotic and are not readily available in Nigeria. There are few or no companies that produce these seeds locally, thus making the farmers wholly reliant on importing these seeds, which is unaffordable and not sustainable in the long term. Government-imposed bans have affected the importation of these materials (Oyekanmi & Moliki, 2021) along with supply chain disruptions due to the pandemic. These bans also affected farmers who were unable to import nutrients for their hydroponics farms. There is also a need to bridge the knowledge gap by getting people to understand the workings of the new processes. This is a challenge when seasoned experts are unwilling to pass on their knowledge to others for fear of losing their relevance.

> [. . .] and a lot of people were reluctant to answer questions or share knowledge with people who didn't do them any favours . . . so there is no definite place to go to access information for all farmers in different localities or community. (Soil-less farmer)

It is imperative for new farmers to bring in people well versed in the processes relating to the practice of UA. This largely relates to employing personnel who have the requisite skills and providing the necessary staff training to operate the equipment and machinery.

4.3.2 Market pricing, structure, and upscaling

Access to open markets affects urban farmers' food prices because they compete with rural farmers. Urban farmers tend to produce more costly food than rural farmers, increasing market competition (Alemu & Grebitus, 2020). Lack of organization and collaboration among farmers leads to non-uniform pricing. Urban farmers set unequal prices to outdo each other, causing market price fluctuations; this is often influenced by how they set up their farms.

The proportion of UA upscaling is low because of government space restrictions. Lack of space (Huang et al., 2015) has limited the number of large-scale urban farmers, reducing their impact. Some delicate and readily perishable agricultural food might be spoilt by logistics due to commuting limitations. Some drivers plan and divert the produce with the connivance of people, citing banditry as the main reason for the loss of goods they are contracted to transport. Bad roads also make it harder to transport goods from source to consumers. Reducing the distance perishable foods travel reduces transaction costs and food waste (Lynch et al., 2013).

4.3.3 Government support

There is very little land available in urban areas for the sustainable practice of UA and the limited spaces available are very expensive (Frayne et al., 2014). Most land available in urban areas is peri-urban as spaces are in zones transitioning from rural to urban and are in the outskirts of urban areas. The government prefers real estate as it is seen as more economical than agricultural land, and the profit margin potential is considerably higher because of the high influx of people into these urban centres that are seen as hubs for economic growth.

Many of the participants interviewed stated that they were unaware of any government policies and incentives supporting UA; this might be because policies are not general topics of discussion in Nigeria owing to the overwhelming lack of trust in the government.

> I don't know of any policy that supports urban agriculture. (Small-scale urban farmer)

> No, I don't know any land use policy that supports urban agriculture maybe because policies are not something people talk about in Nigeria. (Soil-less farmer)

The few that were aware of such government policies and incentives stated that such incentives were usually not enough. They alluded to several reasons that included and were not limited to people in charge of the allocation of these incentives hijacking the incentives for personal use, thereby truncating the effect of what was disbursed by the government. The government often makes policies but seldom enforces these policies; there are also instances where policies created often have adverse effects on previously formulated policies while trying to protect other sectors (Adenubi et al., 2021).

4.4 Enabling upscaling practice

It is apparent that the government of Nigeria is showing increased interest in UA and is beginning to identify the impact of UA on food security and sustainability (Wolf et al., 2022). There is also a gradual shift in the perception of the citizens as they are beginning to ask more questions, especially about the profitability of UA as opposed to total rejection of the idea earlier.

To tackle the issues of setting up an urban farm, such as the high cost or purchase and importation of materials as well as limited access to funds, urban farmers have devised several ways of using and adapting locally sourced and available materials to set up their farms. As a result of the inaccessibility of materials for setting up their farms, farmers were forced to look for alternative ways to replicate the urban growing system to ensure continuity in their businesses. Some of these alternatives avoid reliance on electricity, which is still a major problem in the country. One of the driving mindsets of this traditional innovation is that it creates an alternative by reducing the need for importing the technology. This also creates an avenue to raise awareness as people are more inclined to show interest when familiar materials are used and when the extent of what can be achieved using locally available materials is seen.

There needs to be continuous education, sensitization, and correction of the people's perception of UA and how beneficial it is now and could be in the future (Ufiobor, 2017). Proper awareness of UA would be necessary to showcase its importance and effectiveness in alleviating poverty in the country. Urban farmers are also enjoined to produce perishable goods with a shorter shelf life and focusing on one area of specialization will enable them to fully optimize the benefits of that area.

5 Conclusion

This research shows that the informal sector in Nigeria drives individuals to cultivate on unauthorized land. This is largely because of the difficulty of acquiring access to land in urban areas as there are no formal land use or zoning rules for UA. Even though the Nigerian government favours UA and has provided incentives, poverty hinders its growth. In Lagos state, the government helps urban farmers with seeds, incentives, and finance opportunities, but intermediary/dealer may take most of it. Lagos state has also earmarked safe territory for urban farmers to build greenhouses. Contrary to prior study, UA in Nigeria is driven by young individuals who are motivated by its high productivity. UA can achieve household sustainability and has the potential to contribute to food security by providing output predictability, but this may not happen immediately and will need the collaboration of all parties.

Policymakers and urban planners must engage directly with urban farmers to address these issues. When stakeholders work together, meaningful change is possible (sustainable development goal, SDG 17). Policymakers and urban planners must collaborate to develop policies that promote UA and include it in land planning, as UA can effectively use urban areas (SDG 15). UA helps address several of the sustainable development objectives, including 'no poverty' and 'zero hunger'. UA creates new local food value chains, monetary flows, and marketplaces, which in turn creates jobs and reduces poverty (Berti & Mulligan, 2016). It reduces food miles, minimizing logistics-related food waste; this enhances local food production and improves nutrition as more fresh foods are accessible (Dosch et al., 2015). This may also promote the sustainability of food production in cities and communities (SDG 11); for example, an aquaponic system that recycles water and uses fish waste as plant fertilizer might generate different production lines. Finally, UA helps promote wellness at all ages (SDG 3) as green areas reduce stress and encourage community engagement.

6 References

Abagale, F. K., Sarpong, D. A., Ojediran, J. A., Osei-Agyemang, R., Shaibu, A. G., & Birteeb, P. T. (2013). Heavy metal concentration in wastewater from car washing bays used for agriculture in the tamale metropolis, Ghana. *International Journal of Current Research*, *5*(6), 1571–1576.

Abou Kamer, M. E., Khalil, G. A. N., & Yousry, M. M. (2022). Yield and quality performance of some new sweet melon lines under water stress conditions. *Journal of the Advances in Agricultural Research*, *27*(1), 148–161. https://doi.org/10.21608/jalexu.2022.114554.1036

Ackerman, K. (2012). Urban agriculture: opportunities and constraints. In F. Zeman (Ed.), *Metropolitan sustainability: Understanding and improving the urban environment* (pp. 118–146). Woodhead Publishing. https://doi.org/10.1533/9780857096463.2.118

Adenubi, O. T., Temoso, O., & Abdulaleem, I. (2021). Has mobile phone technology aided the growth of agricultural productivity in sub-Saharan Africa? *South African Journal of Economic and Management Sciences*, *24*(1), 1–9. https://doi.org/10.4102/sajems.v24i1.3744

Aduloju, O. T. B., Bako, A. I., & Anofi, A. O. (2021). Specifics knowledge links between COVID-19 and urban food systems in Nigeria. *Contemporary Social Science*, *17*(2), 157–172. https://doi.org/10.1080/21582041.2021.1955957

Alemu, M. H., & Grebitus, C. (2020). Towards sustainable urban food systems: Analysing contextual and intrapsychic drivers of growing food in small-scale urban agriculture. *PLOS ONE*, *15*(12), Article e0243949. https://doi.org/10.1371/journal.pone.0243949

Alimba, J. O., Olumba, C. C., & Onunka, C. N. (2018, October 8–10). Assessing how food production in urban areas contribute to household food security in Southeast Nigeria. In Proceedings of the 2nd

international conference on food security and hidden hunger, Alex-Ewueme Federal University, Ndufu Alike, Ebonyi State, Nigeria (pp. 6–10). https://www.researchgate.net/profile/Cynthia-Onunka/publication/339096335_Assessing_How_Food_Production_in_Urban_Areas_Contribute_To_Household_Food_Security_in_Southeast_Nigeria/links/5e3d56d0a6fdccd9658ec141/Assessing-How-Food-Production-in-Urban-Areas-Contribute-To-Household-Food-Security-in-Southeast-Nigeria.pdf

Arbolino, R., De Simone, L., Carlucci, F., Yigitcanlar, T., & Ioppolo, G. (2018). Towards a sustainable industrial ecology: Implementation of a novel approach in the performance evaluation of Italian regions. *Journal of Cleaner Production*, *178*, 220–236. https://doi.org/10.1016/j.jclepro.2017.12.183

Binns, T., & Nel, E. (2019). Urban agriculture in Zambia. In W. Leimgruber & C.-y. D. Chang (Eds.), *Rural areas between regional needs and global challenges: Transformation in rural space* (pp. 227–242). Springer. https://doi.org/10.1007/978-3-030-04393-3_13

Broom, D., & Breene, K. (2020, November 23). *This is why food security matters now more than ever*. World Economic Forum. https://www.weforum.org/agenda/2020/11/food-security-why-it-matters/

Caputo, P., Zagarella, F., Cusenza, M. A., Mistretta, M., & Cellura, M. (2020). Energy-environmental assessment of the UIA – OpenAgri case study as urban regeneration project through agriculture. *Science of the Total Environment*, *729*, Article 138819. https://doi.org/10.1016/j.scitotenv.2020.138819

Chipungu, L., Magidimisha, H. H., Hardman, M., & Beesley, L. (2015). The importance of soil quality in the safe practice of urban agriculture in Zimbabwe, Kenya and South Africa. In F. Q. Brearley & A. D. Thomas (Eds.), *Land-use change impacts on soil processes: Tropical and savannah ecosystems* (Chapter 7, pp. 72–84). CABI Publishing. https://doi.org/10.1079/9781780642109.0072

De Zeeuw, H., Van Veenhuizen, R., & Dubbeling, M. (2011). The role of urban agriculture in building resilient cities in developing countries. *The Journal of Agricultural Science*, *149*(S1), 153–163. https://doi.org/10.1017/S0021859610001279

Diehl, J. A., Sweeney, E., Wong, B., Sia, C. S., Yao, H., & Prabhudesai, M. (2020). Feeding cities: Singapore's approach to land use planning for urban agriculture. *Global Food Security*, *26*, Article 100377. https://doi.org/10.1016/j.gfs.2020.100377

Dona, W., C. G., Mohan, G., & Fukushi, K. (2021). Promoting urban agriculture and its opportunities and challenges—a global review. *Sustainability*, *13*(17), Article 9609. https://doi.org/10.3390/su13179609

Dos Santos, M. J. P. L. (2016). Smart cities and urban areas – Aquaponics as innovative urban agriculture. *Urban Forestry & Urban Greening*, *20*, 402–406. https://doi.org/10.1016/j.ufug.2016.10.004

Dosch, F., Haury, S., Skowski, J., Wahler, B., Willinger, S., Arndt, T., . . . Mösch, S. (2015). *Grün in der Stadt – Für eine lebenswerte Zukunft* [*Green in the city – for a future worth living in*]. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB).

Berti, G., & Mulligan, C. (2016). Competitiveness of small farms and innovative food supply chains: The role of food hubs in creating sustainable regional and local food systems. *Sustainability*, *8*(7), Article 616. https://doi.org/10.3390/su8070616

FAO. (2020). *FAOSTAT*. Food and Agriculture Organization (FAO), Rome, Italy. https://www.fao.org/faostat/en/#data

Frayne, B., McCordic, C., & Shilomboleni, H. (2014). Growing out of poverty: Does urban agriculture contribute to household food security in Southern African cities? *Urban Forum*, *25*(2), 177–189. https://doi.org/10.1007/s12132-014-9219-3

Gwan, A. S., & Kimengsi, J. N. (2020). Urban expansion and the dynamics of farmers' livelihoods: Evidence from Bamenda, Cameroon. *Sustainability*, *12*(14), Article 5788. https://doi.org/10.3390/su12145788

Halvey, M. R., Santo, R. E., Lupolt, S. N., Dilka, T. J., Kim, B. F., Bachman, G. H., . . . & Nachman, K. E. (2021). Beyond backyard chickens: a framework for understanding municipal urban agriculture policies in the United States. *Food Policy*, *103*, Article 102013. https://doi.org/10.1016/j.foodpol.2020.102013

Houessou, M. D., van de Louw, M., & Sonneveld, B. G. (2020). What constraints the expansion of urban agriculture in Benin? *Sustainability*, *12*(14), Article 5774. https://doi.org/10.3390/su12145774

Huang, Y., Li, T., Wu, C., He, Z., Japenga, J., Deng, M., & Yang, X. (2015). An integrated approach to assess heavy metal source apportionment in peri-urban agricultural soils. *Journal of Hazardous Materials*, *299*, 540–549. https://doi.org/10.1016/j.jhazmat.2015.07.041

Hume, I. V., Summers, D. M., & Cavagnaro, T. R. (2021). Self-sufficiency through urban agriculture: Nice idea or plausible reality? *Sustainable Cities and Society*, *68*, Article 102770. https://doi.org/10.1016/j.scs.2021.102770

Johnson, K. E., & Ifeoma, U. (2018). Rural development as a panacea for rural–urban migration in Nigeria. *Arts & Humanities Open Access Journal*, *2*(5), 241–244. https://doi.org/10.15406/ahoaj.2018.02.00065

Lynch, K., Maconachie, R., Binns, T., Tengbe, P., & Bangura, K. (2013). Meeting the urban challenge? Urban agriculture and food security in post-conflict Freetown, Sierra Leone. *Applied Geography*, *36*, 31–39. https://doi.org/10.1016/j.apgeog.2012.06.007

McDougall, R., Kristiansen, P., & Rader, R. (2019). Small-scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(1), 129–134. https://doi.org/10.1073/pnas.1809707115

Morgan, A. E., & Fanzo, J. (2020). Nutrition transition and climate risks in Nigeria: Moving towards food systems policy coherence. *Current Environmental Health Reports*, *7*(4), 392–403. https://doi.org/10.1007/s40572-020-00292-3

National Bureau of Statistics. (2020). *Nigerian Living Standards Survey 2018–19*. https://nigerianstat.gov.ng/nada/index.php/catalog/68/study-description

Olumba, C. C., Alimba, J. O., & Tasie, O. (2019, February). *Assessing the factors influencing access to land for urban agriculture in southeast Nigeria*. Policy Research Brief 116, Nigeria Agricultural Policy Project. Department of Agriculture, Food, and Resource Economics.

Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*, *33*(4), 695–720. https://doi.org/10.1007/s13593-013-0143-z

Oyekanmi, A. A., & Moliki, A. O. (2021). An examination of gender inequality and poverty reduction. *Journal of Sustainable Development in Africa*, *23*(1), 31–43.

Schmutz, U., Kneafsey, M., Kay, C. S., Doernberg, A., & Zasada, I. (2018). Sustainability impact assessments of different urban short food supply chains: Examples from London, UK. *Renewable Agriculture and Food Systems*, *33*(6), 518–529. https://doi.org/10.1017/S1742170517000564

Schoen, V., Blythe, C., Caputo, S., Fox-Kämper, R., Specht, K., Fargue-Lelièvre, A., . . . & Fedeńczak, K. (2021). 'We have been part of the response': The effects of COVID-19 on community and allotment gardens in the Global North. *Frontiers in Sustainable Food Systems*, *5*. https://doi.org/10.3389/fsufs.2021.732641

Silverman, D. (2017). How was it for you? The Interview Society and the irresistible rise of the (poorly analysed) interview. *Qualitative Research*, *17*(2), 144–158. https://doi.org/10.1177/1468794116668231

Soper, R. (2021). How health-conscious urban gardeners aim to increase vegetable consumption in their community while simultaneously supporting Black entrepreneurship. *Journal of Agriculture, Food Systems, and Community Development*, *10*(2), 413–430. https://doi.org/10.5304/jafscd.2021.102.029

Tornaghi, C., & Certomà, C. (Eds.) (2019). *Urban Gardening as Politics*. Routledge. https://doi.org/10.4324/9781315210889

Ufiobor, A. K. (2017). *Nigeria agriculture and sustainability: Problems and solutions*. Thesis for Bachelor of Sustainable Coastal Management, Novia University of Applied Sciences. https://www.theseus.fi/bitstream/handle/10024/132525/Ufiobor_Kelvin.pdf.pdf?sequence=1

United Nations. (2016). *Food security and nutrition and sustainable agriculture*. https://sustainabledevelopment.un.org/topics/foodagriculture

United Nations, Department of Economic and Social Affairs, Population Division (UN-DESA). (2018). *World urbanization prospects: The 2018 revision* (Online edition). https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

United Nations, Department of Economic and Social Affairs, Population Division (UN-DESA). (2019). *World population policies*. https://www.un.org/development/desa/pd/data/world-population-policies

Wan, N. F., Cai, Y. M., Shen, Y. J., Ji, X. Y., Wu, X. W., Zheng, X. R., . . . and Li, B. (2018). Increasing plant diversity with border crops reduces insecticide use and increases crop yield in urban agriculture. *Elife*, *7*, Article e35103. https://doi.org/10.7554/eLife.35103

Wolf, F., Moncada, S., Salvia, A. L., Balogun, A. L. B., Skanavis, C., Kounani, A., & Nunn, P. D. (2022). Transformative adaptation as a sustainable response to climate change: Insights from large-scale case studies. *Mitigation and Adaptation Strategies for Global Change*, *27*(3), 1–26. https://doi.org/10.1007/s11027-022-09997-2

World Health Organization (WHO) (2015). *Global health observatory*. http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

Zezza, A., & Tasciotti, L. (2010). Urban agriculture, poverty, and food security: Empirical evidence from a sample of developing countries. *Food Policy*, *35*, 265–273. https://doi.org/10.1016/j.foodpol.2010.04.007

Growth of informal transport in two Ghanaian cities

Implications for urban planning and policymaking

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Abstract: In sub-Saharan Africa, informal transport modes such as motorcycles, motor tricycles, minibus paratransit, and autorickshaws are preferred for first-and-last-mile trips. This has several socio-economic benefits but also contributes to traffic crashes, transport pollution, and congestion levels. These negative externality effects have direct correlations with the volume of informal transport in cities; therefore, projecting their growth dimensions is important for urban planning. However, no study has yet projected the growth trends of informal transport in African cities. This study uses the Gompertz time series model to estimate the growth of registered roadworthy vehicles and informal transport in Koforidua and Sunyani, Ghana, from 2019 to 2030. Results show that by 2030, informal transport comprising motorcycles, motor tricycles, and autorickshaws will dominate the vehicle fleet in both cities. This obligates strict enforcement of the requirements of vehicle roadworthiness, investments in sustainability-based smart transport infrastructures, traffic impact assessment, and bus rapid transit. It is imperative to foster stakeholder collaboration between urban planners and transport policymakers to improve smart micromobility solutions for sustainable cities.

Keywords: Ghana, informal transport, sustainable development goals, vehicle growth

Acknowledgements: The authors are grateful to the Driver and Vehicle Licensing Authority of Ghana for providing the data used in this paper.

1 Introduction

Sub-Saharan Africa's (SSA) informal transport comprises motorcycles, motor tricycles, minibus paratransit, and autorickshaws. They are preferred for first-and-last-mile journeys (Ehebrecht et al., 2018). This is due to poor public transport, lower travel costs, poor road network, time-saving, employment creation, and availability (Diaz Olvera et al., 2016; Dumba, 2017; Ehebrecht et al., 2018; Onyango, 2018; Oteng-Ababio & Agyemang, 2012, 2015). However, these transport modes contribute to traffic crashes, congestion, and environmental pollution (Amegah & Agyei-Mensah, 2017). Campaigns to regulate the sector have been futile and where minimum success is achieved, they are often difficult to implement. Therefore, some countries such as Ghana and some states in Nigeria have proposed a complete ban on the sector. Nonetheless, such drastic measures will see a significant hike in private car ownership (Shao et al., 2022).

Globally, transport is characterized by congestion, air pollution, and traffic-related crashes. This situation is worsening in developing countries that have a high influx of informal transport in the traffic stream (Tomassetti et al., 2020) and increasing car culture. Despite the concerns, research on informal transport is limited specifically on evidence of growth in the sector. The sustainable development goals (SDGs) of the United Nations (2022) aim to build sustainable cities and communities (SDG 11). This requires cities to be safe, inclusive, resilient, and offer sustainable transportation. Therefore, a recommendation for improving the informal transport sector through effective control and regulation becomes imperative. Empirical studies should aim at understanding the growth implications of the sector to socio-economic policy nexus.

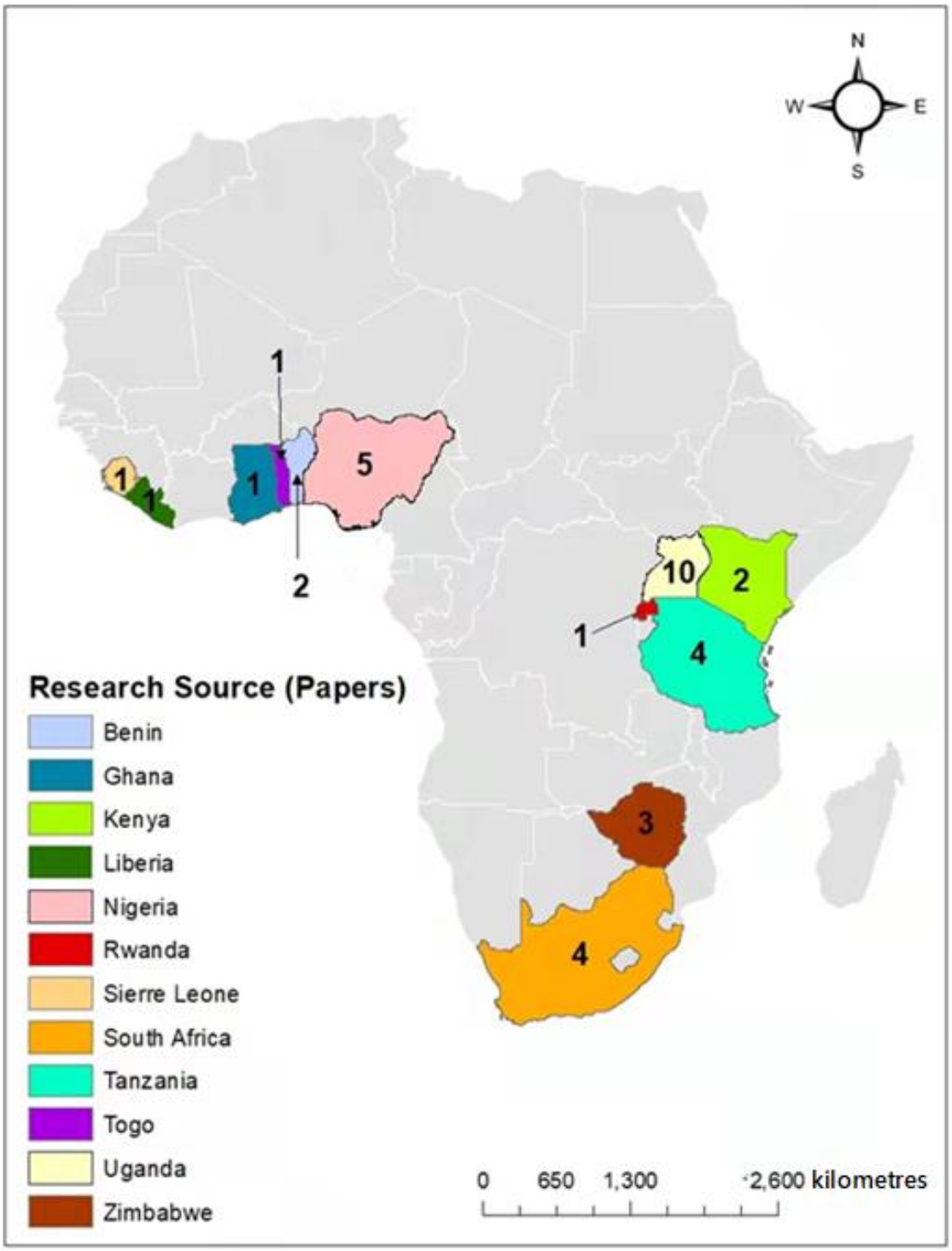
Rapid population growth in West African cities is associated with demand and ownership of motor vehicles ranging from personal vehicles to minibuses/paratransit (Imoro Musah et al., 2020). This car culture growth is no different in Ghana as statistics on vehicle registration and use are increasing. It was estimated that vehicular registration per annum grew at 33.6% as of May 2021 (Bank of Ghana, 2021). The rapid rise is attributed to the poor public transport system and the interest to own vehicles, which is considered 'prestigious and respectful' among many in society. Transport growth studies across Ghana are mainly focused on large cities; based on population and economic functions these are Accra (population and economic), Kumasi (population and economic), Tamale (population), and Takoradi (economic) (Dumba, 2017; Obiri-Yeboah et al., 2021; Oteng-Ababio & Agyemang, 2015). However, there is a paucity of research on the sector's growth in small cities despite the rapid hike in vehicles. According to OECD (2022), small cities have a population between 50,000 and 200,000.

Globally, several policies have been implemented to improve public transport. These include expanding the bus rapid transit (BRT) systems (Carrigan et al., 2013), encouraging shared and active mobility (Lin & Yang, 2019), and providing discount incentives for public transport users (Voon et al., 2017). However, these transport policies and strategies have received little focus in Ghana. To make effective policies, knowledge of growth trends of informal transport should be easily integrated into urban planning.

1.1 Informal transport sector research overview across SSA

In SSA, research on informal transport has largely focused on motorcycle taxis, with a few studies focusing on autorickshaws and motor tricycles. A search of English-language papers from SSA in the Web of Science core collection with a year limitation of 2010–21 found 35 papers. Figure 1 shows the originating countries of past contributions, exempting the review papers (not country-specific). Research activities are clustered in a few countries in SSA, whereas informal transport exists in several countries.

Figure 1: The country origin of past studies and the number of publications between 2010 and 2021



Source: Authors' own.

1.2 Ghana's informal transport sector and SDGs

One of the main influencing factors for the growth of informal transport is the insufficient public transport supply in SSA countries and the employment avenue that the informal transport has created. Given the high demand, finding the appropriate regulatory frameworks can enable SSA countries to improve informal transport services and operations. This would help to deal with

problems regarding their regulation and driver safety. It was also found that in the urban road network, intersections and midblock sections have the most incidences of motorcycle taxi injuries (Dumba, 2017). Particularly, motorcycle taxis are also associated with fatal injuries (Kitara & Karlsson, 2020; Nabifo et al., 2021). Obiri-Yeboah et al. (2021) noted that, despite the positive attitude to maintenance, autorickshaw operators have a poor attitude to safety and traffic regulations, which has resulted in police harassment oftentimes. Effective policy control would also help modulate their emission control that has also been of concern (Ehebrecht et al., 2018; Lawin et al., 2016). These insights call for better urban planning and policies to regulate informal transport in SSA.

In line with the SDGs, planning and designing sustainable, safe, and inclusive transportation cannot be overemphasized. Transportation plays a significant role in achieving all the SDGs (May, 2013). Particularly, SGD 11 necessitates that all cities will have good transport infrastructure and enhanced safety. Reliable, safe, and clean transportation enhances subjective well-being and happiness in cities (Blais & El-Geneidy, 2014; Chatterjee et al., 2020). The informal economy is an equally important target under the SDGs (Hrelja et al., 2017), so making informal transport attractive and promoting orderly operation cannot be overemphasized. Achieving sustainable transport and resilient cities as part of SDG 11 is realistically based on the success of existing regulations and implementation. However, recent reports by the World Health Organization show that all the regulatory schemes and plans aimed at sustainable transport in Ghana are facing implementation lapses (Essel & Spadaro, 2020). These policies are noticeably started in larger cities like Accra and Kumasi. Ultimately, it is difficult to achieve SDG 11 under these implementation lapses. Perhaps, a new strategy that begins in small cities can be experimented. Although smaller cities have lower traffic densities, it is worth knowing the growth trends of informal transport to plan their station allocations, uniforms, and other formal/informal regulations and controls. For instance, traffic signal timing plans may vary in a city or give priority to a specific transport mode that is dominant in the traffic stream.

It is noteworthy that there is no previous projection of the growth dimensions of informal transport in smaller cities in the literature on informal transport from SSA. This lack of empirical findings inhibits effective urban planning, policymaking, and traffic control. Therefore, this study focused on projecting the growth of registered roadworthy vehicles between 2019 to 2030 in Koforidua and Sunyani, Ghana, to learn about the growth trends of informal transport. Gompertz time series model was used and the implications for policymakers and urban planners are discussed. This study enriches the literature on informal transport. It also elucidates the policy implications of the growth trends, which is relevant for public policymaking and urban planning in SSA. In addition, the growth trends can guide future economic growth and employment forecasts as well as the travel preferences of commuters.

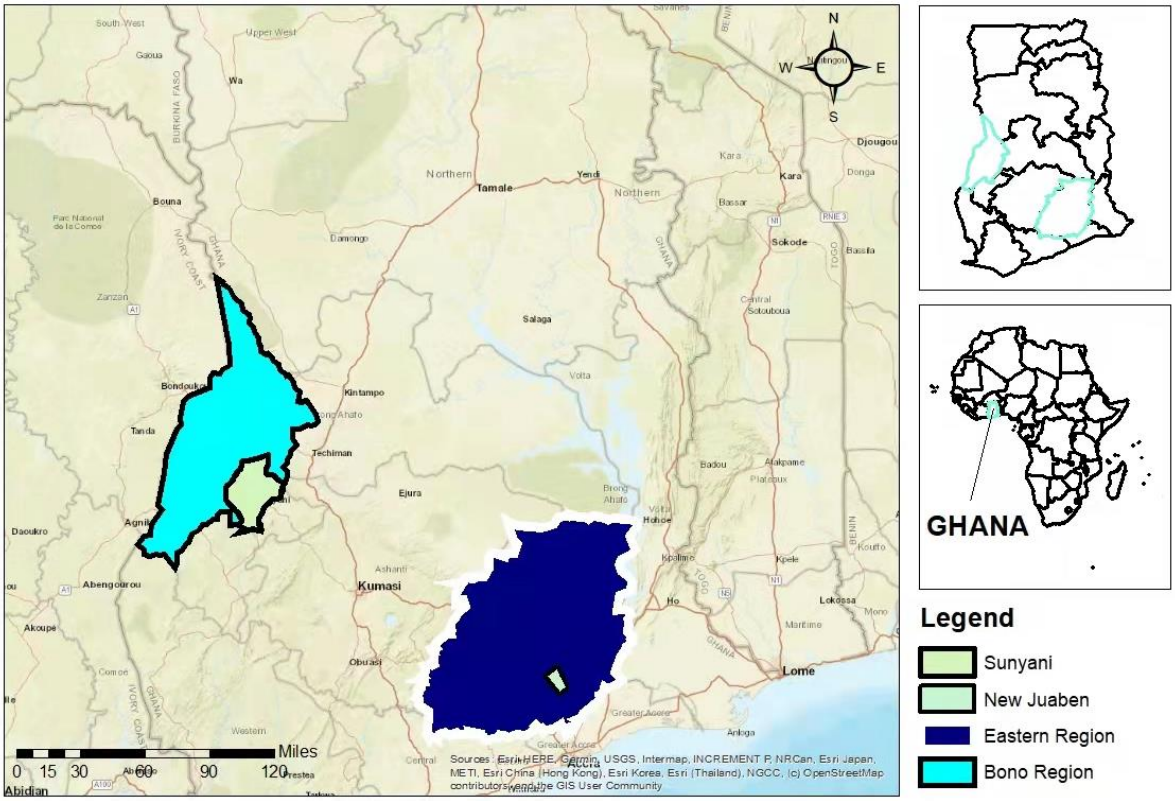
2 Methodology

2.1 Case study cities

The study area is the Koforidua and Sunyani municipalities of Ghana, as shown in Figure 2. Koforidua is the regional capital of the eastern region, the third fastest-growing region of Ghana in terms of population. It comprises the New Juaben South municipal and New Juaben North municipal areas. The 2021 Ghana Population and Housing Census (PHC) reported a total population of 183,727 people in the city (GSS, 2021a). As a commercial centre for the eastern region it is home to many businesses, which makes it a highly mobile city. Sunyani lies in the Sunyani municipality of Ghana and is the capital city of the Bono region. It is located about 373

km from the national capital of Accra. There are five municipalities in the Bono region including Sunyani municipality. Sunyani covers a land area of roughly 506.7 km^2. Per the recent decennial 2021 PHC, the total population of the municipality is 193,595 people (49.8% men and 50.2% women) out of a regional population of about 1.2 million (GSS, 2021a).

Figure 2: Geographical setting of the study



Source: Authors' own.

These two cities were selected because they both have a good taxi market, which makes it easy to implement shared mobility strategies. Also, land ownership is vested in the state, which makes it relatively easier to implement any sustainable strategies that would require land acquisition. In the last decade, both regions have also experienced drastic population and economic growth, rapid urbanization, and increased human and vehicular mobility (GSS, 2021b, 2021c).

2.2 Data collection

Data were collected from the Driver and Vehicle Licensing Authority (DVLA) of Ghana. DVLA is the government agency responsible for the registration of vehicles and the issue of driver's licenses in Ghana. Therefore, the data are reliable and verifiable, with frequency and percentages in both cities shown in Table 1.

The data comprised records of annual registered vehicles in Koforidua and Sunyani from 2017 to 2019. A digitized vehicle registration and documentation process emerged in 2017 to optimize the vehicle licensing process, reduce errors, and make data accessible. The database contains the number of registered vehicles for 21 vehicle types, classified according to capacity and official name in Ghana.

Table 1: Overview of registered vehicles in the two cities

Vehicle type	Year 2017		Year 2018		Year 2019		Total
	Sunyani	Koforidua	Sunyani	Koforidua	Sunyani	Koforidua	
Motorcycle	818	597	810	630	812	1434	5,101
Tricycle (autorickshaw and motor tricycle)	537	9	1,460	90	1,708	498	4,302
Private motor vehicle <2,000 cubic capacity	437	406	366	417	333	380	2,339
Commercial motor vehicle <2,000 cubic capacity	292	213	283	322	364	361	1,835
Private motor vehicle >2,000 cubic capacity	300	259	207	318	198	216	1,498
Commercial motor vehicle >2,000 cubic capacity	30	3	17	11	6	4	71
Private buses and coaches	27	91	15	39	17	26	215
Commercial buses and coaches	41	164	58	152	42	141	598
Rigid cargo trucks <16 tonnes	6	18	13	4	7	26	74
Rigid cargo trucks 16–22 tonnes	6	15	5	10	10	7	53
Rigid cargo trucks >22 tonnes	4	3	2	11	5	7	32
Articulator trucks <24 tonnes	7	2	1	5	5	1	21
Articulator trucks 24–32 tonnes	1	1	1	4	6	1	14
Articulator trucks >32 tonnes	1		7		3	7	18
Articulator tipper truck	1		1		8	5	15
Construction equipment	3						3
Combine harvester					2		2
Agricultural equipment	2		2		9	3	16
Mining equipment					4		4
Particular identification mark					364		364
Special registration			7		55		62
Total	2,513	1,781	3,255	2,013	3,958	3,117	16,637

Source: Authors' own.

2.3 Data analysis and vehicle projection model

Descriptive analysis was computed to analyse the annual growth rate for the three-year duration in both cities. Consequently, the authors projected the volume of motorcycles, tricycles, private motor vehicles, commercial motor vehicles, and buses in both cities by 2030. Other vehicle types were excluded from the projections because they do not fall in travellers' modal split. For this study, the Gompertz time series model was used for projections. It represents the long-run relationship between vehicle ownership per 1,000 population and economic indicators such as income or gross domestic product (GDP) per capita. The model with the sigmoid function assumes that the growth rate starts slow and moves faster after some years, then slows down again when the end of the year being projected is approaching. This model has been used previously for vehicle ownership projections (Català et al., 2020; Kong, 2018; Satoh, 2021; Singh et al., 2020). The research team used the model calibrated by Singh et al. (2020) for projections in the present study. The generalized Gompertz model can be specified as in Equation 1:

$$V_{t,i} = Se^{\alpha e^{\beta y_{t,i}}} \quad (1)$$

where $V_{t,i}$ denotes the long-run equilibrium level of on-road vehicles; S is the saturation level of vehicles (per 1,000 population); $y_{t,i}$ represents the GDP per capita; e is Euler's number

(e=2.71828), and parameters α and β indicate the negative growth rate of vehicle ownership over economic growth.

For projections in this study, the main parameters included the saturation level of the vehicles (vehicles per 1,000 capita), the GDP per capita, the average percentage increase in the number of registered vehicles, and the α and β parameters. The World Bank data on GDP per capita for Ghana in the year 2019 was used in the model (see World Bank, 2020). The saturation level (67), $\alpha(-7.488)$, and $\beta(-0.424)$ were adopted from Keshavarzian et al. (2012). An average growth rate of 1.5% was adopted for these small cities compared with 2.2% adopted for large cities in the Middle East (Keshavarzian et al., 2012). From Equation 1, since α and β are negative, $V_{t,i}$=S. Consequently, adjustments were made to the saturation level with the average annual growth rate of the vehicles registered in the candidate cities represented by θ resulting in Equation 2:

$$V_{t,i} = S\theta \quad (2)$$

By multiplying θ by the saturation level, the long-run equilibrium level of on-road vehicles ($V_{t,i}$) was derived and used to compound the growth of vehicles for the 11-year duration.

3 Results and discussion

The results (Table 2) indicate that tricycles, motorcycles, rigid cargo trucks (<16 tonnes), commercial motor vehicles (>2,000 cubic capacity), and articulator trucks (from 24 to 32 tonnes) had high annual growth rates for the three years in Koforidua. However, tricycles and articulator trucks seem to have high annual growth rates (>70 tonnes).

Table 2: Annual vehicular growth rate in the two cities

Vehicle type	Average growth rate (2017–2019)	
	Koforidua	Sunyani
Motorcycles	67	60
Tricycles	92	94.5
Private motor vehicles <2,000 cubic capacity	−3	−12.5
Private motor vehicles >2,000 cubic capacity	−4.5	−17.65
Commercial motor vehicles <2,000 cubic capacity	31.5	13
Commercial motor vehicles >2,000 cubic capacity	88	−54
Private buses and coaches	−45	−15.5
Commercial buses and coaches	−7	6.5
Rigid cargo trucks <16 tonnes	90	35.5
Rigid cargo trucks 16–22 tonnes	−31.5	41.5
Rigid cargo trucks >22 tonnes	5.5	50
Articulator trucks <24 tonnes	35	78
Articulator trucks 24–32 tonnes	83	86
Articulator trucks >32 tonnes	—	89
Articulator tipper truck	—	93
Agricultural equipment	—	61
Special registration	—	80
Total	34	26

Note: The empty cells (—) represent data unavailability.

Source: Authors' own.

By the estimations, tricycles and motorcycles will have the largest fleets if no major transport policies emerge as projected for both cities by 2030 for the selected vehicle types, as shown in Table 3. However, private motor vehicles, commercial motor vehicles, and buses are projected to increase marginally.

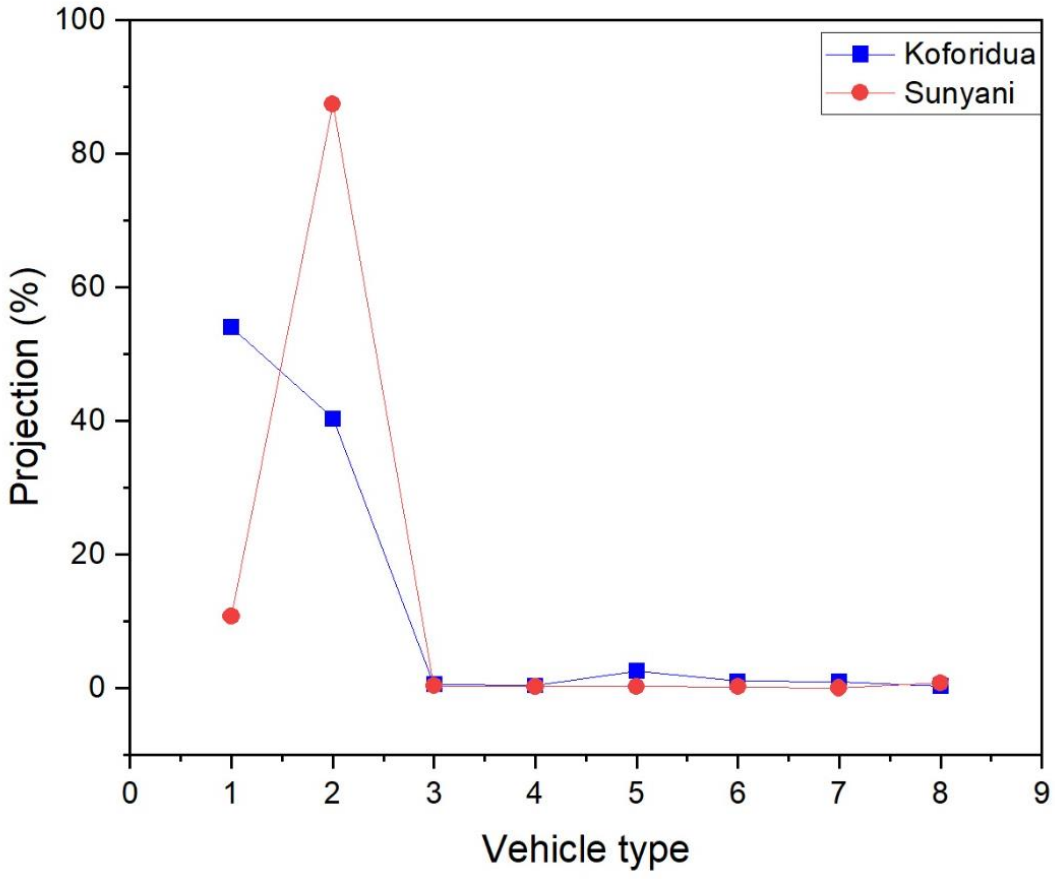
Table 3: Projected modal split of eight vehicle types by 2030

Index	Vehicle type	2030 Projection	
		Koforidua	Sunyani
1	Motorcycles	157,205	100,373
2	Tricycles	117,493	816,723
3	Private motor vehicles <2,000 cubic capacity	1,496	2,752
4	Private motor vehicles >2,000 cubic capacity	1,098	2,411
5	Commercial motor vehicles <2,000 cubic capacity	7,364	2,353
6	Commercial motor vehicles >2,000 cubic capacity	2,947	1,583
7	Private buses and coaches	2,796	175
8	Commercial buses and coaches	757	7,521

Source: Authors' own.

Additionally, the projected percentage of each vehicle type for the period from 2019 to 2030 is illustrated in Figure 3. Trends indicate that tricycle use is likely to dramatically increase over the 11-year analyses.

Figure 3: Projected percentage of each vehicle type (2019–30)



Source: Authors' own.

The general overview from the two Ghanian cities of Koforidua and Sunyani shows that motorcycles and tricycles commonly used as taxis and ride-sourcing services are growing at a fast rate and the travel patterns will require policy actions. These modes are prone to crashes and high fatality rates in Africa, and particularly in Ghana. Although vehicle ownership and travel decisions are derived from demand (Stanojević et al., 2020), and as this modal split trajectory continues to gain traction, dynamic optimization of intersection signal timing would be helpful in both cities. Traffic regulations are also required to be strictly enforced in situations of this nature (Ang et al., 2019; Oteng-Ababio & Agyemang, 2015). The traffic police must pay attention to speed, visibility, and motorcyclist alertness, which have been identified by past research as the main contributors to motorcycle crashes (Dodge & Halladay, 2008; Yousif et al., 2020). Furthermore, installing segregated lanes for motorcycles, at least at signalized intersections, will enhance safety because of their now increasing traffic volume (Cohen, 2013; Le Vu, 2016) and the threat posed to other road users.

The results revive an ongoing discussion about the regulation or ban of informal transport. Considering the growth projections, urban planners can consider formalizing their operations and integrating them with mainstream public transport. An outright ban will motivate people to own private vehicles (Shao et al., 2022) as mobility tools and consequentially increase congestion and pollution levels in Ghanaian and other African cities. However, this would require sufficient stakeholder engagement (Ehebrecht et al., 2018). It is imperative to create driver unions and make policies explicit on the allowable traffic zones for these modes. These include the distance individuals can travel within a city, the time of day the traffic zones can operate, and the use of safety tools such as helmets and reflector gadgets (Atubi & Ali, 2009; Bradbury, 2015; Ndadoum et al., 2016). Providing traffic segregation infrastructure and reducing huge first-and-last-mile accessibility shortfalls by public transport can offer not only equitable transport but also inclusive mobility outcomes (Acheampong & Asabere, 2022).

With the majority of vehicles in the study areas having a vehicle life/age of more than 10 years, the imposition of environmental taxes and incentives is seen as a plausible opportunity to limit the importation of overaged vehicles (Moonsammy et al., 2021; Pojani & Stead, 2015). Individuals and organizations importing overaged vehicles can be demotivated by high payment of import duties or payment of carbon emission levies, whereas persons and companies importing underage vehicles can have the benefit of accruing carbon emission levies over time.

It could be generally accepted that small-holder cities will have less public use vehicle systems based on the small population and convenience of travel. Therefore, the implementation of a generalized BRT system may not yield significant results in terms of reduction in cumulative transport-related emissions. Yet, with rigorous policy implementation to commence frequent and robust traffic impact assessment (TIA) studies, knowledge of road management could be obtained to find efficient and incentivized means to promote public bus transport within smaller cities (Lin & Yang, 2019). Alternative ways to reduce emissions are to encourage start-ups of emerging shared mobility systems and electric vehicle services and the use of active mobility (Voon et al., 2017). To significantly increase active transport rates in both cities, deliberate improvement in pedestrians and cycling infrastructure is paramount.

4 Conclusion

In this study, the Gompertz time series model was used to project the growth of registered roadworthy vehicles (2019–30) in two small cities in Ghana. The implications for policymaking and urban policy were discussed. This study contributes to the growing discussion on how to

control and regulate informal transport in SSA. It is also relevant to enhance the well-being of residents in small cities. This rare case of small cities in literature provides a basis for future works. The results showed a high percentage of informal transport in the transport fleet of Koforidua and Sunyani. The projections show that assuming no urban planning decisions are made, and policymaking status quo remains, informal transport will dominate the traffic stream in these cities by 2030.

Improvement in active and shared mobility infrastructure and incentives are required to curtail the projected vehicle volumes of informal transport. The idea is to enhance the use of more sustainable transport modes. Other policies such as TIA, BRT systems, intersection signal optimization, subsidies on emission test kits, and strict enforcement of traffic regulations are proposed to improve well-being and safety in cities. In line with the SDGs, urban planners and transport policymakers in small cities can also form associations for the operators of these informal transport modes where they will be given adequate training and safety education. The strategy of giving free safety kits periodically can also be incorporated in planning decisions as validated in Tanzania (Sumner et al., 2014).

The present study had some limitations. The analyses used a limited dataset covering only three years. This is because the digitized registration of roadworthy vehicles started in 2017. Moreover, non-roadworthy vehicles were unaccounted for in the projections because they were not present in the vehicle register. Also, the projection covered informal transport modes such as motorcycles, autorickshaws, motor tricycles, and minibuses (paratransit) as these are the modes registered in Ghana. Other informal transport modes that may exist in other countries were excluded. Additionally, literature that discusses population growth, urbanization of other areas within Ghana, population shifts, demographic projection trends, electrification of the fleet, carbon dioxide targets worldwide, and general SDGs were excluded.

Therefore, future studies can explore further projection of informal transport in other cities of SSA. Studies can focus on non-roadworthy vehicles and empirically measure transport exhaust emissions. Besides, funded research can be directed at non-roadworthy and end-of-life vehicles (comprehensive life-cycle analysis) in SSA. Case studies can put more emphasis on small cities in SSA to help urban planners and policymakers. Considering the growth rate of motorcycles and tricycles, policy studies addressing the regulation of these modes would be beneficial.

5 References

Acheampong, R. A., & Asabere, S. B. (2022). Urban expansion and differential accessibility by car and public transport in the Greater Kumasi city-region, Ghana: A geospatial modelling approach. *Journal of Transport Geography*, *98*, Article 103257. https://doi.org/10.1016/j.jtrangeo.2021.103257

Amegah, A. K., & Agyei-Mensah, S. (2017). Urban air pollution in sub-Saharan Africa: Time for action. *Environmental Pollution*, *220*, 738–743. https://doi.org/10.1016/j.envpol.2016.09.042

Ang, B. H., Lee, S. W. H., Oxley, J., Yap, K. K., Song, K. P., Kamaruzzaman, S. B., Chin, A. v., Tan, K. M., Khor, H. M., & Chen, W. S. (2019). Self-regulatory driving and riding practices amongst older adults in Malaysia. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 782–795. https://doi.org/10.1016/j.trf.2019.03.014

Atubi, A., & Ali, A. (2009). Motorcycle taxis in Enugu: Implications for development. *Sustainable Human Development Review*, *1*(4), 133–148.

Bank of Ghana. (2021, July). Monetary Policy Report. *Real Sector Developments*, 2(4/2021), 1–7. https://www.bog.gov.gh/wp-content/uploads/2021/08/Real-Sector-Developments-July-2021.docx.pdf

Blais, D., & El-Geneidy, A. M. (2014, January 12–16). *Better living through mobility: The relationship between access to transportation, well-being and disability* [Conference paper]. In The Transportation Research Board (TRB) 93rd Annual Meeting, Washington, DC. https://trid.trb.org/view/1287865

Bradbury, A. (2015, May). *Tanzania motorcycle taxi rider training: Assessment and development of appropriate training curriculum. Final report.* AFCAP Project Reference TAN2015E. Transaid. https://assets.publishing.service.gov.uk/media/57a09dcd40f0b652dd001b96/61280-TRANSAID-2015-MotorcycleTaxi-Training-FinalReport-AFCAP-TAN2015E-v150616c.pdf

Carrigan, A., King, R., Velasquez, J. M., Raifman, M., & Duduta, N. (2013). *Social, environmental and economic impacts of BRT systems: Bus rapid transit case studies from around the world* [Report]. EMBARQ Global, World Resources Institute. https://www.wrirosscities.org/sites/default/files/Social-Environmental-Economic-Impacts-BRT-Bus-Rapid-Transit-EMBARQ.pdf

Català, M., Alonso, S., Alvarez-Lacalle, E., López, D., Cardona, P.-J., & Prats, C. (2020). Empirical model for short-time prediction of COVID-19 spreading. *PLOS Computational Biology*, *16*(12), Article e1008431. https://doi.org/10.1371/journal.pcbi.1008431

Chatterjee, K., Chng, S., Clark, B., Davis, A., De Vos, J., Ettema, D., Handy, S., Martin, A., & Reardon, L. (2020). Commuting and wellbeing: A critical overview of the literature with implications for policy and future research. *Transport Reviews*, *40*(1), 5–34. https://doi.org/10.1080/01441647.2019.1649317

Cohen, E. (2013). Segregated bike lanes are safest for cyclists. *Canadian Medical Association Journal*, *185*(10), E443–E444. https://doi.org/10.1503/cmaj.109-4468

Diaz Olvera, L., Guézéré, A., Plat, D., & Pochet, P. (2016). Earning a living, but at what price? Being a motorcycle-taxi driver in a sub-Saharan African city. *Journal of Transport Geography*, *55*, 165–174. https://doi.org/10.1016/j.jtrangeo.2015.11.010

Dodge, L. D., & Halladay, M. (2008). Motorcycle safety and intelligent transportation systems [Conference paper]. In *15th World Congress on Intelligent Transport Systems and ITS America Annual Meeting*, *ITS Connections: Saving Times, Saving Lives* (Vol. 6, pp. 4279–4288), New York.

Dumba, S. (2017). Informal public transport driver behaviour and regulatory policy linkage: An expose. *Journal of Transport and Supply Chain Management*, *11*(0), Article a315. https://doi.org/10.4102/jtscm.v11i0.315

Ehebrecht, D., Heinrichs, D., & Lenz, B. (2018). Motorcycle-taxis in sub-Saharan Africa: Current knowledge, implications for the debate on 'informal' transport and research needs. *Journal of Transport Geography*, *69*, 242–256. https://doi.org/10.1016/j.jtrangeo.2018.05.006

Essel, D., & Spadaro, J. V. (2020). *Health and economic impacts of transport interventions in Accra, Ghana*. World Health Organization. https://apps.who.int/iris/handle/10665/338963

GSS. (2021a). *Ghana 2021 Population and Housing Census publications: General report*, Volume 3A. Ghana Statistical Service. https://census2021.statsghana.gov.gh/

GSS. (2021b). *Ghana 2021 Population and Housing Census publications: General report*, Volume 3B. Ghana Statistical Service. https://census2021.statsghana.gov.gh/

GSS. (2021c). *Ghana 2021 Population and Housing Census publications: General report*, Volume 3C. Ghana Statistical Service. https://census2021.statsghana.gov.gh/

Hrelja, R., Monios, J., Rye, T., Isaksson, K., & Scholten, C. (2017). The interplay of formal and informal institutions between local and regional authorities when creating well-functioning public transport systems. *International Journal of Sustainable Transportation*, *11*(8), 611–622. https://doi.org/10.1080/15568318.2017.1292374

Imoro Musah, B., Peng, L., & Xu, Y. (2020). Urban congestion and pollution: A quest for cogent solutions for Accra city. *IOP Conference Series: Earth and Environmental Science*, *435*(1), Article 012026. https://doi.org/10.1088/1755-1315/435/1/012026

Keshavarzian, M., Kamali Anaraki, S., Zamani, M., & Erfanifard, A. (2012). Projections of oil demand in road transportation sector on the basis of vehicle ownership projections, worldwide: 1972–2020. *Economic Modelling*, *29*(5), 1979–1985. https://doi.org/10.1016/j.econmod.2012.06.009

Kitara, D. L., & Karlsson, O. (2020). The effects of economic stress and urbanization on driving behaviours of boda-boda drivers and accidents in Gulu, Northern Uganda: A qualitative view of drivers. *Pan African Medical Journal*, *36*, Article 47. https://doi.org/10.11604/pamj.2020.36.47.21382

Kong, X. (2018). Research on the prediction method of Gompertz model for high subgrade settlement. In W. Firkha, S. Varaksin, & A. Viana de Fonseca (Eds.), *Soil testing, soil stability and ground improvement, GeoMEast 2017, Sustainable civil infrastructures* (pp. 363–369). Springer. https://doi.org/10.1007/978-3-319-61902-6_29

Lawin, H., Agodokpessi, G., Ayelo, P., Kagima, J., Sonoukon, R., Mbatchou Ngahane, B. H., Awopeju, O., Vollmer, W. M., Nemery, B., Burney, P., & Fayomi, B. (2016). A cross-sectional study with an improved methodology to assess occupational air pollution exposure and respiratory health in motorcycle taxi driving. *Science of the Total Environment*, *550*, 1–5. https://doi.org/10.1016/j.scitotenv.2016.01.068

Le Vu, P. (2016). *Crash risk models for motorcycle-dominated traffic environment of urban roads in developing countries* [PhD thesis, University of Birmingham] University of Birmingham Research Archive. https://etheses.bham.ac.uk/id/eprint/7121/1/Phan16PhD.pdf

Lin, X., & Yang, J. (2019). Supporting green transportation with transport impact assessment: Its deficiency in Chinese cities. *Transportation Research Part D: Transport and Environment*, *73*, 67–75. https://doi.org/10.1016/j.trd.2019.06.004

May, A. D. (2013). Urban transport and sustainability: The key challenges. *International Journal of Sustainable Transportation*, *7*(3), 170–185. https://doi.org/10.1080/15568318.2013.710136

Moonsammy, S., Oyedotun, T. D. T., Oderinde, O., Durojaiye, M., & Durojaye, A. (2021). Exhaust determination and air-to-fuel ratio performance of end-of-life vehicles in a developing African country: A case study of Nigeria. *Transportation Research Part D: Transport and Environment*, *91*, Article 102705. https://doi.org/10.1016/j.trd.2021.102705

Nabifo, S. C., Izudi, J., & Bajunirwe, F. (2021). Alcohol consumption and sports-betting among young male motorcycle taxi boda boda riders in urban southwestern Uganda. *BMC Public Health*, *21*(1), Article 363. https://doi.org/10.1186/s12889-021-10406-7

Ndadoum, N., Marambaye, D., & Amane, T. (2016). Possibilities and limits of urban transport services in developing countries: The case study of motorcycle taxis and minibuses in N'Djamena, the capital of Chad. *International Transportation*, *68*(1), 31–35.

Obiri-Yeboah, A. A., Ribeiro, J. F. X., Asante, L. A., Sarpong, A. A., & Pappoe, B. (2021). The new players in Africa's public transportation sector: Characterization of auto-rickshaw operators in Kumasi, Ghana. *Case Studies on Transport Policy*, *9*(1), 324–335. https://doi.org/10.1016/j.cstp.2021.01.010

OECD. (2022). *Urban population by city size* (indicator). https://doi.org/10.1787/b4332f92-en

Onyango, G. M. (2018). Urban public transport in informal settlements: Experiences from Kisumu City, Kenya. *Bulletin of Geography*, *40*(40), 145–156. https://doi.org/10.2478/bog-2018-0020

Oteng-Ababio, M., & Agyemang, E. (2012). Virtue out of necessity? Urbanisation, urban growth and Okada services in Accra, Ghana. *Journal of Geography and Geology*, *4*(1). https://doi.org/10.5539/jgg.v4n1p148

Oteng-Ababio, M., & Agyemang, E. (2015). The Okada war in urban Ghana: A polemic issue or policy mismatch? *African Studies Quarterly*, *15*(4), 25–44. http://www.africa.ufl.edu/asq/v15/v15i4a2.pdf

Pojani, D., & Stead, D. (2015). Sustainable urban transport in the developing world: Beyond megacities. *Sustainability (Switzerland)*, *7*(6), 7784–7805. https://doi.org/10.3390/su7067784

Satoh, D. (2021). Discrete Gompertz equation and model selection between Gompertz and logistic models. *International Journal of Forecasting*, *37*(3), 1192–1211. https://doi.org/10.1016/j.ijforecast.2021.01.005

Shao, Q., Zhang, W., Cao, X. (Jason), & Yang, J. (2022). Nonlinear and interaction effects of land use and motorcycles/e-bikes on car ownership. *Transportation Research Part D: Transport and Environment*, *102*, Article 103115. https://doi.org/10.1016/j.trd.2021.103115

Singh, N., Mishra, T., & Banerjee, R. (2020). Projection of private vehicle stock in India up to 2050. *Transportation Research Procedia*, *48*, 3380–3389. https://doi.org/10.1016/j.trpro.2020.08.116

Stanojević, D., Stanojević, P., Jovanović, D., & Lipovac, K. (2020). Impact of riders' lifestyle on their risky behavior and road traffic accident risk. *Journal of Transportation Safety & Security*, *12*(3), 400–418. https://doi.org/10.1080/19439962.2018.1490367

Sumner, S. A., Pallangyo, A. J., Reddy, E. A., Maro, V., Pence, B. W., Lynch, C., Turner, E. L., Egger, J. R., & Thielman, N. M. (2014). Effect of free distribution of safety equipment on usage among motorcycle–taxi drivers in Tanzania: A cluster randomised controlled trial. *Injury*, *45*(11), 1681–1686. https://doi.org/10.1016/j.injury.2014.04.034

Tomassetti, L., Torre, M., Tratzi, P., Paolini, V., Rizza, V., Segreto, M., & Petracchini, F. (2020). Evaluation of air quality and mobility policies in 14 large Italian cities from 2006 to 2016. *Journal of Environmental Science and Health, Part A*, *55*(7), 886–902. https://doi.org/10.1080/10934529.2020.1752070

United Nations. (2022). *Sustainable development goals*. https://sdgs.un.org/goals

Voon, N. H., Kadir, S. N. H. A., Belayan, M. A., Poon, S. H., & Zahran, E.-S. M. M. (2017). Rides for rewards (R4R): A mobile application to sustain an incentive scheme for public bus transport. In S. Phon-Amnuaisk, T. W. Au, & S. Omar (Eds.), *Computational Intelligence in Information Systems (CIIS 2016), Advances in Intelligent Systems and Computing* (Vol. 532, pp. 60–71). Springer. https://doi.org/10.1007/978-3-319-48517-1_6

World Bank. (2020). *GDP per capita (current US$) – Ghana*. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD

Yousif, M. T., Sadullah, A. F. M., & Kassim, K. A. A. (2020). A review of behavioural issues contribution to motorcycle safety. *IATSS Research*, *44*(2), 142–154. https://doi.org/10.1016/j.iatssr.2019.12.001

Impact of Nigerian housing policy on sustainable residential real estate

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Abstract: Residential real estate is indisputably an essential sector for countries, especially regarding housing for residents. Nigeria, however, is faced with several challenges to this sector that requires appropriate management, regulation, and sustenance. In the country presently, there is huge population growth with many people living in conditions that are detrimental to health and well-being. Housing demand is extremely high, and current policies are not maintaining supply. This research investigates and appraises the effects, benefits, and challenges of housing policies in Nigeria, and their significance to sustainable housing in the federal capital territory of Abuja. The study aims to investigate the impact of a proper housing regulation system on the sustainability of residential real estate. Exploratory qualitative work is adopted based on a systematic literature review, which was rigorously conducted to reduce bias and improve the research objectivity. Primary data were acquired from three interview participants: a landlord, a tenant, and a real estate developer. Study findings provide an insight into the significance and limitations of housing policy as a tool for achieving sustainability in residential real estate. Focus on housing in the city of Abuja, and the impact of the Nigerian housing policy there, reveals that these limitations are because of the inability of the authorities to implement the policies made. Several research gaps relating to the key concepts in this study have been identified. Future research is recommended on alternative housing policies for the development of Nigeria's residential real estate.

Keywords: housing, housing policy, sustainability, sustainable housing, residential real estate, Nigeria

1 Introduction

In 2015, at a United Nations summit, world leaders gathered and adopted 17 sustainable development goals, which were aimed at ensuring that efforts were mobilized to 'end all forms of poverty, fight inequalities and tackle climate change, while ensuring that no one is left behind' (United Nations, 2022a). The 11th goal from this summit is titled 'sustainable cities and communities' and its first target is to ensure access to adequately safe and affordable housing and basic services for all, and to upgrade slums by 2030. All countries at this summit have this as a target for their residential real estate, which encompasses housing for individuals, or groups of people, and consists of several types of living arrangements, including single-family homes, apartments, condominiums, and townhouses (Corporate Financial Institute, 2020).

There are several tools through which residential real estate could be improved and regulated and sustained in countries, and a major tool is housing policy. Although most housing policies are created to fix existing problems, they are also directives that could ascertain a sustainable residential real estate.

Nigeria was under British colonial rule for over a century in which the economy was dominated, and boundaries defined by the British, lasting until the 1960s, when foreign rule came to an end with decolonization and independence (Falola and Genova, 2009). The country's history of colonial rule inevitably influenced the way it is run, and its residential real estate is no exception.

Nigeria experiences persistent housing challenges, and though the provision for housing has been continuously made available by the government, even before the country attained its independence, housing problems in Nigeria persist and many of the country's population does not have access to good living conditions and affordable housing (Ademiluyi, 2010). Sustainability in the country's residential real estate is a major issue, as it appears far-fetched with the present problems and the focus of housing policies. Therefore, there is a need to determine the impact of housing policies on sustainable residential real estate, to evaluate the reasons housing policies have not brought about solutions to problems in the country, and to further recommend how these policies can foster sustainability for present and future generations.

1.1 Definition of terms

- *Housing*: This refers to the entirety of the various types of shelter that are used as places of residence for individuals, families, and households (Adams, 1984). In this research, housing is considered in terms of structure and living arrangements as well as usage and ownership of houses; that is, people who live in them and owners of houses, respectively.
- *Housing policy*: This is a tool derived from laws, regulations, and administrative practices, used in town planning for the resolution of housing problems, resulting in the achievement of sustainable housing (Ibimilua and Ibitoye, 2015). It is 'the activity of the authorities aimed at setting modern goals, defining tasks, principles, developing programs, tools and methods to ensure the implementation of the constitutional right of all citizens to meet various needs and opportunities, as well as the requirements established by law' (Gahraman, 2020, p. 235).
- *Sustainability*: Sustainability was defined by the United Nations Brundtland Commission in 1987 as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations, 2022b). It is defined as the observation of balancing between development, environmental protection, and social equity (Abdul Hamid et al., 2018). In this study, sustainability is maintaining and preserving

the current developments, while ensuring that the needs of future generations are not compromised.

- *Sustainable housing*: There is no universally accepted definition of sustainable housing (Saidu & Yeom, 2020). According to Moghayedi et al. (2021), sustainable housing refers to buildings constructed using sustainable methods and materials and promoting green practices that enhance a more sustainable lifestyle.

2 Methodology

Using the research onion by Saunders et al. (2012), this research uses an interpretivist philosophy, understanding human differences in the role of social actors. It adopts a deductive approach and uses a multi-method qualitative methodological choice of a systematic literature review and interviews. The strategies applied include survey and archival research, whereas the time horizons are cross-sectional.

The techniques and procedures involve a mix of primary and secondary data collection. A single research question was put forward for this research: what is the impact of Nigeria's housing policies on sustainable housing in Abuja? This research relied heavily on secondary data sources, using a systematic literature review approach, which is an empirical method, administered using 'explicit and demanding' criteria, with the aim of achieving an exhaustive, unbiased, transparent, and accountable process of execution (Davies et al., 2013).

Primary data were obtained from interviewing three key participants: (i) a landlord in England, (ii) a tenant in Scotland, and (iii) a real estate developer in Abuja, Nigeria. Owing to the influence of British colonial rule on Nigeria's residential real estate, the different backgrounds of the participants offers broad views on the subject.

The interviews were done via Zoom, a video conference application, in which several enquiries derived from the research question were made to the participants. The interviews were open, allowing the participants to speak freely for an hour, on average, answering set questions, and were conducted following the University of Bolton's ethical protocols (University of Bolton, 2021). Verbatim transcripts were obtained from the recorded files on Zoom, and NVivo 12 software was used for thematic coding. In the analysis of the study, the interviews were integrated with the literature using the analytical table template in Farrell et al. (2017).

2.1 Search terms

A search was conducted using the University of Bolton's Library database, Discover@Bolton, which is an exhaustive search platform that gives access to all the databases and resources that the university has available, or is subscribed to, including books, e-books, electronic journals, and newspaper articles. The University of Bolton is currently subscribed to 123 databases. Table 1 outlines terms chosen and used in the search, with Boolean operators, alongside the results of the search and the literature retrieved.

The search terms used include housing policy, sustainable development, sustainable housing, residential real estate, housing, Nigeria, and Abuja. In total 360 literatures were retrieved from the search, which were in turn screened against the set criteria. The outcome was 20 relevant literatures used for the study.

Table 1: Search terms used and the results of the search

Number	Search term	Results	Retrieved
1	('Housing policy') AND ('Sustainable development') AND ('Residential real estate')	85	81
2	('Housing policy') AND (('Sustainable development') OR ('Sustainable housing')) AND ('Residential real estate') AND ('Nigeria')	11	11
3	('Housing policy') AND (('Sustainable development') OR ('Sustainable housing')) AND (('Residential real estate') OR ('Housing')) AND ('Nigeria') AND ('Abuja')	121	117
4	('Housing policy') AND ('Residential real estate') AND ('Nigeria') AND ('Abuja')	7	7
5	('Housing policy') AND ('Sustainable housing') AND ('Nigeria')	173	144
Total		397	360

Source: Authors' own.

2.2 Justification of criteria

The set of criteria for this review was chosen to ensure that valid and credible literature that is most relevant to the research is used (see Table 2). For the 'recency' criterion, the year 2016 was chosen as the minimum as it was the year the sustainable development goals of the United Nations came into force. Some titles might be misleading, hence the need to also screen the abstract in relation to the research question. Full access to the literature was required to examine the entire document including the methodologies, analysis, and conclusions for the research. The contents of the full paper were required to relate to the research question.

Table 2 is a representation of the set of criteria and the number of relevant literatures obtained from each.

Table 2: Criteria for systematic literature review

Type	Criteria	Literature count
Retrieved	Literature that could be retrieved	360
Similarity	Eliminate repeated papers	282
Recency	Must be within the years 2016–21	171
Title	Must relate to the research topic or question	115
Access	Must be able to access full paper	95
Abstract	Must relate to the research question	46
Content	Must relate to the research question	20

Source: Authors' own.

3 Literature review

A systematic literature review has been adopted for this research, alongside the interviews, in which rigorous steps and criteria were used to get the most accurate, relevant, and up-to-date works on the research topic (see Tables 1 and 2). According to Silva et al. (2018), a systematic approach is efficacious in identifying, evaluating, and interpreting available research, relevant to study area or phenomenon of interest, thereby ensuring that the study can be audited, replicated, updated, and is unbiased and thorough.

This review was driven by the research question in the study: what is the impact of Nigeria's housing policies on sustainable housing in Abuja? It follows similar steps as used by Davies et al. (2013) in their systematic literature review, including scoping the review, searching for studies,

screening the studies, describing and mapping, quality and relevance appraisal, synthesizing study findings, conclusion, and recommendation. Thematic coding and qualitative analysis were done systematically, using the NVivo 12 software program used for collecting, organizing, analysing, and visualizing unstructured or semi-structured data. Using this software, selected literatures that met the 'filter by content' criterion were examined alongside the interviews that led to several findings.

3.1 Findings

After a rigorous selection and analysis of literature, analytical tables were created containing consistencies, inconsistencies, arguments, and other views as well as observations, implications, or interpretations of coded data. These tables were designed using the template of analytical tables from Farrell et al. (2017). The data were coded into three main categories: (i) sustainable housing, (ii) housing policy, and (iii) Nigerian housing policy. Several related subcategories were created for better analysis of the different themes under these main themes. These subcategories were further analysed by consistencies or agreement within the literatures and interviews, inconsistencies, arguments, and distinctive views, alongside the implications, interpretations, and observations from the various viewpoints of the sources. A narrative was then created from the literature and interviews, resulting in the findings of this study.

Table 3 is one sample of 12 analytical tables used in this research. It contains one data code and the analysis to show how the table was used in the study.

3.1.1 Sustainable housing

The concept of sustainable housing has increasingly become essential in the literature on residential real estate, especially with the creation of the sustainable development goals, of which the 11th goal is 'sustainable cities and communities' (United Nations, 2022b). Several authors approach sustainable housing in terms of affordable housing, hence the term sustainable affordable housing, which is one that manages the available housing resources and its limitations, while preserving and conserving it for future generations, income group notwithstanding (Ezennia & Hoskara, 2019; Oyebanji et al., 2017; Ahmed & Sipan, 2019; Moghayedi et al., 2021). The focus is on the dwelling units, the residents, and all actors regulating and influencing it. Other authors approached sustainable housing from a standpoint beyond dwelling units and extended it to the sustainability of the surrounding environment (Qusen Zumaya & Baqir Motlak, 2021). Shalbolova et al. (2020) examined sustainable cities, in which people live longer with an ecologically clean environment, and consistent improvement of the quality of life (also see Table 3).

There is no established set of standards that can be deemed as adequate to monitor or evaluate sustainable housing (Qusen Zumaya & Baqir Motlak, 2021). Nevertheless, several authors have introduced various indicators, including the use of sustainable construction methods and materials, affordability, energy efficiency, safety, eco-effectiveness, and proximity to essential facilities (Abdul Hamid et al., 2018; Qusen Zumaya & Baqir Motlak, 2021; Ahmed & Sipan, 2019; Ebekozien, 2020). These have been grouped by most authors as economic, social, and environmental indicators.

Table 3: Sample analytical table

Data coding number	Main category heading	Sub-category heading	Sources	Data consistencies/similar views	Data inconsistencies/arguments/other views	Observations, implications, or interpretations
1	Sustainable housing	Approach	• Ezennia and Hoskara (2019) • Moghayedi et al. (2021) • Qusen Zumaya and Baqir Motlak (2021) • Shalbolova et al. (2020) • Oyebanji et al. (2017) • Ahmed and Sipan (2019)	• Several authors approach sustainable housing in terms of affordable housing (Ezennia & Hoskara, 2019; Oyebanji et al., 2017; Ahmed & Sipan, 2019). • Moghayedi et al. (2021) examined sustainable innovative affordable housing. Focus is on the dwelling unit and residents and all influencing it.	• Other authors approached sustainable housing from a standpoint beyond dwelling units and extending to the surrounding environment (Qusen Zumaya & Baqir Motlak, 2021). • Shalbolova et al. (2020) opined the approach of sustainable cities, in which people would live long with an ecologically clean environment, and consistent improvement of the quality of life.	• The concept of sustainable housing has increasingly become essential in the literature on residential real estate, especially with the creation of the sustainable development goals, of which the 11th goal is ‘sustainable cities and communities’ (United Nations, 2022b).

Source: Authors’ own.

Although sustainable housing has undeniable benefits, it is also laden with challenges. Sustainable housing is beneficial in tackling the challenges confronting urban dwellers, improving biodiversity and prudently utilizing natural resources (Moghayedi et al., 2021; Oyebanji et al., 2017). However, Abdul Hamid et al. (2018) argued that, despite the benefits of sustainable housing, the extra cost of new technologies would be borne by developers. Interview participant 3 (i.e. a real estate developer in Abuja, Nigeria) also opined that population is a challenge to sustainable housing, stating that sustainable housing is unlikely to be achieved for all groups of people.

3.1.2 Housing policy

In examining housing policy, most authors usually focus on its significance rather than its meaning. The general agreement is that they are created by governments or authorities and are important for economic development and addressing housing problems, with a focus on the needs of citizens in terms of quality, quantity, and housing prices (Alteneiji et al., 2020; Gahraman, 2020; Iheme, 2017). However, there is an argument that some housing policies, such as those on pricing, do not reflect citizens' needs (Bai et al., 2020).

Housing policy is essential for governments of all countries as a directive for regulating housing processes. However, its effectiveness has been questioned time and again. It has been observed to be a valuable tool, as authors opine that it is strengthened and made more effective through development and implementation, good institutional framework, as well as public–private partnership (Alteneiji et al., 2020; Ebekozien, 2021; Gahraman, 2020; Iheme, 2017). Implementation is noted as key to housing policy, as it determines its success or failure (Iheme, 2017). Participant 2 (i.e. a tenant in Scotland) concurs with this view, stating that housing policy is a necessary tool for the control and regulation of housing. Participants 1 (i.e. a landlord in England) and 3 of the interviews maintained unfavourable views about the effectiveness of housing policies. Participant 1 argued that the government could use them to eliminate whatever it perceives as impediments to the effectiveness of its housing programme. Participant 3 argued that housing policies would be unsuccessful as the population would always be greater than the number of houses available.

3.1.3 Nigerian housing policy

Although there have been many attempts to address housing problems with policies and programmes, the Nigerian residential real estate is still laden with persistent challenges. Authors trace Nigerian housing policies back to when it was under colonial administration, adopting British policies to cater for the housing needs of expatriates and indigenous staff of the colony (Saidu & Yeom, 2020; Aliu et al., 2018). Other authors opine that the first national housing policy in Nigeria was launched in 1991, with the aim being for all Nigerians to have access to affordable and decent accommodation (Ahmed & Sipan, 2019; Anierobi & Obasi, 2021).

The Nigerian government authorities are responsible for planning, carrying out, and sustaining housing policies in the country. Although the federal and state governments dominate formulation and implementation of housing policies, the local authority, however, is the only tier of government that can provide absolute monitoring and compliance (Aliu et al., 2018). Iheme (2017) maintains that the 2012 National Housing Policy of Nigeria gave room for all tiers of government to be involved in its implementation, but the formulation was still handled by the federal government.

There is a congruence in the literature that the most recent housing policy in Nigeria is the 2012 National Housing Policy, which aims to address housing issues for all income groups (Ebekozien, 2021). No other housing policy document has been referred to in the literature, hence the notion

that the 2012 National Housing Policy is the most recent official one. The main aim of the Nigerian government's housing policies has consistently been the provision of adequate housing for all Nigerians, regardless of income group, especially for those on a low income or poor (Ahmed & Sipan, 2019; Aliu et al., 2018; Ackley et al., 2018). The housing policy in Nigeria, however, does not favour all income groups. Some authors argue that it benefits only high- and middle-income groups and neglects low-income groups (Anierobi & Obasi, 2021; Ebekozien, 2020, 2021), whereas others argue that housing developments are not within reach of either middle- or low-income groups (Ackley et al., 2018).

There seems to be a consensus in the literature that previous housing policies in Nigeria have been inadequate or have failed to achieve that which they were created for (Aliu et al., 2018; Ackley et al., 2018; Iheme, 2017; Ebekozien, 2021; Afolabi et al., 2019a, 2019b; Anierobi & Obasi, 2021; Ezennia & Hoskara, 2019). Some authors, however, maintain that previous policies were well-planned and have had some impact, as the government has been making attempts to provide affordable housing for low-income groups (Ahmed & Sipan, 2019; Iheme, 2017). Interview participant 2 agreed that there has been some positive impact of housing policies in Nigeria, but this impact is still outweighed by its inadequacies.

The low impact of the housing policies in Nigeria can be attributed to the challenges the country faces. Several authors trace the problems of the national housing policies to the government's inadequacies, including the inability to finance housing provision, inappropriate policies that are political in nature, and corruption (Ahmed & Sipan, 2019; Aliu et al., 2018; Iheme, 2017; Anierobi & Obasi, 2021; also Participant 2). Other authors note the challenges presented by Nigerian residents. Ebekozien (2021) identified a major challenge from the low-income groups and rural–urban migration, as people seek better places to live and population growth in one area over another is an impediment to adequate housing provision. Akrofi et al. (2020) opined that creation of unauthorized buildings by residents presents a major challenge to housing policy success and they further recommended punitive sanctions to deter the same. Participant 2 also pointed out the lack of knowledge of these policies on the part of citizens as an impediment to their impact.

3.1.4 Impact of Nigerian housing policies on sustainable housing in Abuja

Abuja is a model city with a defined master plan, centrally located geographically, with people from different socio-economic and cultural backgrounds living together in various public and private housing estates from pilot housing schemes and programmes (Saidu & Yeom, 2020). Being the federal capital city of Nigeria, it was chosen as the study area for this research. However, exploration of available literature led to the discovery of a gap in the subject area. We found no literature that focused on examining the impact, challenges, or effects of housing policies on the sustainability of residential real estate or sustainable housing in Abuja. Even generally, in Nigeria, research on sustainability of housing projects is highly inadequate (Chiamaka & Aduwo, 2019). Nevertheless, several references were made in various literatures that touched directly or indirectly on the main concepts of the study.

Most of the literature maintained an unfavourable view of the impact of the Nigerian national housing policy on sustainable residential real estate. Iheme (2017) opined that land is a basic requirement for sustainable housing delivery, but housing policies in Nigeria have made the process of accessing lands difficult and expensive, especially with the problematic 1978 Land Use Act in place. Many scholars pinpointed the major limitations of implementing these housing policies (Ahmed & Sipan, 2019; Ebekozien, 2021; Iheme, 2017). Aliu et al. (2018, p. 254) buttressed this point, stating that the inefficacy of what would otherwise be good housing programmes has been 'bungled by poor implementation and crass negligence'. Implementation of national housing policies involves the monitoring of housing enterprises in the provision of utilities; it uses

quantitative and qualitative indicators as factors for expanding a sustainable urban environment (Shalbolova et al., 2020); therefore, they are essential.

Although all three interview participants agreed on the importance of housing policy, they also had unfavourable views about its impact on the sustainability of residential real estate and recommended improvements by the authorities. Participant 2 identified the problem in Nigeria's housing policy as the government's inability to forecast properly or have a continuity plan that could ensure sustainability and agreed with the scholars that there is a gap between policy formulation and implementation, hence the low impact of sustainable residential real estate.

4 Conclusion and recommendations

The importance of sustainable housing and sustainability in residential real estate cannot be overemphasized. It is then no surprise that governments all around the world are seeking to incorporate sustainability into their housing policies, especially with the advent of the sustainable development goals. Nigeria is no exception; sustainability is not a new concept in research on its residential real estate.

This study has identified that there is a direct relationship between housing policies and sustainability in residential real estate, as laws covering sustainable development of physical, economic, environmental, and social aspects of housing are created through national housing policies (Abdul Hamid et al., 2018). There is, however, a gap in the literature addressing this direct relationship. In Nigeria little research exists on the impact of housing policy on sustainable residential real estate, even though such policies determine the sustainability of the sector.

The present research sought to discover the impact of Nigerian housing policy on sustainable residential real estate, and the results show very low positive effects of previous and current housing policies. The major problem identified was in the implementation of these policies, which was limited by government action and inaction. Thus, it is recommended that the Nigerian government focuses on implementing the policies it has formulated. Furthermore, the most recent official national housing policy is identified as the one formulated in 2012, which by any standard can be said to be outdated and does not reflect the sustainable development goals created in 2015. Consequently, a new official housing policy that considers sustainable housing and overall sustainability of residential real estate is recommended.

Further research is recommended on how housing policies in Nigeria can ensure sustainability in its residential real estate and how this can be successfully implemented. This entails in-depth study of the goals and policy mechanisms embodied in the housing policy, how this compares with other countries, and detailed analysis of the drivers for successful policy implementation. Further consideration of what impacts are expected from effective housing policy and how they can be measured are also recommended.

5 References

Abdul Hamid, S. H., Hidayah Syed Jamaludin, S. Z., & Mahayuddin, S. A. (2018). Achieving sustainable affordable housing scheme from the perspective of a multi eco-system. *IOP Conference Series: Materials Science and Engineering*, *429*(1), Article 012029. https://doi.org/10.1088/1757-899X/429/1/012029

Ackley, A., Teeling, C., & Atamewan, E. E. (2018). Factors affecting the shortage and or provision of sustainable affordable housing in developing countries: A case-study of cross river state, Nigeria.

Journal of Sustainable Architecture and Civil Engineering, *22*(1), 27–38. https://doi.org/10.5755/j01.sace.22.1.20573

Adams, J. (1984). The meaning of housing in America. *Annals of the Association of American Geographers*, *74*(4), 515–526. https://doi.org/10.1111/j.1467-8306.1984.tb01471.x

Ademiluyi, I. (2010). Public housing delivery strategies in Nigeria: A historical perspective of policies and programmes. *Journal of Sustainable Development in Africa*, *12*(6), 153–161.

Afolabi, A. O., Akinbo, F. T., & Akinola, A. (2019a). Vertical architecture construction: Prospects and barriers in solving Lagos' housing deficit. *Journal of Physics: Conference Series*, *1378*(4), Article 042032. https://doi.org/10.1088/1742-6596/1378/4/042032

Afolabi, A. O., Ojelabi, R. A., Omuh, I. O., & Tunji-Olayeni, P. F. (2019b). 3D house printing: A sustainable housing solution for Nigeria's housing needs. *Journal of Physics: Conference Series*, *1299*(1), Article 012012. https://doi.org/10.1088/1742-6596/1299/1/012012

Ahmed, Y., & Sipan, I. (2019). Public private partnership as a determinant factors of affordable housing in Abuja, Nigeria. *ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(4) 71–78. https://doi.org/10.5194/isprs-archives-XLII-4-W16-71-2019

Akrofi, M. M., Avogo, F. A., & Wedam, E. A. (2019). Sustainable urban development and the challenge of unauthorized buildings: Assessing demographic drivers in peri-urban areas of Ghana. *Journal of Housing and the Built Environment*, *34*(2), 571–598. https://doi.org/10.1007/s10901-018-09642-y

Aliu, I. R., Towry-Coker, L., & Odumosu, T. (2018). Housing policy debacle in sub-Saharan Africa: An appraisal of three housing programs in Lagos, Nigeria. *African Geographical Review*, *37*(3), 241–256. https://doi.org/10.1080/19376812.2017.1284005

Alteneiji, K., Alkass, S., & Abu Dabous, S. (2020). Critical success factors for public–private partnerships in affordable housing in the United Arab Emirates. *International Journal of Housing Markets and Analysis*, *13*(5), 753–768. https://doi.org/10.1108/IJHMA-06-2019-0061

Anierobi, C., & Obasi, C. O. (2021). Urbanization and rural–urban migration: Toward involving the church in addressing pro-poor urban housing challenges in Enugu, Nigeria. *SAGE Open*, *11*(3), 1–13. https://doi.org/10.1177/21582440211040123

Bai, Y., Song, J., Wu, S., Wang, W., Lo, J. T. Y., & Lo, S. M. (2020). Comparing the impacts of location attributes on residents' preferences and residential values in compact cities: A case study of Hong Kong. *Sustainability*, 12(12), Article 4867. https://doi.org/10.3390/su12124867

Chiamaka, U., & Aduwo, E. B. (2019). Evaluation of sustainability concepts in public housing projects in Ogun State, Nigeria. *Journal of Physics: Conference Series*, *1378*(4), Article 042076. https://doi.org/10.1088/1742-6596/1378/4/042076

Corporate Financial Institute. (2020). *Real estate* [online]. Retrieved on 23 December 2020 from https://corporatefinanceinstitute.com/resources/careers/jobs/real-estate/

Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P., & Howe, A. (2013). Creative learning environments in education: A systematic literature review. *Thinking Skills and Creativity*, *8*, 80–91. https://doi.org/10.1016/j.tsc.2012.07.004

Ebekozien, A. (2020). Community participation in affordable housing provision in developing cities: A study of Nigerian cities. *Journal of Human Behavior in the Social Environment*, *30*(7), 918–935. https://doi.org/10.1080/10911359.2020.1772164

Ebekozien, A. (2021). A qualitative approach to investigate low-cost housing policy provision in Edo State, Nigeria. *International Planning Studies*, *26*(2), 165–181. https://doi.org/10.1080/13563475.2020.1779671Ezennia, I. S., & Hoskara, S. O. (2019). Exploring the severity of factors influencing sustainable affordable housing choice: Evidence from Abuja, Nigeria. *Sustainability*, 11(20), Article 5792. https://doi.org/10.3390/su11205792

Farrell, P., Sherratt, F., & Richardson, A. (2017). *Writing built environment dissertations and project: Practical guidance and examples*. John Wiley.

Falola, T., & Genova, A. (2009). *Historical Dictionary of Nigeria*. Scarecrow Press.

Gahraman B. S. (2020). Housing policy as a component of the state social policy. *Economic and social development: Book of proceedings*, *4*(18/19 June), 234–241.

Ibimilua, A. F., & Ibitoye, O. A. (2015). Housing policy in Nigeria: An overview. *American International Journal of Contemporary Research*, *5*(2), 53–59.

Iheme, J. O. (2017). *Factors for the implementation of affordable federal public housing policies in south-south region of Nigeria* [Doctoral dissertation, University of Salford]. University of Salford Institutional Repository. https://usir.salford.ac.uk/id/eprint/44156/

Moghayedi, A., Awuzie, B., Omotayo, T., Le Jeune, K., Massyn, M., Ekpo, C. O., Braune, M., & Byron, P. (2021). A critical success factor framework for implementing sustainable innovative and affordable housing: A systematic review and bibliometric analysis. *Buildings*, *11*(8), Article 317. https://doi.org/10.3390/buildings11080317

Oyebanji, A. O., Liyanage, C., & Akintoye, A. (2017). Critical success factors (CSFs) for achieving sustainable social housing (SSH). *International Journal of Sustainable Built Environment*, *6*(1), 216–227. https://doi.org/10.1016/j.ijsbe.2017.03.006

Qusen Zumaya, J., & Baqir Motlak, J. (2021). Sustainable housing indicators and improving the quality of life: The case of two residential areas in Baghdad city. *IOP Conference Series: Earth and Environmental Science*, *754*(1), Article 012002. https://doi.org/10.1088/1755-1315/754/1/012002

Saidu, A. I., & Yeom, C. (2020). Success criteria evaluation for a sustainable and affordable housing model: A case for improving household welfare in Nigeria cities. *Sustainability*, *12*(2), Article 656. https://doi.org/10.3390/su12020656

Saunders, M., Lewis, P., & Thornhill, A. (2012). *Research Methods for Business Students* (6th ed.). Pearson Education Limited.

Shalbolova, U., Chikibayeva, Z., Yegemberdiyeva, S., & Kim, Y. (2020). Housing and communal services as a factor of the urban sustainability. *E3S Web of Conferences*, *208*, Article 04013. https://doi.org/10.1051/e3sconf/202020804013

Silva, D., Ferreira, L., Melo, I., Silva, C., & Oliveira, A. (2018). Systematic literature review: Customer's requirements for social housing design. In *Proceedings of the International Conference for Sustainable Design of the Built Environment (SDBE 2017)* (pp. 355–365), London.

United Nations. (2022a). *United Nations sustainable development agenda*. https://www.un.org/sustainabledevelopment/development-agenda-retired/

United Nations, (2022b). *Sustainability: Academic impact*. https://www.un.org/en/academic-impact/sustainability

University of Bolton. (2021). *Research & teaching ethics framework*. University of Bolton, Manchester, UK. https://www.bolton.ac.uk/join-us/research-programmes/research-policies-and-documents/research-ethics-framework/

Communities and Stakeholders

Stakeholder perceptions of public participation in environmental impact assessment in the Nigerian road construction sector

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Abstract: Public participation (PP) is a vital component of the environmental decision-making process, playing a significant role in attaining the United Nations sustainable development goals (SDGs). The SDG agenda supports actions to develop sustainable, inclusive, and resilient infrastructure, achieve economic sustainability, and improve environmental protection. Responsive, inclusive, and effective partnerships in the environmental decision-making process are universal factors, which facilitate the achievement of the SDGs in both Global South and Global North countries. Through dialogue with project stakeholders this study built on previous research to offer a more comprehensive insight into how a plan or project performs according to SDG protocols. The study explores stakeholder perceptions of PP in environmental impact assessment (EIA) in three large road infrastructure projects in Abuja, Nigeria, and analyses the extent to which public engagement practices meet the expectations of sustainability frameworks, with particular emphasis on SDGs 8, 9, 11, 13, 15, 16, and 17. Using a qualitative case study approach (review of literature and semi-structured interviews), the preliminary findings of this research revealed PP practice does not meet the expectations of the SDG framework except for Target 16.1, where the participatory process helps in resolving conflicts arising during the project's implementation. Some key recommendations are highlighted to improve the effective implementation of PP practice, such as reduction in administrative bureaucracies, commitment to international protocols and treaties in EIA implementation, and monitoring the gaps in SDG implementation.

Keywords: environmental impact assessment, public participation, stakeholder perceptions, sustainable development goals

1 Introduction

In 2015, the United Nations adopted the 2030 agenda for sustainable development comprising 17 sustainable development goals (SDGs) that set out a transformative vision for social, economic, and environmental development (see United Nations 2018). The SDG framework supports actions to develop inclusive and resilient infrastructure, achieve economic sustainability, and improve environmental protection protocols. SDG 9 emphasizes the need to build sustainable infrastructure and innovation to facilitate economic growth, so the sustainable development of road infrastructure has a potential role to play in achieving SDG targets (Senadjki et al., 2022). Moreover, road infrastructure is considered under the category of projects that require environmental impact assessment (EIA) in Nigeria.

In most countries, including Nigeria, EIA is an important regulatory tool with the potential to achieve environmental sustainability and, therefore, is considered part of a project's permit to operate (Bøss et al., 2021). EIA is the process of identifying, evaluating, predicting, and mitigating the environmental and social impacts of proposed development projects before environmental decision-making (Glasson & Therivel, 2019). Consequently, PP is a vital component of EIA, playing a significant role in the environmental decision-making processes (Hasan et al., 2018). Many scholars argue that the success of EIA depends on the extent to which public inputs are integrated into the project decision-making process, since this enables transparency, accountability, and the harnessing of local knowledge (Brombal et al., 2017; Glucker et al., 2013; Hasan et al., 2018).

Nigeria has committed to meeting the objectives of SDG and related targets in 2030. However, progress towards these goals and targets is experiencing some setbacks because of the coronavirus (COVID-19) pandemic (Albu, 2021; Odey et al., 2021). Some scholars have emphasized the need to monitor and make organizations and firms accountable to help accomplish SDG targets (Bebbington & Unerman, 2018; Hopper, 2018). Nevertheless, recent studies examined how corporate organizations meet the expectation of SDGs and how impact assessment (IA) contributes to SDG performance (Erin et al., 2022; Ibeh & Walmsley, 2021; Kørnøv et al., 2020). Partidário and Verheem (2019) argue that SDGs can lead to objective-driven IA and, similarly, IA can translate the SDGs into practical realities. The present study builds on previous research of Bøss et al. (2021), which examined state-of-the-art EIA and strategic environmental assessment practices in terms of how they performed according to SDG targets. Their study examined SDG performance in 45 environmental assessment reports, using a review method to analyse and reflect on practice. They call for further research to offer a more comprehensive insight into how a plan or project performs according to SDG protocols through dialogue with project stakeholders to minimize the gap between the practices and the SDG framework. Motivated by this concern, the present study explores stakeholder perceptions of PP in EIA in three large road infrastructure projects in Nigeria and analyses the extent to which public engagement practices meet the expectations of the SDG framework. Table 1 summarizes the SDGs and their key targets that are connected to this study.

This study benchmarks public engagement based on how the EIA and SDG policies are achieved (social and individual norms), the extent of public influence, and democratic capacity in the decision-making process. The study further assesses the extent to which the participatory process mitigates negative environmental effects of road projects, and the attainment of the wider PP policy objectives and SDG targets, such as environmental sustainability, stakeholder partnerships, and economic and social sustainability. The research findings have been linked to the SDG framework, drawing insights into the effective implementation of sustainable development strategies in sub-Saharan countries.

Table 1: Sustainable development goals (SDGs) and key targets relevant to this study

SDGs	Targets	Key targets
SDG 8	8.3	Encourage development-oriented policies that promote job creation and productive activities.
SDG 9	9.1	Develop reliable, quality, and sustainable infrastructure to support human well-being and economic development.
SDG 11	11.2	Provide sustainable and accessible transport for all and improve road safety.
	11.6	Reduce the adverse environmental effects of cities including air quality and municipal management.
SDG 13	13.3	Improve environmental awareness, education, and human capacity on climate change mitigation.
SDG 15	15.5	Protect biodiversity and reduce the degradation of natural habitats.
SDG 16	16.1	Reduce all forms of violence everywhere.
	16.7	Ensure inclusive, responsive, representative, and participatory decision-making processes at all levels.
	16.1	Guarantee public access to information and safeguard fundamental freedom in conformity with national policies and international treaties.
SDG 17	17.16	Improve partnerships for sustainable development through a multi-stakeholder partnership that shares knowledge and expertise.
	17.17	Promote and encourage effective public, civic society, and public–private partnerships.

Source: Authors' own based on United Nations (2018).

2 Methodology and study area

This study uses a qualitative research approach to explore how PP practices meet the expectations of the SDG framework. The study was designed based on the specific selected sustainable development goals and targets as presented in the introduction section. The semi-structured interviews were conducted with EIA stakeholders to explore key issues of PP in EIA. The interview approach is the best research tool for 'getting at the truth' as it gives a clear picture and a better understanding of the phenomenon under study (Ruane, 2011). A total of 16 EIA stakeholders participated in the interviews. The interviewees consisted of stakeholders responsible for the planning and implementation of EIA in Nigeria, including experts from the government regulating agencies, traditional leaders, EIA consultants, and non-governmental organization (NGO) representatives. Face-to-face interviews were conducted with community leaders and staff of the government agencies, while the remaining interviews were performed through phone calls with other stakeholders. The interview recordings were transcribed into a Microsoft Word document. Responders were anonymized, and their identities protected on the transcribed document as part of ethical considerations. The study participants were identified through existing personal contacts, and subsequent participants were recruited using a snowballing sampling technique until saturation point, as noted by Malterud et al. (2016). NVivo 12 qualitative data analysis software was used to perform thematic analysis of interview responses (Braun & Clarke, 2006; Thompson, 2021). The coding was performed deductively to allow the researcher to maintain focus on the research objectives. The coding was conducted by developing a set of primary themes based on the research framework to analyse stakeholder perceptions. These primary themes were further classified into sub-themes pertinent to the research objectives that were derived from the literature.

Abuja, the Nigerian capital, was considered a suitable case study because the city has a substantial number of ongoing road projects compared with other cities; the study area comprised five municipal council areas. Furthermore, the city represents a diverse socio-economic background

and has both rural and urban characteristics. Three road projects within the five municipal areas of Abuja were chosen to undertake the research using a purposive sampling technique.

3 Results and discussion

The core themes from the qualitative results of PP practices are analysed to determine the stakeholder perception of how wider PP and SDG policies were achieved (social and individual norms). These policies are closely related to different democratic ideals, as highlighted by several scholars (Baker & McLelland, 2003; Barton, 2002; Rega & Baldizzone, 2015). Additionally, the extent to which the participatory process mitigates the negative environmental effects of the projects and how SDG protocols were achieved are analysed. These protocols were derived from substantive and transactive philosophies and principles and supported by EIA literature on PP effectiveness. (Chanchitpricha & Bond, 2013; Loomis & Dziedzic, 2018; Theophilou et al., 2010). Table 2 summarizes the key terms of the principles and philosophies of the EIA effectiveness dimensions as outlined in the literature. This section provides insight into a detailed evaluation of how the participatory practice meets the expectation of SDG protocols.

Table 2: EIA effectiveness dimensions

Dimension	Explication
Normative effectiveness	Is the process democratic and representative?
	How are communities involved in shaping activities/plans and in all decision-making processes?
Substantive effectiveness	Are wider policy objectives attained?
	Does the EIA identify and mitigate negative environmental impact?
Transactive effectiveness	How do partnerships ensure all interested groups can participate and what are the ways to address inequality?

Source: Adapted and synthesized from Bond et al. (2018), Loomis and Dziedzic (2018), Chanchitpricha and Bond (2013), Wilson and Wilde (2003), and Burns and Heywood (2004).

3.1 Democratic capacity and practice (SDGs 16 and 17)

Democratic capacity and practice are among the core primary themes explored in this section, which are fundamental in achieving SDGs 16 and 17. Stoeglehner et al. (2009) recommended that democratic efficiency is a form of normative effectiveness, whereby the right decision can be made according to the norms of the populace. Participant responses were classified into three sub-themes. These include the articulation of public interest and influencing decision-making, the openness of decision-makers to participants' views, and access to project information. These sub-themes were adapted and supported by key literature (Glucker et al., 2013; Hartley & Wood, 2005; Kanu et al., 2018; Robinson & Bond, 2003). The detailed views on each of those sub-themes are discussed in the following sections.

3.1.1 Articulation of interest and influencing decision-making process

Articulation of participants' interest in the project design is an essential element of PP in the EIA process (Kanu et al., 2018). Barton (2002) further suggested that communities affected by a planned project need to give their consent and be allowed to influence the decision-making process. However, this has a link with the realization of Target 16.7. Participants' interests were not properly articulated in the project design as revealed by several actors during the interviews, with most of the community leaders explaining, 'we were not allowed to express our concerns during the project planning . . .' (CSH-CL_01).[3] Several issues were raised by the community leaders of Awawa, Yangoji, and Nyannya communities along the Nasarawa–Toto–Abaji Road and Abuja–Lokoja Road, relating to economic and social impacts of the project, such as dust and smoke during the construction period and traffic disturbance, including vehicle–animal collision. Furthermore, practitioners from non-government regulating bodies expressed their worries over the proponent attitudes towards the participants. An EIA consultant further exposed that 'they don't pay attention to the community interest . . .' (EIA-CONcol_01).[4] Thus, most of the views provided a broader overview of the lack of inclusive and responsive participatory practice that guarantees an inclusive decision-making process as established in Target 16.7.

This study further exposed that the host communities were not allowed to influence the decision-making process, although practitioners from government agencies perceived these benefits as being realized: 'we allow the public to influence the decision . . .' (GA-NESREA_02).[5] However, most study participants from non-regulating bodies and the community leaders lamented that both the regulators and the proponents offered little attention to community participation just because the project belongs to the government, which in turn limits the participants' ability to influence decisions during the project design. Therefore, the processes were characterized by political influence and administrative manipulation. A similar limitation was revealed by Hasan et al. (2018) in Bangladesh, where the public has limited influence in the decision-making process in most government projects. This is linked to the problems of weak institutional capacity and inadequate enforcement of environmental laws. Indeed, these are the key obstacles to EIA implementation in most Global South countries (Amechi, 2010; Hemba & Phil-Eze, 2021). In Nigeria, in particular, environmental and EIA laws are burdened with problems of ineffective application during the process (Brown, 2021). Looking at the global crisis of the COVID-19 pandemic, Enríquez-de-Salamanca (2021) believed economic recovery is a priority and EIA may be placed in a secondary position. This implies a greater bias that can favour the development overdue process, and this can affect the community's capacity to influence the decision-making process as well as attainment of SDGs.

3.1.2 Openness to stakeholders' views

The openness of decision-makers to stakeholders' views is another important driver in the attainment of SDGs, particularly Targets 16.7 and 17.16, which guaranteed an inclusive participatory process that shares knowledge and expertise (Ramirez-Rubio et al., 2019). The study further exposed that during the EIA panel review exercise the meeting was controlled by government officials and the proponents, and all community participants were considered passive members without capacity to enter into dialogue. Emphasis was placed on the one-way flow of

[3] 'CSH' indicates the code for community stakeholders. This and similar references throughout are interviewee IDs.

[4] 'EIA-CON' indicates the code for stakeholders from the EIA consultant.

[5] 'GA-NESREA' indicates the code for stakeholders from a government agency (National Environmental Standards and Regulations Enforcement Agency).

information from officials to citizens, with no opening for negotiation. Most community leaders revealed, 'our views were not considered . . .' (CSH-CL_02). Khan and Chaudhry (2021) discovered a similar practice in Pakistan, where the participation meeting was one-sided and used as an avenue just to inform rather than engage the public. However, the same experience was revealed from all communities except for one along Abuja–Abaji–Lokoja Road section IV, where they were allowed to express their concerns but, even then, their views and concerns were left unrecognized.

The EIA practitioners further clarified that in most cases, the process does not allow for different stakeholder views: 'they restrict the community inputs . . .' (EIA-CONcol_01). Consequently, an EIA consultant attributed this problem to the local people because they are often found to be 'inexperienced in attending participatory meetings . . .' (EIA-CONcol_03). That makes them silent participants instead. Thus, the process was conducted under restricted control, and the findings depict that participatory practice was not in accordance with Target 17.16, aimed at promoting multi-stakeholder partnerships to share knowledge and expertise from all stakeholders. It is evidenced that engagement with local communities can increase project ownership and trust (Erfani & Roe, 2020).

3.1.3 Access to projects information

Nigeria is one of the United Nations member states that affirms and guarantees freedom of expression and public access to information (Ayoubi et al., 2022). Despite this the current practice appears to be that host communities 'have little access to the project information . . .' (CSH-CL_05). This is a major barrier to EIA policy implementation (Ajulor, 2018; Amobi & Onyishi, 2015). On the one hand, practitioners from the government agencies explained that they strictly follow the EIA procedural guidelines during the processes: 'we ensure the public has access to the project information . . .' (GA-FMEV_03).[6], yet, in practice, the scenarios are different, as highlighted by several actors during the interviews. Target 16.10 recognizes the importance of access to information as a human right to all. However, most of the study participants highlighted non-access and non-disclosure of relevant project information during the participatory process, especially the environmental and social effects of the projects. These are particular challenges in most Nigerian projects and many Global South countries (Asiyanbi, 2016; Ayoubi et al., 2022; Baradei, 2020; Nuesiri, 2017).

The study further revealed that most times, community members do not pay attention to the project information, although this happens because of ignorance or lack of awareness on the part of community members as highlighted by their community leaders. Thus, the views collected revealed a mixture of responses surrounding PP practice, yet the majority are negative.

3.2 Mitigation of impact and economic and social sustainability

This section explores how the participatory process mitigates the negative environmental effects of the project and how wider EIA policy objectives, such as economic and social sustainability and partnership among the stakeholders, are achieved. The primary focus is on the realization of SDGs 8, 11, 15, 16, and 17. Bøss et al. (2021) stressed the importance of identifying what SDG objective was achieved because of application to improve performance. This section provides insight into a detailed evaluation of how the participatory practice meets the purposes for which it is designed.

[6] 'GA-FMEV' indicates the code for stakeholders from a government agency (Federal Ministry of Environment).

3.2.1 Mitigation of impact

Loomis and Dziedzic (2018) and Roos et al. (2020) observed that mitigation of negative impacts is one of the important benefits of EIA. Therefore, the involvement of the public in the impact identification process plays a significant role in project design (O'Faircheallaigh, 2010). Responses from all community leaders revealed that they were not allowed to contribute during the impact identification process, except for one community leader who participated during the scoping workshop. Likewise, the overwhelming views from EIA consultants and NGO groups voiced negative comments and revealed that there was little involvement of local communities at the preliminary stages of the process. During the review meeting to contribute to impact identification processes, an EIA consultant added, 'we were made to understand many communities were not involved during the scoping exercise . . .' (EIA-CONcol_05). Furthermore, there were some practical issues raised by some of the community leaders. For instance, in the context of communities along Abuja–Abaji–Lokoja Road section IV, most of the community members lack environmental awareness; their concern is always with the financial benefits of the project in terms of compensation. As a result, the proponents abuse the environmental protection protocols during the project implementation process.

Despite the limitations of lack of knowledge on environmental issues, some community members identified direct potential effects of noise, dust, and vehicular accident during project execution. However, the proponent failed to address these direct issues because they were raised after the final draft of the EIA reports. Yet 'those concerns have not been reflected in the post-EIA management plan', as narrated by an EIA consultant (EIA-CONcol_02). This indicates that issues of concern were not effectively reorganized and addressed through appropriate mitigation measures before implementing the project. A similar result was found by Kaku et al. (2022) on the eastern coast of Tanzania, where community concerns were not properly rationalized at the earliest stages of the EIA process, resulting in social and environmental effects. Looking at the global concern about the overall sustainability of the planet, SDGs 11 and 15 require the protection of biodiversity and the reduction of environmental effects on natural habitat. Therefore, the integration of the concept of environmental sustainability in the design and implementation of construction projects is part of sustainability protocols (Abastante et al., 2021). In the present study there were many negative responses from non-government regulating bodies, where they exposed the reduced attention paid to environmental protection protocols during the project implementation process.

3.2.2 Economic and social sustainability

Improving economic and social sustainability is one of the fundamental objectives of the EIA. Bond et al. (2016) argue that a legitimate IA is one that is consistent with environmental and social sustainability. However, it is paramount to understand how the participatory process promotes economic and social sustainability, such as conflict resolution, job creation, empowerment, and partnership among the stakeholders, which are part of PP policy objectives (Bond et al., 2013; Burton, 2004; Lawrence, 2013; Roos et al., 2020). Most of the responses from all study participants revealed positive feedback relating to conflict resolution (fewer social conflicts). Most of the community leaders affirmed that the involvement of local communities has assisted in resolving social conflict. A community leader stated, 'We step-in in resolving conflict between the company and the youths' group . . .' (CSH-CL_04). This was because of community opposition over the company's inappropriate behaviour in handling the project. The community movement group was organized to protect the entire community's interest and is responsible for promoting environmental protection programmes. Thus, the practice conformed with Target 16.1 aiming to reduce all forms of violence everywhere.

Target 8.3 encourages development-oriented programmes that promote job creation and productive activities. The lack of job opportunities and poor commitment to community empowerment by the proponents were among the issues raised by the study participants. The participatory process has not resulted in any direct jobs for members of the communities except in two cases. Although Roos et al. (2020) believed that the creation of job opportunities is part of the economic benefits of EIA, scholars recognized that issues of sustainable development should cut across job creation and empowerment of citizens, to address social issues and promote economic and social development (Heras-Saizarbitoria et al., 2021; Tan, 2019).

Furthermore, Targets 17.16 and 17.17 encourage multi-stakeholder partnerships to share knowledge and expertise. Similarly, the World Bank traced the need for multi-stakeholder partnerships in the IA process (Loayza, 2012). Most of the study participants exposed that there was close collaboration among the various relevant government agencies (representing federal, state, and local government) and the proponents (project developers), with little consideration for other stakeholders, particularly the affected communities, NGOs, and community-based organizations. An EIA consultant revealed, 'collaboration with NGOs and community-based organizations was very low except in a few cases . . .' (NGO-SH_01).[7] A community leader further revealed that 'community-based organizations were excluded from the process . . .' (CSH-CL_03). Similar limitations were found by Ashade and Mutereko (2021) in the public–private partnership of infrastructural projects in Nigeria, where there were no inclusive partnerships with community groups. However, the finding further revealed that collaboration is more effective in communities that are closer to the centre than in other communities that are far away from the city centre, for the fear of agitation due to their level of awareness and influence.

3.3 Summary of findings

The qualitative findings suggest that public engagement practice does not meet the expectations of sustainability frameworks, except for Target 16.1 where the practice was in line with the expectation of SDGs. However, the attainment of SDG 17 is questionable because partnerships in the process were limited to government-related agencies rather than a multi-stakeholder partnership (see Table 3).

Table: 3 Summary analysis of the SDG achievement

SDGs	Targets	Achievement	Key point
SDG 8	8.3	_	Does not conform with expectations of the SDG framework
SDG 9	9.1	_	Does not conform with expectations of the SDG framework
SDG 11	11.2	_	Does not conform with expectations of the SDG framework
	11.6	_	Does not conform with expectations of the SDG framework
SDG 13	13.3	_	Does not conform with expectations of the SDG framework
SDG 15	15.5	_	Does not conform with expectations of the SDG framework
SDG 16	16.1	+	Conforms with expectations of the SDG framework
	16.7	_	Does not conform with expectations of the SDG framework
	16.1	_	Does not conform with expectations of the SDG framework
SDG 17	17.16	?	The partnerships are limited to government-related agencies only.
	17.17	?	The partnerships are limited to government-related agencies only.

Source: Authors' own.

[7] 'NGO-SH' indicates the code for stakeholders from a non-governmental organization.

4 Conclusion and recommendations

This article has focused on analysing how public engagement practices meet the expectations of the SDG framework in three large road construction projects in Nigeria. To achieve the research objectives, the paper was developed based on SDGs 8, 9, 11, 13, 15, 16, and 17. The outcome of the analysis exposed limited access to project information, a lack of inclusive participatory process, and a lack of opportunities to influence decision-making. This implies manipulation in the processes due to weak institutional capacity and inadequate enforcement of environmental laws. Besides, partnerships among stakeholders were limited to government agencies neglecting the host communities.

In the context of conflict resolution, most responses have gained positive feedback, where the participatory process helps in resolving conflicts arising during projects implementation; this is in line with Target 16.1 that aims to reduce all forms of conflicts everywhere, aimed at ensuring peaceful and inclusive societies that are safe and free from fear of violence. The participatory process does not provide opportunities for job creation and empowerment, and other negative issues raised include a lack of attention to environmental protection protocols by the developers resulting in several environmental effects. Furthermore, the views of practitioners from government-regulating agencies are contrary to practical application, as expressed by other study participants.

This study provides a comprehensive summary of the crucial issues arising from PP practice in Nigeria, especially in road construction projects. We merely wish to raise the idea that PP practice is not in line with the expectations of sustainability frameworks. Nevertheless, to achieve progress toward global sustainable development, particularly in Global South countries, a range of actions could be taken to improve performance. Based on the outcome of this study, we highlight the following recommendations.

- Reduction in administrative bureaucracies and enforcement of environmental rules should be strengthened, to ensure the enforcement of laws, policies, and standards and encourage multi-stakeholder and community partnership at all levels.
- The integration of EIA and SDGs can be a catalyst for achieving the SDGs while addressing long- and medium-term goals, promoting youth empowerment, job creation, access to information, inclusive participatory process, and fighting systematic manipulation and corruption.
- Institutional and behavioural changes are needed, to improve best practices. Thus, commitment to international protocols and treaties on sustainability frameworks (the provision of international agreement) shall be strictly followed and monitored.
- Community awareness campaigns should be strengthened on the importance of sustainable development goals and targets at all tiers of government, federal, state, and local councils to speed up the implementation process.
- The national policy on the environment shall establish a systematic periodic review, to monitor the gaps in SDG implementation, and ensure transparency and appropriate implementation of the EIA.

5 References

Abastante, F., Lami, I. M., & Gaballo, M. (2021). Pursuing the SDG11 targets: The role of the sustainability protocols. *Sustainability*, *13*(7), Article 3858. https://doi.org/10.3390/su13073858

Ajulor, O. V. (2018). The challenges of policy implementation in Africa and sustainable development goals. *International Journal of Social Sciences*, *3*(3), 1497–1518. https://doi.org/10.20319/pijss.2018.33.14971518

Albu, D. (2021). The sustainable development goals report 2021. *Drepturile Omului*, 2, Article 115.

Amechi, E. P. (2010). Linking environmental protection and poverty reduction in Africa: An analysis of the regional legal responses to environmental protection. *Law, Environment and Development Journal*, *6*, 112–129.

Amobi, D., & Onyishi, T. (2015). Governance and climate change in Nigeria: A public policy perspective. *Journal of Policy and Development Studies*, *9*(2), 199–209. https://doi.org/10.12816/0011217

Ashade, O., & Mutereko, S. (2021). Building trust and support for partnership agendas through the requisites of early community involvement. *African Journal of Inter/Multidisciplinary Studies*, *3*(1), 270–281. https://doi.org/10.51415/ajims.v3i1.874

Asiyanbi, A. P. (2016). A political ecology of REDD+: Property rights, militarised protectionism, and carbonised exclusion in Cross River. *Geoforum*, *77*, 146–156. https://doi.org/10.1016/j.geoforum.2016.10.016

Ayoubi, L., Fernandez Gibaja, A., & Hudson, A. (2022). *To recovery and beyond: 2021 UNESCO report on public access to information (SDG 16.10. 2)*. https://unesdoc.unesco.org/ark:/48223/pf0000380520

Baker, D. C., & McLelland, J. N. (2003). Evaluating the effectiveness of British Columbia's environmental assessment process for first nations' participation in mining development. *Environmental Impact Assessment Review*, *23*(5), 581–603. https://doi.org/10.1016/S0195-9255(03)00093-3

Baradei, L. (2020). Politics of evidence based policy making: Reporting on SDG 16 in Egypt. *International Journal of Public Administration*, *43*(5), 425–440. https://doi.org/10.1080/01900692.2019.1668414

Barton, B. (2002). Underlying concepts and theoretical issues in public participation in resources development. In Zillman, D. M., Lucas, A., Pring, G. R. (eds), *Human rights in natural resource development: Public participation in the sustainable development of mining and energy resources*. Oxford Academic, pp. 77–120. https://doi.org/10.1093/acprof:oso/9780199253784.003.0003

Bebbington, J., & Unerman, J. (2018). Achieving the United Nations Sustainable Development Goals: An enabling role for accounting research. *Accounting, Auditing & Accountability Journal*, *31*(1), 2–24. https://doi.org/10.1108/AAAJ-05-2017-2929

Bøss, E. R., Kørnøv, L., Lyhne, I., & Partidario, M. R. (2021). Integrating SDGs in environmental assessment: Unfolding SDG functions in emerging practices. *Environmental Impact Assessment Review*, *90*, Article 106632. https://doi.org/10.1016/j.eiar.2021.106632

Bond, A., Morrison-Saunders, A., & Howitt, R. (2013). Framework for comparing and evaluating sustainability assessment practice. In A. Bond, A. Morrison-Saunders, & R. Howitt (Eds.), *Sustainability assessment: Pluralism, practice and progress*. Routledge. https://doi.org/10.4324/9780203112625

Bond, A., Pope, J., Morrison-Saunders, A., & Retief, F. (2016). A game theory perspective on environmental assessment: What games are played and what does this tell us about decision making rationality and legitimacy? *Environmental Impact Assessment Review*, *57*, 187–194. https://doi.org/10.1016/j.eiar.2016.01.002

Bond, A., Retief, F., Cave, B., Fundingsland, M., Duinker, P., Verheem, R., & Brown, A. (2018). A contribution to the conceptualisation of quality in impact assessment. *Environmental Impact Assessment Review*, *68*, 49–58. https://doi.org/10.1016/j.eiar.2017.10.006

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brombal, D., Moriggi, A., & Marcomini, A. (2017). Evaluating public participation in Chinese EIA. An integrated Public Participation Index and its application to the case of the New Beijing Airport. *Environmental Impact Assessment Review*, *62*, 49–60. https://doi.org/10.1016/j.eiar.2016.07.001

Brown, C. (2021). The legislative and institutional framework for compliance and enforcement in the petroleum sector in Nigeria: A review. *International Journal of Advanced Multidisciplinary Research and Studies*, *1*(2), 23–33.

Burns, D., & Heywood, F. (2004). *Making community participation meaningful: A handbook for development and assessment*. Policy Press.

Burton, P. (2004). Power to the people? How to judge public participation. *Local Economy*, *19*(3), 193–198. https://doi.org/10.1080/0269094042000253608

Chanchitpricha, C., & Bond, A. (2013). Conceptualising the effectiveness of impact assessment processes. *Environmental Impact Assessment Review*, *43*, 65–72. https://doi.org/10.1016/j.eiar.2013.05.006

Enríquez-de-Salamanca, Á. (2021). Project justification and EIA: Anything goes? *Environmental Impact Assessment Review*, *87*, Article 106540. https://doi.org/10.1016/j.eiar.2020.106540

Erfani, G., & Roe, M. (2020). Institutional stakeholder participation in urban redevelopment in Tehran: An evaluation of decisions and actions. *Land Use Policy*, *91*, Article 104367. https://doi.org/10.1016/j.landusepol.2019.104367

Erin, O. A., Bamigboye, O. A., & Oyewo, B. (2022). Sustainable development goals (SDG) reporting: an analysis of disclosure. *Journal of Accounting in Emerging Economies*, *12*(5), 761–789. https://doi.org/10.1108/JAEE-02-2020-0037

Glasson, J., & Therivel, R. (2019). *Introduction to environmental impact assessment* (5th ed.). Routledge. https://doi.org/10.4324/9780429470738

Glucker, A. N., Driessen, P. P., Kolhoff, A., & Runhaar, H. A. (2013). Public participation in environmental impact assessment: Why, who and how? *Environmental Impact Assessment Review*, *43*, 104–111. https://doi.org/10.1016/j.eiar.2013.06.003

Hartley, N., & Wood, C. (2005). Public participation in environmental impact assessment: implementing the Aarhus Convention. *Environmental Impact Assessment Review*, *25*(4), 319–340. https://doi.org/10.1016/j.eiar.2004.12.002

Hasan, M. A., Nahiduzzaman, K. M., & Aldosary, A. S. (2018). Public participation in EIA: A comparative study of the projects run by government and non-governmental organizations. *Environmental Impact Assessment Review*, *72*, 12–24. https://doi.org/10.1016/j.eiar.2018.05.001

Hemba, S., & Phil-Eze, P. O. (2021). Implementation of EMP in EIA follow-up of oil and gas projects in the Niger Delta region of Nigeria: A case of Bayelsa and Rivers states. *Environmental Research, Engineering and Management*, *77*(1), 96–108. https://doi.org/10.5755/j01.erem.77.1.23960

Heras-Saizarbitoria, I., Urbieta, L., & Boiral, O. (2021). Organizations' engagement with sustainable development goals: From cherry-picking to SDG-washing? *Corporate Social Responsibility and Environmental Management*, *29*(2), 316–328. https://doi.org/10.1002/csr.2202

Hopper, T. (2018). Stop accounting myopia – think globally: A polemic. *Journal of Accounting & Organizational Change*, *15*(1), 87–99. https://doi.org/10.1108/JAOC-12-2017-0115

Ibeh, C., & Walmsley, B. (2021). *The role of impact assessment in achieving the sustainable development goals in Africa*. In IAIA21 Smartening impact assessment in challenging times. International Association for Impact Assessment (IAIA) 2021 conference, 18–21 May. International Association for Impact Assessment.

Kaku, P. M., Zhu, H., & Fangninou, F. F. (2022). Evaluation of the EIA process in Zanzibar: The participation of stakeholders in public and private projects. *Environment, Development and Sustainability*, 1–21. https://doi.org/10.1007/s10668-022-02334-2

Kanu, E. J., Tyonum, E. T., & Uchegbu, S. N. (2018). Public participation in environmental impact assessment (EIA): A critical analysis. *Architecture and Engineering*, *3*(1), 7–12.

Khan, M., & Chaudhry, M. N. (2021). Role of and challenges to environmental impact assessment proponents in Pakistan. *Environmental Impact Assessment Review*, *90*, Article 106606. https://doi.org/10.1016/j.eiar.2021.106606

Kørnøv, L., Lyhne, I., & Davila, J. G. (2020). Linking the UN SDGs and environmental assessment: Towards a conceptual framework. *Environmental Impact Assessment Review*, *85*, Article 106463. https://doi.org/10.1016/j.eiar.2020.106463

Lawrence, D. P. (2013). *Impact assessment: Practical solutions to recurrent problems and contemporary challenges*. John Wiley & Sons.

Loayza, F. (2012). *Strategic environmental assessment in the World Bank: Learning form recent experience and challenges*. World Bank. https://doi.org/10.1596/27119

Loomis, J. J., & Dziedzic, M. (2018). Evaluating EIA systems' effectiveness: A state of the art. *Environmental Impact Assessment Review*, *68*, 29–37. https://doi.org/10.1016/j.eiar.2017.10.005

Malterud, K., Siersma, V. D., & Guassora, A. D. (2016). Sample size in qualitative interview studies: Guided by information power. *Qualitative Health Research*, *26*(13), 1753–1760. https://doi.org/10.1177/1049732315617444

Nuesiri, E. O. (2017). Feigning democracy: Performing representation in the UN-REDD funded Nigeria-REDD programme. *Conservation and Society*, *15*(4), 384–399. https://doi.org/10.4103/cs.cs_16_106

O'Faircheallaigh, C. (2010). Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making. *Environmental Impact Assessment Review*, *30*(1), 19–27. https://doi.org/10.1016/j.eiar.2009.05.001

Odey, G. O., Alawad, A. G. A., Atieno, O. S., Carew-Bayoh, E. O., Fatuma, E., Ogunkola, I. O., & Lucero-Prisno III, D. E. (2021). COVID-19 pandemic: Impacts on the achievements of sustainable development goals in Africa. *The Pan African Medical Journal*, *38*, Article 251. https://doi.org/10.11604/pamj.2021.38.251.27065

Partidário, M., & Verheem, R. (2019). Impact assessment and the sustainable development goals (SDGs). *FasTips*, *19*(May). https://www.iaia.org/uploads/pdf/Fastips_19%20SDGs.pdf

Ramirez-Rubio, O., Daher, C., Fanjul, G., Gascon, M., Mueller, N., Pajín, L., Plasencia, A., Rojas-Rueda, D., Thondoo, M., & Nieuwenhuijsen, M. J. (2019). Urban health: An example of a 'health in all policies' approach in the context of SDGs implementation. *Globalization and Health*, *15*(1), 1–21. https://doi.org/10.1186/s12992-019-0529-z

Rega, C., & Baldizzone, G. (2015). Public participation in strategic environmental assessment: A practitioners' perspective. *Environmental Impact Assessment Review*, *50*, 105–115. https://doi.org/10.1016/j.eiar.2014.09.007

Robinson, M., & Bond, A. (2003). Investigation of different stakeholder views of local resident involvement during environmental impact assessments in the UK. *Journal of Environmental Assessment Policy and Management*, *5*(01), 45–82. https://doi.org/10.1142/S1464333203001267

Roos, C., Cilliers, D., Retief, F., Alberts, R., & Bond, A. (2020). Regulators' perceptions of environmental impact assessment (EIA) benefits in a sustainable development context. *Environmental Impact Assessment Review*, *81*, Article 106360. https://doi.org/10.1016/j.eiar.2019.106360

Ruane, J. M. (2011). *Essentials of research methods: A guide to social science research*. Blackwell Publishing.

Senadjki, A., Awal, I. M., Nee, A. Y. H., & Ogbeibu, S. (2022). The belt and road initiative (BRI): A mechanism to achieve the ninth sustainable development goal (SDG). *Journal of Cleaner Production*, *372*, Article 133590. https://doi.org/10.1016/j.jclepro.2022.133590

Stoeglehner, G., Brown, A., & Kørnøv, L. B. (2009). SEA and planning: 'Ownership' of strategic environmental assessment by the planners is the key to its effectiveness. *Impact Assessment and Project Appraisal*, *27*(2), 111–120. https://doi.org/10.3152/146155109X438742

Tan, S. (2019). Achieving goal 16 of the sustainable development goals and environmental lessons for Malaysia. *TRaNS: Trans-Regional and-National Studies of Southeast Asia*, *7*(2), 233–269. https://doi.org/10.1017/trn.2019.9

Theophilou, V., Bond, A., & Cashmore, M. (2010). Application of the SEA directive to EU structural funds: Perspectives on effectiveness. *Environmental Impact Assessment Review*, *30*(2), 136–144. https://doi.org/10.1016/j.eiar.2009.08.001

Thompson, K. (2021). Introduction to qualitative analysis with NVivo. https://ir.lib.uwo.ca/wlpres/80/

United Nations. (2018). *The 2030 agenda and the Sustainable Development Goals: An opportunity for Latin America and the Caribbean*. LC/G.2681-P/Rev.3. United Nations Santiago.

Wilson, M., & Wilde, P. (2003). *Benchmarking community participation: Developing and implementing the active partners benchmarks*. Joseph Rowntree Foundation York.

Relationship between complexity and perception of aesthetics

A case study of the Modern Movement in architecture

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Abstract: Aesthetic preferences and the aesthetics of the environment are crucial topics for environmental psychology and the perception of the built environment. Even though people might not consciously focus on the aesthetic qualities of the objects in their daily lives, studies suggest that aesthetics has an impact on people's well-being and psychological health. The experience achieved by aesthetics more often involves the individual's feeling towards an object, and different objects and forms can trigger various sensations for people. When people have a positive feeling about a place, it can help them love the place and appreciate its value. When the Modern Movement started to be seen in architecture, its focal point was improving the living standards of people, which did not necessarily focus on aesthetic qualities or preferences in the first place. Furthermore, it created a new architectural language and aesthetic expression. With the famous quote of Louis Sullivan, 'form follows function', a new era began where aesthetics was not the priority but the consequences of design. This research aims to assess via an experiment the impact of aesthetic qualities and the relationship between complexity and aesthetics on the evaluation of Modern Movement façades. The experiment investigated whether modifications affect appreciation of a structure. Participant responses were assessed using a Likert scale. The results demonstrated that the relationship between complexity and aesthetics also affects the evaluation of the Modern Movement, and the interim complexity is more likely to be appreciated for this style as well.

Keywords: aesthetics, built environment, Modern Movement, perception, preference

1 Introduction

Need and preference are different concepts, not only in the subject of aesthetics but also in our daily lives. People might require various elements for the continuity of their lives; however, their values or preferences can improve their quality of life. Especially the events of the last couple of years with the impact of the COVID-19 pandemic have made people realize the importance of health in their lives and how the place they inhabit can affect or contribute to their well-being, both physically and mentally. As Mastandrea et al. (2019) state, the positive emotions people get from aesthetic experiences can change their mood and indirectly promote health. However, aesthetic preferences or aesthetic appreciations are often shaped by an individual's perception and senses, which makes them intrinsic. The experience achieved by aesthetics more often involves the individual's feelings towards an object and their prior knowledge.

According to various research, the aesthetic experience is also linked with aesthetic pleasure (Leder et al., 2004; Silvia, 2005). As Démuthová and Démuth (2017) explain, when people experience beauty, their brain releases epinephrine, dopamine, phenylethylamine, and endorphins. Therefore, aesthetics not only is related to the reward systems at cognitive levels but also has a physical impact. Nowadays, researchers are aware of aesthetics playing a central role in judgements of one's built environment (Brielmann et al., 2022). However, the connection between aesthetics and judgement of the built environment is still a debate and not fully proven. The perception of an environment has various indicators, which are established by the impact they create on the users. According to Buxton (2005), design is more related to the experience of the user rather than the creation of products. In architecture and perception of the architecture, one of the most critical impacts can be created by façades, which can be regarded as the display of the design. When the Modern Movement era in architecture started, the impact of buildings on the built environment started to decrease. As Samalavičius (2017) states, architectural modernism was primarily an isolated enterprise practised by small groups of vanguard architects and artists before the Second World War, and only established itself as a ruling ideology, aesthetics, and praxis in the post-war era. Therefore, buildings did not contain prior knowledge for the observers. Performing an analysis of the façades of structures can give valuable information about the aesthetic perception of the built environment as they are more likely to be judged by their physical characteristics. A pilot experiment is performed in this study as part of broader research in Kaunas, Lithuania, which aims to assess the impact of aesthetic qualities and the relationship between complexity and aesthetics on Modern Movement façades.

Section 1 introduces the topic of perception and aesthetic perception in general and in architecture. Section 2 provides information about the impact of architecture and aesthetics on the well-being of people. Section 3 analyses the characteristics of the Modern Movement and its aesthetic perception. Section 4 explains the pilot experiment and reveals the scores achieved for each selected building. Finally, the last section discusses the experiment's outcome.

2 Aesthetic perception, built environment, and well-being

Aesthetic perception is not any different from other modes of perception, but it has a more dominant outcome. It reveals emotions such as pleasure or displeasure. According to Shusterman (2013), evaluation of aesthetics occurs by the emotions associated with the bodily and behavioural changes that objects evoke during an interaction. However, according to Scruton (2013), aesthetic pleasure is not the reflection of the immediate response of the senses, such as reflexive behaviour. Instead, it is shaped by the thought process of the people. As stated in various research, most of

the time, people tend to choose visual objects that have been demonstrated to them previously (Reber et al., 2004; Zajonc, 2000). This is due to the emerging familiarity, which can suggest that the objects are less harmful and more likely to increase the feeling of pleasure. As Xenakis and Arnellos (2014) state, aesthetic perception creates a potential for connection, which results in reducing uncertainty. As a result, the aesthetic qualities or features catalyse the observer's first interaction for communication. Aesthetics is related to identifying and comprehending various factors that contribute to perceiving an object or a process considered beautiful (Ghomeishi, 2021). These factors can be physical but they can also be related to cultural memories or the experiences people have. Therefore, the aesthetic perception or the pleasure gained by aesthetics is a different kind of pleasure that depends on knowledge.

Aesthetically pleasing involvements provide people with a pleasurable sensory experience, a pleasing perceptual structure, and a pleasurable symbolic association (Gjerde, 2010). Since perception is purposive and selective, if an object does not contain any data, mental image, or memory created previously, the perception of that object might be problematic. Perception of the built environment can also be considered the same. Using patterns and symbols that people associate themselves with can help to establish a connection and make people feel comfortable in a given environment because of the existing mental images. According to Stamps (2000), in most urban design principles, architectural façades can be identified as a reference to a two-dimensional plane as they have a silhouette in that plane. However, they are not merely expressive sculptures; they also have a function and they carry associations. The main aim of an architect might not be to design a beautiful building, but it still requires them to design one that is aesthetically pleasing for the people who will inhabit that environment. As Jam et al. (2022) state, the building façade has considerable effects on the aesthetic experience of observers, and when people spend time in aesthetically pleasing spaces, it can contribute to their well-being. Also, a salutogenic design, which can specifically be used in hospitals or other health institutions, has the ability to stimulate and engage people both mentally and socially and can support an individual's sense of control (Dilani, 2012). As stated in *The Handbook of Salutogenesis*, substantial evidence and research demonstrate that aesthetic design changes in healthcare settings can influence and improve health outcomes for patients (Mittelmark et al., 2017). Therefore, these principles can be used in other building designs as well.

The origin of architecture was to create a shelter that protected people from danger. From the beginning, architecture aimed to decrease the stress that circumstances and conditions of an environment could cause. The sense of scale achieved by architecture in the environment can also give a calming or stressing effect that originates from people's emotional memory from years of evolution. However, the aesthetic characteristics of the environment can affect stress levels as well. For example, curved lines establish the impression that the observed object is not dangerous, whereas spikey lines seem to be perceived as hurtful. As Ulrich (1995) states, environments can affect a variety of health indicators, such as anxiety and blood pressure. Therefore, the aesthetic choices made while designing an environment can be highly influential. Furthermore, the ambient features of the interiors, such as the existence of plants, natural light, and artworks, can change the perception of a room. However, according to Dijkstra et al. (2006), various research demonstrate that adding natural elements only caused a slightly positive effect on the participants of the experiments. Therefore, the impact of natural elements on the perception of people and their behaviour requires further investigation to find better architectural solutions in design.

Scholars suggest various methods for evaluating the design of architectural objects. For example, Yin (2019) attempted to develop a measurable index that can evaluate the aesthetic performance of each geometry in contemporary buildings, whereas Ilbeigi and Ghomeishi (2017) used content analysis to analyse the difference between perceptions of architects and non-architects about the evaluation of architectural façades. However, the evaluation of physical characteristics related to

the architectural style, especially the evaluation of Modern Movement artefacts, is a relatively under-examined topic. The artefacts of this era aimed to establish an architecture that is hygienic and full of light, which has a positive effect on people's mental health. However, due to their design principles, these structures have a generic nature derived from their universal and international style. Therefore, these characteristics can establish a disconnection and lack of prior knowledge. Furthermore, blank façades without ornamentation can affect complexity levels. It can be beneficial to investigate the characteristics of these structures to understand the relationship between complexity, aesthetics, and perception.

3 Aesthetics of the Modern Movement

The approach towards design underwent a crucial change when the Modern Movement occurred in architecture. The design of spaces started to focus more on requirements rather than the preferences of users. According to Brielmann et al. (2022), modernist architecture challenges the cognition of people rather than supporting it. Therefore, even though the main focus in this era was the user itself, the preferences of users living in the environment were not considered.

According to Auping (2002), Tadao Ando stated that, in most cases, the products of modern architecture have no stories to tell, and they are purely functional without messages that can stir the imagination of people. Its geometrical forms and neutral-coloured façades establish its own architectural language; however, it is not related to any traditionally appreciated aesthetic values. Therefore, it merely exists without provoking the audience in any aspect. While the pioneers of this era attempted to establish a sense of presence and scale, these characteristics of the structures did not create a crucial impact on the built environment they were constructed in. Furthermore, the floating outer walls that started to be used in this period affected people's perception of mass because of their more fragile form. Machine aesthetics, first defined by the renowned Swiss-French architect Le Corbusier, emerged as another level of perception of aesthetics that focused on functionality, standardization, and rationalization in both the plan and the façades of the structures. The surface volume, flexibility, and regularity also started to be used as aesthetic principles. While in streamline modernism, the horizontal lines had a curvilinear character, the school of Bauhaus used more cubic forms, which express sharp edges. Ellard's (2015) research in psychology and aesthetics suggests that people choose curved contours universally, even in different contexts ranging from simple shapes to typography. They perceive curves as softer, more inviting, and more beautiful, and they perceive notched edges as harder, more repulsive, and signifying risk. The presentation of curves produces strong activation in brain areas associated with reward and pleasure, whereas notched edges can increase activity in people's response systems (Vartanian et al., 2011). Therefore, the aesthetics of Bauhaus might have affected laypeople's perception of the environment and architectural objects.

One of the elements commonly seen in the Modern Movement era was the plate glass with bigger openings that established the connection between inner and outer space. However, according to various research on psychology and ecology, people prefer to see more than be seen (Sale, 1969; Appleton, 1975; Ellard, 2015). This characteristic was developed by people's ancestors who used to live in natural environments and it is still valid in people's behaviours in urban settings. Therefore, the feeling of continuously being on display can create discomfort. Furthermore, this era intended to establish a design that could be acceptable for everybody. However, this approach caused people to not have a connection with these structures. Hence, when these buildings are evaluated by laypeople, either as an object in the environment or as cultural heritage, they tend to be seen as more disposable. Replacement of structures can result from losing function, but if the function still exists, it can be from not being appreciated as a form because they do not have a

novelty. Therefore, it might be possible to state that characteristics of the physical form of modernist structures might not have novelty in most cases.

In the modernist era, the building design was standardized, and blank façades became common design characteristics. According to the research performed by the eye-tracking glasses, when the façades contain blank surfaces, most of the gaze does not scan these areas (Doğan, 2020) because of insufficient information for visual attention. However, the complexity of the stimulus is an essential determinant of visual attention as well as aesthetic preferences. As stated by Delplanque et al. (2019), for an object to be aesthetically preferred, it should neither be too simple nor too complex as these characteristics can trigger either boredom or distraction for the observer. The complexity level can directly impact the aesthetic perception of a façade. According to the experiment regarding façades performed by Imamoglu (2000), people prefer the intermediate levels of complexity compared with minimum and maximum levels. Furthermore, according to Reis and Dias Lay (2010), excessive simplicity with a lack of diversity and visual richness establishes an inadequate visual motivation for people, which establishes a negative impression. Therefore, in most cases, blank façades are not well appreciated. However, simple façades do not necessarily mean that the façade is blank. The bandings on the plasters or using different materials can keep the surfaces interesting. Furthermore, the effects in the three-dimensional spatial configuration might keep the people engaged with the surface. However, the feature of being unexpected is one of the essential triggers for people that catches their attention because curiosity is one of the crucial catalysers. Therefore, the non-existence of small details can establish an impact. When people have less attention, they will not spend an effort to focus on these areas, and the perception of the façade can be unpleasant for the people. To analyse all these factors that might affect the perception of the Modern Movement façades, an experiment is performed.

4 Experiment

4.1 Method

This experiment aims to collect data about the relationship between complexity and aesthetic appreciation of the façades of various buildings with the expression of the Modern Movement. The data were collected by an online survey published in May 2021 (Figure 1). The drawings used in the experiment were prepared by measuring the structures on the site and sketching them by vector-based software. In the survey, three variations of seven different building drawings were used. The buildings were selected from the designated properties of the UNESCO nomination file of Kaunas (Lithuania). In the first stage, the buildings were drawn as they are, and none of the characteristics of the façades were manipulated. Subsequently, the main characteristics of the buildings were deleted, such as ornaments, bandings on the plaster, column capitals, and any object that gave the façade a different identity. Lastly, the vertical lines and continuous windowsills were deleted to establish a minimal structure appearance (Figure 1).

This research attempted to gain insight into which kind of façades individuals would prefer to see in their environment. In the design of the experiment, a qualitative approach and non-probability sampling were adopted. With a purposive and convenience sampling technique, 128 responses were collected from the participants in the experiment. However, 125 responses were found valid since some participants did not answer all the questions. The participants were requested to fill out the survey in which they were asked to evaluate the drawings of façades on a Likert scale from 1 to 10, where 1 represented the criterion ‘not attractive’ and 10 represented ‘very attractive’, according to their preferences. Additionally, the snowball sampling method was adopted in selecting the participants. The potential participants willing to take part in the experiment were

asked to transfer the experiment. Participants were heterogeneous regarding age, which ranged from 15 years to 60 years and older (15–24 years: 10, 25–39 years: 63, 40–59 years: 35, 60+ years: 17). Furthermore, participants were also heterogeneous for gender (female: 71, male: 51, prefer not to say: 3). Therefore, the criteria of age and gender were found irrelevant to the experiment; however, the data were collected for information.

Figure 1: Collage of the demonstrated drawings

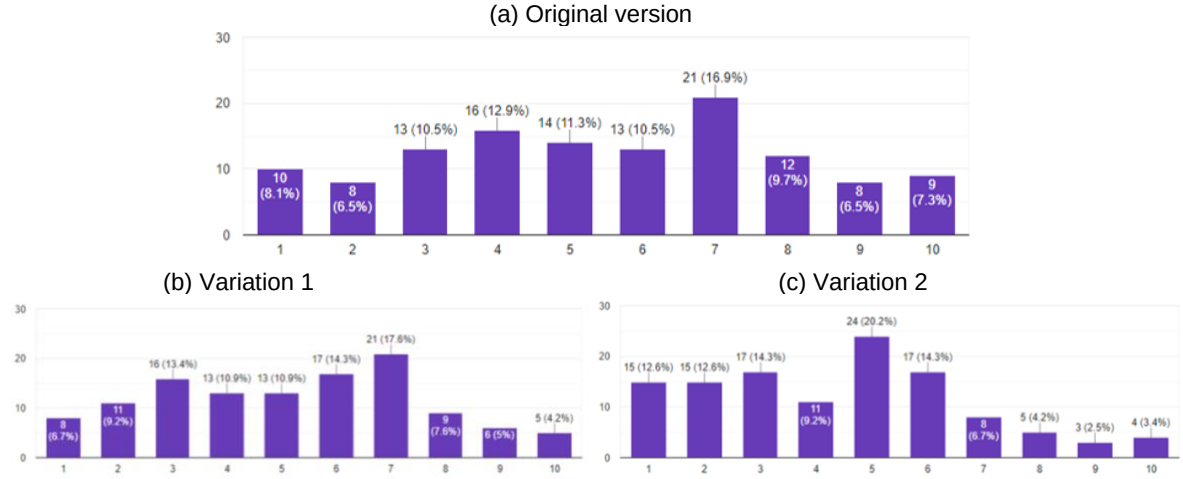
Source: Author's own.

4.2 Analysis and results

One of the limitations of the experiment is that it was only performed on individual façades, and they were not analysed in the built environment for their relationship with other structures. Not considering the impact of context on perception might produce arguable results. However, this investigation is part of broader research and will be extended. The same methodology will also be implemented on other façades from different eras in the future. Starting the investigation with the Modern Movement era was found to be beneficial because most of the time these structures are not well appreciated by the non-experts (Doğan, 2018). The analysis revealed various outcomes for each building.

In the first building, the distinctive entrance with an arch changed to a more rectangular form for evaluation. According to the results, making this change and lowering the complexity did not establish a significant difference. The highest score (score of 7) that the participants gave was for the original design of the building (Figure 2a), and for the manipulated version in which the specific entrance changed (Figure 2b). Finally, the version in which the building had a minimalist approach was evaluated with a score of 5 by the participants, which was the lowest out of all three variations (Figure 2c).

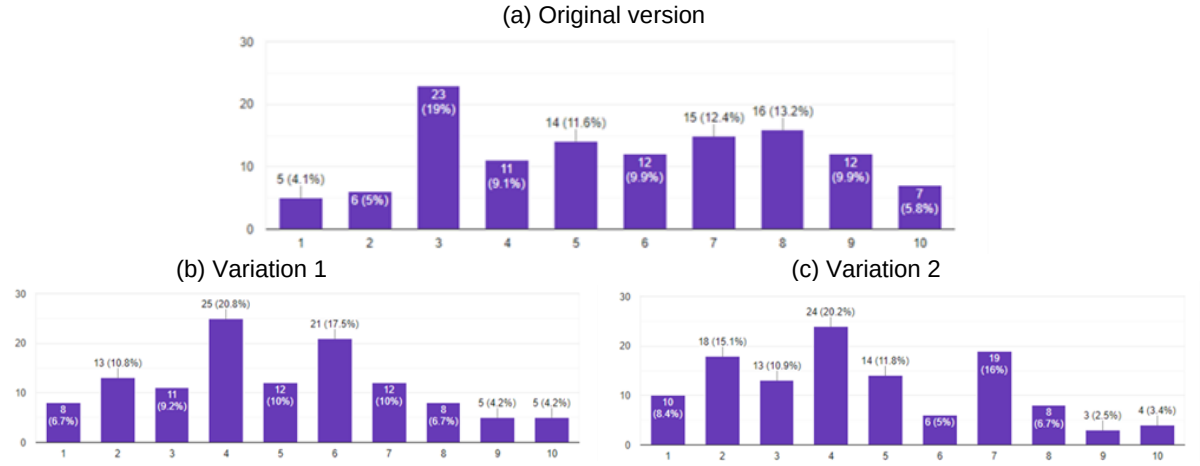
Figure 2: Results for Building 1



Source: Author's own.

The second building also had a distinctive entrance with porthole windows and a unique door, which is part of the composition of the entrance. When the drawings were manipulated for this building, the porthole windows were turned into rectangular windows and the door was changed to a basic door. Furthermore, the horizontal emphasis created by the windowsills and the banding on the plaster was changed by shortening the windowsills and deleting the bandings. After these changes, when the building was shown to the participants, their preference was towards the less complex variation of the façade rather than the original one. While the original façade scored 3 (Figure 3a), both manipulated versions of the structure were evaluated higher and scored 4 by the participants (Figure 3b and 3c).

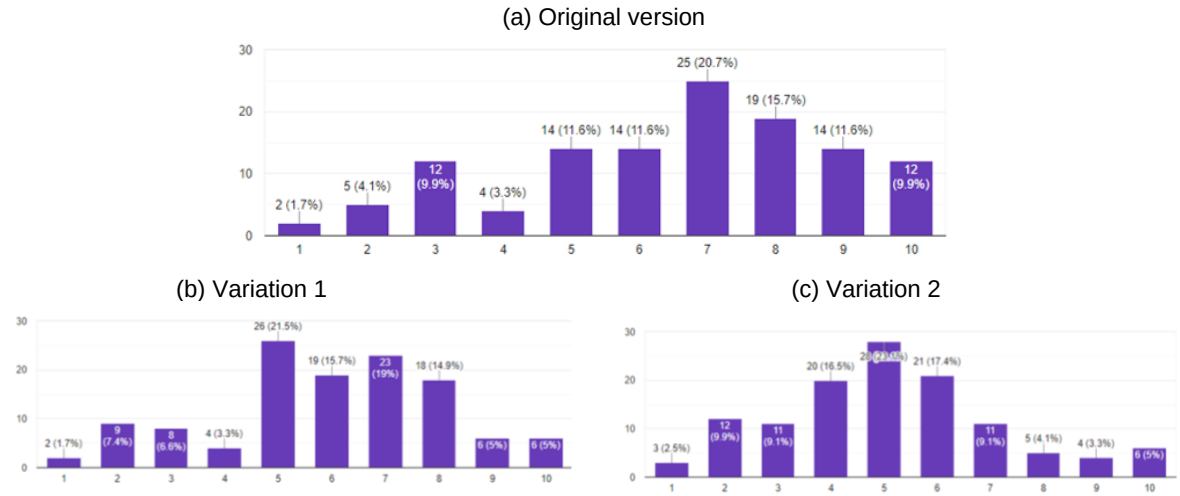
Figure 3: Results for Building 2



Source: Author's own.

The original design of the third building contained elements such as circles and rectangular parts on the façade that were achieved by creating different levels on the plaster and a stepped gable that hides most of the roof. In the process of changing the façade, the circular and rectangular elements were deleted in the first variation. In the second variation, the stepped gable and the difference in the elevation of the roof were changed into a straight line. According to the survey answers of the participants, the original version of the building scored 7 (Figure 4a), whereas the other two versions scored 5 (Figure 4b and 4c).

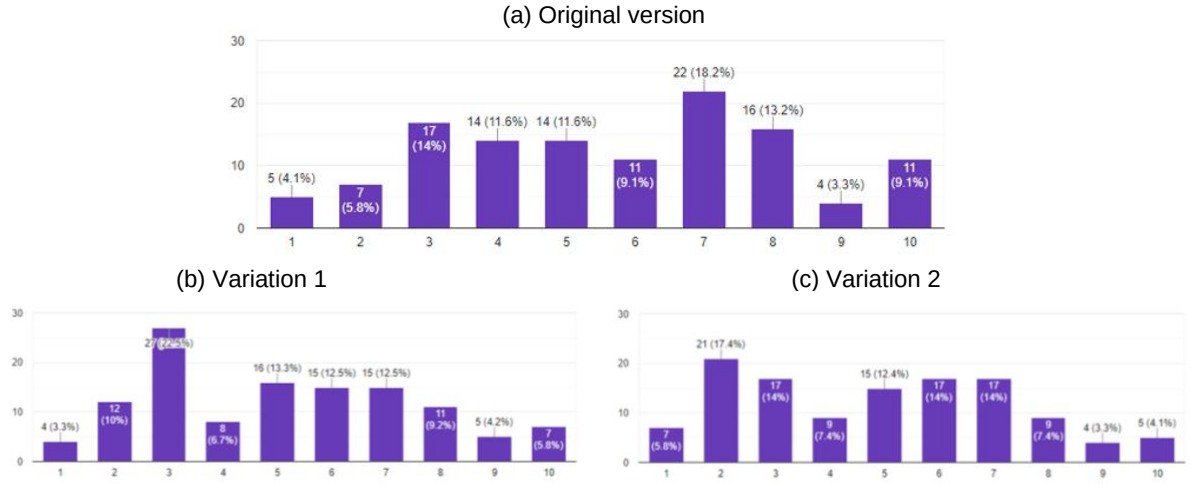
Figure 4: Results for Building 3



Source: Author's own.

The fourth building is one of the buildings with unique Modern Movement elements on its surface. In the process of preparing different variants of this façade, first of all, the circle elements on the façade that were achieved by creating different levels on the plaster, bandings, small façade mouldings, and the decorative door were deleted. For the second variation, the windowsills establishing the horizontal impact were deleted and only under the window frames were kept. After these changes, when the building was shown to the participants, the original design of the façade scored 7 (Figure 5a), and although the more minimalist variation scored 2 (Figure 5c), the variation with the more horizontal emphasis scored 3 (Figure 5b).

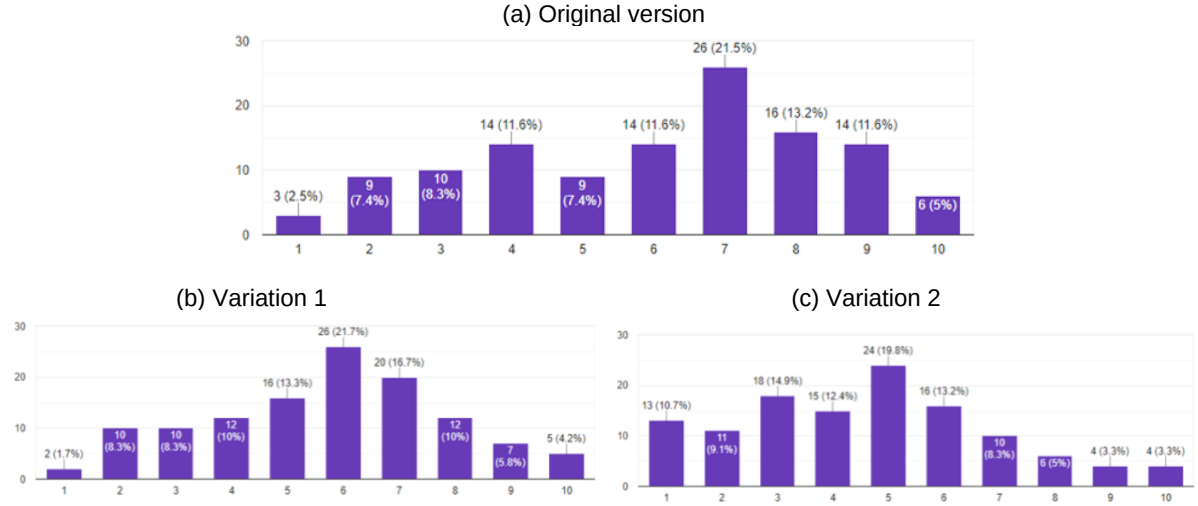
Figure 5: Results for Building 4



Source: Author's own.

The fifth building had a peculiar entrance with a keystone impression on top of the vertical emphasis, which also established an elevation change on the parapet of the roof. Furthermore, it had a façade moulding between the floors and bandings on the plaster between the windows. In the first variation, the keystone and the façade mouldings were deleted. In the second variation, the monumental entrance was changed entirely (including the horizontal elements on the window frames), and the bandings between the windows were deleted. Moreover, the elevation change on the roof was moved to the same level. Based on these changes, the participants gave the first variation a score of 6 (Figure 6b) and the second variation a score of 5 (Figure 6c). The original façade was given a score of 7 (Figure 6a).

Figure 6: Results for Building 5



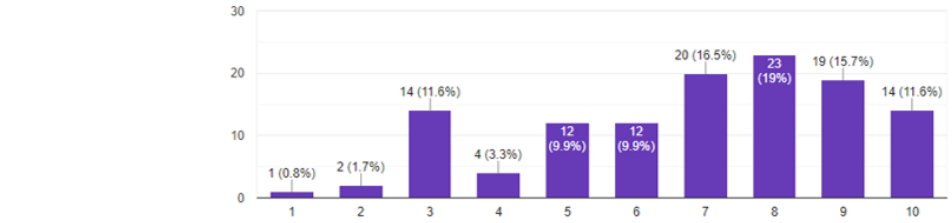
Source: Author's own.

The original design of the sixth building was one of the most decorated façades in this survey. The building contained circular ornaments in a rectangular boundary between the first- and second-floor windows. There were circles and floral elements on top of the entrance doors. Moreover, between the second-floor windows, there were columns with capitals. The building had a vertical emphasis, with different elevation levels at the parapet of the roof. For the first variation, the decorative elements were deleted. For the second variation, the elements that establish the vertical emphasis and the different elevations on the roof parapet were also erased. After all these changes,

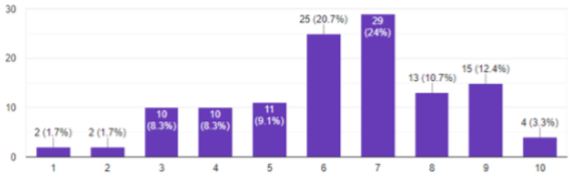
when the drawings were shown, the highest score was given to the original version of the building (Figure 7a). The first variation without the ornaments achieved a score of 7 (Figure 7b) and the most minimalist version of the façade achieved a score of 5 (Figure 7c).

Figure 7: Results for Building 6

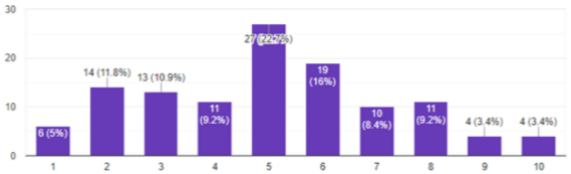
(a) Original version



(b) Variation 1



(c) Variation 2

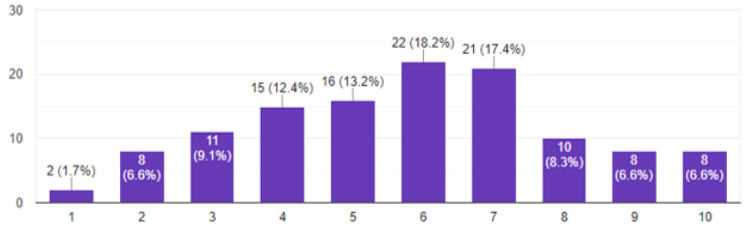


Source: Author's own.

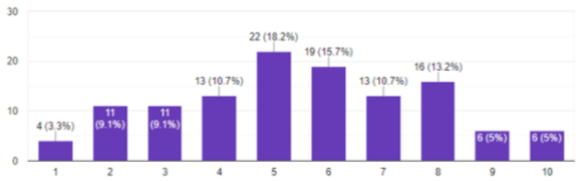
The last building of the survey also contained dominant Modern Movement characteristics. On the façade of the structure, circle elements on the top floor were achieved by creating different levels on the plaster. In addition, it had bandings, small façade mouldings, mouldings around the windows, vertical decorative elements, and a unique door. In the first variation, the elements that gave the building its Modern Movement characteristics were deleted, except the door. The horizontal elements on top of the door and the garage entrance were erased. In the second variation, the mouldings around the windows and the mouldings connecting the windows, which gave a horizontal emphasis, were erased and changed into more individualistic windows. According to the results, the original design of the building achieved a score of 6 (Figure 8a). Interestingly, the most minimalist form of the façade also scored 6 (Figure 8c) and the first variation of the façade scored 5 (Figure 8b).

Figure 8: Results for Building 7

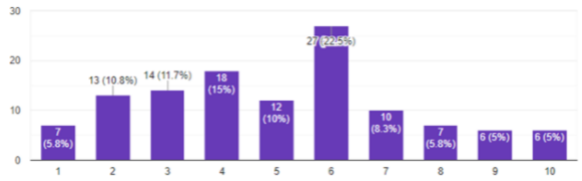
(a) Original version



(b) Variation 1



(c) Variation 2



Source: Author's own.

5 Discussion and conclusion

An environment not only influences the way people think but it also influences the way they feel. One essential characteristic that affects how people feel about the architecture surrounding them is aesthetic qualities. People's interaction with an object or artefact begins with their senses. Still, consideration must be given to the notion that such interaction is also down to the individual's memories, prior knowledge, and experiences. As such, aesthetic qualities not only establish a reaction as a reflex but they also catalyse the feelings attached to these qualities. When the Modern Movement era started, people only had the chance to evaluate architecture with their senses and without the help of their past experiences. However, it might be easier to associate or connect with traditional artefacts since they have been subject to ongoing interaction with people for centuries. Therefore, evaluation of Modern Movement structures could only be achieved by assessing the physical qualities, and it could not be entirely judged as aesthetic perception because it did not involve prior knowledge.

The pilot experiment performed in this research demonstrated that when the Modern Movement façades were compared with their variations, most of the time, the original designs were identified as attractive. The only building that was not found as attractive in its original design was the second building. This is most likely for two different reasons. The first reason is that the façade lacked harmony between its circular and rectangular elements, because converting all the circular elements into rectangular shapes in one of the variations affected the attractiveness levels positively. Even though symmetry is not commonly seen in Modern Movement artefacts, regularity is one of its characteristics. Therefore, the use of different geometrical forms might have established eclectic apparel to the Modern Movement building, which was not well appreciated. The second reason is the increased complexity levels due to these different geometrical forms. As was proven by extensive research, complexity has an impact on the perception of aesthetics in architectural objects. The characteristics of the Modern Movement with no ornaments and blank façades tend to reduce the impact of curiosity, which affects the attractiveness levels negatively. However, in the case of this building, mixed usage of the circular and rectangular forms increased the complexity levels to maximum, and it might have reduced the attractiveness. The experiment showed that the relationship between complexity and aesthetics also affects the evaluation of the Modern Movement, and the interim complexity is more likely to be appreciated for this style as well.

The experiment also revealed that the problem regarding the perception of Modern Movement may not be merely its characteristics and aesthetic qualities but to what it is compared. If they are examined in contrast to monumental and traditional architecture, they are less likely to be appreciated. Furthermore, as the original versions were chosen for the experiment over more neutral and minimalistic versions of the same buildings, it is conceivable that designing minimalistic structures in the surroundings of the Modern Movement buildings might help to evaluate them more positively within their surroundings. It should be noted that the results of the present experiment only include individual façades. Therefore, the impacts that can be established in an environment cannot be generalized. Nevertheless, this research can serve as a starting point for analysing the perception of Modern Movement façades individually and within their environments for their aesthetic qualities. However, such issues still require more detailed research in future investigations.

6 References

Appleton, J. (1975). *The experience of landscape*. Wiley Publishing.

Auping, M. (2002). *Seven interviews with Tadao Ando*. Profile Books.

Brielmann, A. A., Buras, N. H., Salingaros, N. A., & Taylor, R. P. (2022). What happens in your brain when you walk down the street? Implications of architectural proportions, biophilia, and fractal geometry for urban science. *Journal of Urban Science*, *6*(3), 1–35. https://doi.org/10.3390/urbansci6010003

Buxton, B. (2005). Experience design vs. interface design. *Rotman Magazine*, *1*, 47–49.

Delplanque, J., De Loof, E., Janssens, C., & Verguts, T. (2019). The sound of beauty: How complexity determines aesthetic preference. *Acta Psychologica*, *192*, 146–152. https://doi.org/10.1016/j.actpsy.2018.11.011

Démuthová, S., & Démuth, A. (2017). Evolutionary and cognitive aspects of beauty (attractiveness). *Kaygı*, *28*, 145–158. https://doi.org/10.20981/kaygi.310255

Dijkstra, K., Pieterse, M., & Pruyn, A. (2006). Physical environmental stimuli that turn healthcare facilities into healing environments through psychologically mediated effects: Systematic review. *Journal of Advanced Nursing*, *56*(2), 166–181. https://doi.org/10.1111/j.1365-2648.2006.03990.x

Dilani, A. (2012). The influence of design and architecture on health. *Journal of Health Management*, *12*(4), 10–17.

Doğan, H. A. (2018). Impact of memento value on the perception of cultural heritage: Case study of the Modern Movement and the dialect of Kaunas. *Journal of Science: Future of Lithuania*, *10*, 1–7. https://doi.org/10.3846/mla.2018.1064

Doğan, H. A. (2020) Perception of the Modern Movement in architecture as cultural heritage. *Journal of Art History & Criticism*, *16*(1), 65–78. https://doi.org/10.2478/mik-2020-0004

Ellard, C. (2015). *Places of the heart: The psychogeography of everyday life*. Bellevue Literary Press.

Gjerde, M. (2010, May). Visual aesthetic perception and judgement of urban streetscapes. In P. Barret (Ed.), *Building a better world, 18th CIB World Building Congress* (pp. 12–22), Salford. https://www.irbnet.de/daten/iconda/CIB18896.pdf

Ghomeishi, M. (2021). Aesthetic preferences of laypersons and its relationship with the conceptual properties on building façade design. *Journal of Asian Architecture and Building Engineering*, *20*(1), 12–28. https://doi.org/10.1080/13467581.2020.1782209

Ilbeigia, M., & Ghomeishi, M. (2017). An assessment of aesthetics in conceptual properties and its relation to complexity among architects and non-architects in residential façade design in Iran. *Journal of Buildings and Sustainability*, *2*(1), 50–58.

Imamoglu, C. (2000). Complexity, liking and familiarity: Architecture and non-architecture Turkish students' assessments of traditional and modern house facades. *Journal of Environmental Psychology*, *20*, 5–16. https://doi.org/10.1006/jevp.1999.0155

Jam, F., Azemati, H. R., Ghanbaran, A., Esmaily, J., & Ebrahimpour, R. (2022). The role of expertise in visual exploration and aesthetic judgment of residential building façades: An eye-tracking study. *Psychology of Aesthetics, Creativity, and the Arts*, *16*(1), 148–163. https://doi.org/10.1037/aca0000377

Leder, H., Belke, B., Oeberst, A., & Augustin, D. (2004). A model of aesthetic appreciation and aesthetic judgments. *British Journal of Psychology*, *95*, 489–508. https://doi.org/10.1348/0007126042369811

Mastandrea, S., Fagioli, S., & Biasi, V. (2019). Art and psychological well-being: Linking the brain to the aesthetic emotion. *Journal of Frontiers in Psychology*, *10*, 739–745. https://doi.org/10.3389/fpsyg.2019.00739

Mittelmark, M. B., Sagy, S., Eriksson, M., Bauer, G. F., Pelikan, J. M., Lindström, B., & Espnes, G. A. (2017). *The handbook of salutogenesis*. Springer Publishing. https://doi.org/10.1007/978-3-319-04600-6

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality and Social Psychology Review*, *8*(4), 364–382. https://doi.org/10.1207/s15327957pspr0804_3

Reis, D. L. A. T., & M. C. Dias Lay. (2010). Internal and external aesthetics of housing estates. *Journal of Environment and Behaviour*, *42*(2), 271–294. https://doi.org/10.1177/0013916509334134

Sale, P. (1969). Pertinent stimuli for habitat selection by the Juvenile Manini, *Acanthurus triostegus sandvicensis*. *Journal of Ecology*, *50*(4), 616–623. https://doi.org/10.2307/1936250

Samalavičius, A. (2017). Questioning architectural modernism and the built environment: Notes on cultural texts and contexts. In *Rethinking modernism and the built environment* (pp. 1–15). Cambridge Scholars Publishing.

Scruton, R. (2013). *The aesthetics of architecture*. Methuen. https://doi.org/10.1515/9780691240374

Shusterman, R. (2013). Affective cognition: From pragmatism to somaesthetics. *Journal of Intellectica*, *2,* 49–68. https://doi.org/10.3406/intel.2013.1056

Silvia, P. J. (2005). Emotional responses to art: From collation and arousal to cognition and emotion. *Review of General Psychology Journal*, *9*, 342–357. https://doi.org/10.1037/1089-2680.9.4.342

Stamps, A. E. (2000). *Psychology and the aesthetics of the built environment*. Kluwer Academic Publishers. https://doi.org/10.1007/978-1-4757-6326-3

Ulrich R. S. (1995) Effects of healthcare interior design on wellness: Theory and recent scientific research. In S. O. Marberry (Ed.), *Innovations in Healthcare Design* (pp. 88–104). Van Nostrand Reinhold Publishing.

Vartanian, O. (2011). Impact of contour on aesthetic judgments and approach–avoidance decisions in architecture. *Proceedings of the National Academy of Sciences*, *110*(2), 10446–10453. https://doi.org/10.1073/pnas.1301227110

Yin, Y. K. (2019). Building facade multi-objective optimisation for daylight and aesthetical perception. *Journal of Building and Environment*, *156*, 178–190. https://doi.org/10.1016/j.buildenv.2019.04.002

Xenakis, I., & Arnellos, A. (2014). Aesthetic perception and its minimal content: A naturalistic perspective. *Journal of Frontiers in Psychology*, *5*, 1038–1053. https://doi.org/10.3389/fpsyg.2014.01038

Zajonc R. B. (2000). Feeling and thinking: Closing the debate over the independence of affect. In *Feeling and thinking: The role of affect in social cognition* (pp. 31–58). Cambridge University Press.

Managing unsolicited public–private partnership proposals by adopting a competitive, fair, and transparent tendering method

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Abstract: Infrastructure development is proportional to a country's rate of economic growth. As a result, every government allocates a significant amount of its budget to infrastructure development. However, the majority of regimes are unable to finance infrastructure development on their own. Public–private partnerships (PPPs) are becoming a more popular instrument for sharing roles in the provision of public services with the private sector. In practice, there are two basic approaches to launching a PPP: solicitation and un-solicitation. Due to their potential to tap the private sector's distinctive ideas and innovations, unsolicited PPP proposals have been increasingly popular in recent years in both emerging and established countries. Numerous countries banded unsolicited PPPs as they were frequently associated with anti-competitive behaviour. Therefore, various countries have used different managerial strategies to deal with unsolicited PPP proposals. One of these strategies is to use a competitive, fair, and transparent tendering process. However, although there are different approaches to creating a competitive, fair, and transparent tendering procedure for unsolicited PPPs, this study developed a conceptual framework that can be used to envision the optimal tendering approach suitable for a host country.

Keywords: public–private partnership, tendering method, unsolicited proposal

1 Introduction

The ability of most governments to provide adequate infrastructure for their inhabitants significantly outpaces population growth and urbanization (Singh & Wayal, 2019). Thus, government efforts have been looking for a way to share responsibilities in the provision of public services, which have historically been under government authority (Ball, 2011; Telliford, 2009). Accordingly, public–private partnership (PPP) has been promoted as a new mode of delivering infrastructure projects (Burger & Hawkesworth, 2011; Fernando & Chandanie, 2018; International Monetary Fund, 2006; Parker, 2009; Singh & Wayal, 2019).

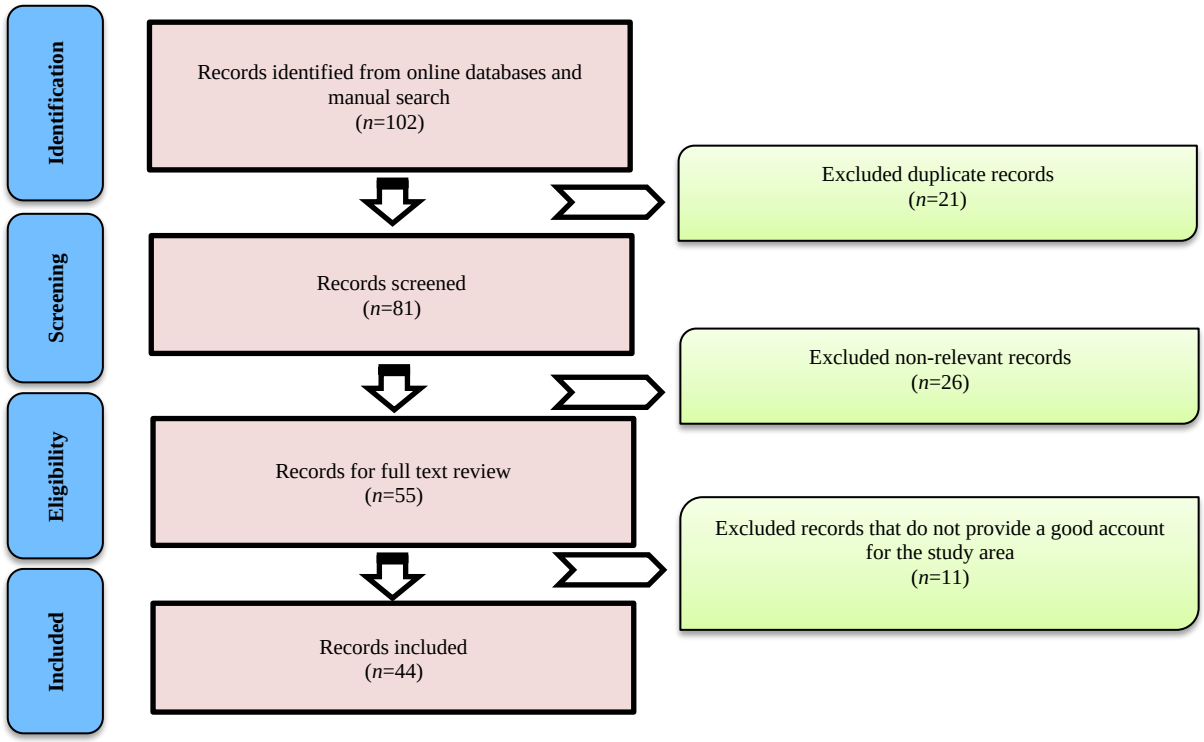
PPP is a long-term alliance between a government agency and a private sector consortium to deliver public assets or services, with the private sector bearing considerable risks and administrative responsibilities (Kelly, 2016; World Bank, 2021). In practice, PPP initiatives can be launched in one of two ways: solicitation or un-solicitation (Public–Private Infrastructure Advisory Facility [PPIAF], 2014; Yun et al., 2015). In the solicited approach, the government identifies a project and then seeks private investors to submit bids and fund it (PPIAF, 2014; World Bank, 2021). In contrast, the unsolicited approach is a private investor presenting a proposal to the government without first receiving a formal invitation from a public agency in pursuit of commercial prospects (Aziz & Nabavi, 2014; Hodges & Dellacha, 2007). The biggest international procurement frameworks, such as the Asian Development Bank, the European Bank for Reconstruction and Development, the United Nations Commission on International Trade Law (UNCITRAL), and the World Bank, have acknowledged and recognized unsolicited proposals (USPs) as a mode of procurement of PPPs (Hodges & Dellacha, 2007; PPIAF, 2014; Verma, 2010; UNCITRAL, 2020b). Neves and Kim (2017) stressed that approximately 30% of projects recorded in the World Bank's Private Participation in Infrastructure Database are unsolicited and World Bank (2017a) viewed that unsolicited PPP bids have become more popular in both industrialized and developing countries in recent years. According to Yun et al. (2015) and Zawawi et al. (2016), the use of unsolicited PPPs is still widely supported by governments, as they allow for faster project delivery and avoid the time-consuming process of competitive tendering. In contrast, Delmon (2015) and Farquharson et al. (2011) argued that since unsolicited PPPs are frequently associated with anti-competitive practices such favouritism, corruption, the misuse of public funds, and incompetence, several countries have taken steps to abolish unsolicited PPPs. Nevertheless, if unsolicited PPPs are managed properly, they allow governments to draw into the private sector's innovative ideas and concepts (PPIAF 2012; World Bank, 2017a). This study aims to explore how to manage unsolicited PPPs by adopting competitive, fair, and transparent bidding processes to mitigate the anti-competitive behaviour that is commonly associated with them.

2 Research methodology

In research, literature reviews are carried out for various purposes (Okoli & Schabram, 2010). A methodical approach to conducting a research study is made simpler with the help of a systematic literature review, which also lessens researcher bias (Khallaf et al., 2018). In addition, a comprehensive review of the literature enables researchers to collect and synthesize existing knowledge in a precise and consistent manner as well as establish a research gap and make recommendations for future studies (Okoli & Schabram, 2010). To address a particular area of interest, systematic reviews, such as the method of preferred reporting items for systematic reviews and meta-analyses (PRISMA), are rigorous studies compiling all relevant information that meets a predetermined set of eligibility criteria (Sohrabi et al., 2021). The PRISMA method is appropriate for literature reviews as it gathers information and produces formative assessments consisting of

all the essential facts pertinent to the area of research (Page et al., 2020). Thus, the PRISMA method was used in this study to search the relevant literature. Figure 1 illustrates the four steps that were followed to perform the literature review after identifying the research problem.

Figure 1: Flow diagram of study selection



Source: Authors' own.

Overall, 102 records from the Web of Science, Scopus, and Science Direct databases and from manual search citation were discovered by the search. Out of these records, 21 identical records were eliminated in total. Using the titles, keywords, and abstracts from the remaining 81 records, 26 of them were deemed to be irrelevant to the original study research question. Following that, the 55 documents that remained were turned over for a thorough review, and of those 55, 11 items were discarded as they were not specifically on PPP procurement. Accordingly, a complete literature synthesis was performed on the remaining 44 papers. Finally, based on a synthesis of the literature a conceptual framework was formed to minimize anti-competitive behaviour in procuring unsolicited PPPs.

3 Opportunities of unsolicited PPP proposals

Unsolicited PPPs are becoming more popular, showing that more governments are interested in using USPs to carry out PPP projects (PPIAF, 2014, 2017). Many governments are enthusiastic about unsolicited PPP proposals as they believe it is a faster method of procuring PPP projects than solicited proposals (Hodges, 2003; Queiroz, 2005; World Bank, 2017c). Hodges and Dellacha (2007) stated that unsolicited PPP projects are innovative ideas that are frequently not included in the public sector's infrastructure plan. The main reason for utilizing USPs in PPPs is the public sector's lack of technical and financial capacity to find, prioritize, and procure projects (PPIAF, 2009; World Bank, 2017c). As part of their submission, several unsolicited PPP proposals include a developed preliminary feasibility study and they give the public entity the advantage of getting an early appraisal of the projects' feasibility (PPIAF, 2017). In addition, according to PPIAF (2017),

by interacting with the private sector about potential risks and possibilities, USPs may help the government determine the market's interest in particular initiatives. As a result, adapting USPs to implement PPPs is significantly beneficial and provides development opportunities to government entities.

4 Challenges of unsolicited PPP proposals

Various researches and academic studies have highlighted impediments to accepting unsolicited PPPs, such as absence of best value for money (Nyagormey et al., 2020; Osei-Kyei & Chan, 2017), lack of fairness (Hodges & Dellacha 2007), allegation of corruption (Ballingall, 2014; PPIAF, 2014, 2017; World Bank, 2017a), strong political opposition and the abuse of power (Hodges & Dellacha 2007; PPIAF, 2014), and lack of transparency and competitive tendering process (Hodges 2003; Osei-Kyei et al., 2018; PPIAF, 2014; Zawawi et al., 2016). Some countries have consistently declined to procure PPPs through USPs because of the negative consequences of USPs (Yun et al., 2015; World Bank; 2017a). Aziz and Nabavi (2014) stressed that USPs, if not well managed, could result in numerous public protests and rallies, poor value for money, and failure to address a country's true sociological and economic needs. Protocols and processes to regulate the use of unsolicited PPP proposals have already been put in place in Argentina, Australia, Chile, China, the Philippines, South Africa, South Korea, Taiwan, and the United States (Virginia state) (Aziz & Nabavi 2014; Hodges & Dellacha 2007; PPIAF 2012). This has revealed that entertaining unsolicited PPPs present significant challenges to the government. There are several countries that have succeeded in establishing effective mechanisms for procurement of unsolicited PPPs and encouraging the private sector to approach the government with useful initiatives by mitigating said challenges.

5 Managing unsolicited PPP proposals

An in-depth analysis of a proposal's innovation, risks, and value for money is necessary for effectively managing unsolicited PPP proposals (PPIAF, 2009; World Bank, 2017a; Zhang, 2005). Government agencies are in charge of completing an extensive and thorough study of the value for money, risk, and innovation when private investors present specific project proposals or concepts. There is no accepted international standard for management of unsolicited PPP proposals. (PPIAF, 2017; UNCITRAL, 2020a). Most governments throughout the world embrace and acknowledge USPs by adopting various inbuilt management systems into their procurement procedures to mitigate the detrimental impact of USPs (Osei-Kyei et al., 2018; PPIAF, 2017; World Bank, 2017c). Table 1 lists the strategies utilized by developed and developing countries to deal with unsolicited PPP proposals.

It has been extensively reported that having a competitive, fair, and transparent tendering procedure is essential for properly managing unsolicited PPP proposals (Hodge 2003; Queiroz, 2005; Zawawi et al., 2022; Zheng & Tiong, 2010). Although competition does not always result in greater public benefit, it gives contracting authorities the ability to engage in more competitive conversations (Hodge 2003). The negative public impression that is frequently associated with the use of unsolicited PPPs is particularly reduced by competition and transparency (Queiroz, 2005).

When there is competition, public agencies are able to reach an agreement with the successful bidder on appropriate prices, maximizing the social benefits of unsolicited PPPs (Hodge, 2003;

PPIAF, 2009). Accordingly, adopting a competitive, fair, and transparent tendering method is one way of managing unsolicited PPPs.

Table 1: Strategies adopted to manage unsolicited proposals

No.	Strategy	Study											
		Ballingall (2014)	Hodges & Dellacha (2007)	Klaus (2011)	Osei-Kyei et al. (2018)	PPIAF (2012)	PPIAF (2014)	PPIAF (2017)	UNCITRAL (2000)	UNCITRAL (2020a)	World Bank (2017c)	Yun et al. (2015)	Zheng & Tiong (2010)
1	Stakeholder participation and extensive public consultation							x					
2	Existence of specific legislation/structured guidelines	x	x		x	x	x	x			x		
3	Assessment of value for money, innovation, cost, and risks of proposals				x	x	x	x				x	x
4	Competitive, fair, and transparent tendering process			x	x			x	x	x	x	x	x
5	Streamlining the proposal approval procedure		x			x	x						
6	Employment of PPP experts for evaluations of proposals				x	x	x						
7	Adequate government incentives and assurances	x			x				x	x		x	
8	Effective coordination between government agencies		x									x	x
9	Protection of the original proponent's intellectual property rights				x		x	x					

Source: Authors' own.

6 Competitive, fair, and transparent tendering method for unsolicited PPP proposals

Unsolicited PPP offers are frequently sole-sourced, which has contributed to the public's negative perception of its utilization (Hodges & Dellacha 2007). By incorporating competition and transparency into the management of unsolicited PPP offers, the public sector can select the most cost-effective offer and, more crucially, agree on contractual conditions that are in the best interests of the general public (PPIAF, 2014; Takano, 2021). According to Osei-Kyei et al. (2018) and PPIAF (2014), three methods for accepting USPs are routinely used in the industry: (i) directly negotiating with the original proposer, (ii) acquiring legal ownership of the project and moving it towards a competitive procurement procedure, and (iii) accepting an USP and turning it into a competitive procurement procedure. Hodges and Dellacha (2007) pointed out that direct negotiation for contract award leads to a lack of accountability and to corruption. Competitive tendering methods, such as the bonus system, best and final offer system, and Swiss challenge system, can be used to replace the conventional approach with a competitive procurement process for an unsolicited PPP proposal (Osei-Kyei et al., 2018; Zawawi et al., 2016; Zheng & Tiong, 2010). Sub-sections 6.1–6.5 discuss the said tendering methods in detail while Sub-section 6.6 summarizes the application of these methods in practice.

6.1 Direct negotiation method

Direct negotiation entails reviewing proposals and negotiating the technical and financial terms with the original proponent, once unsolicited PPP proposals are received by the government entity (Osei-Kyei et al., 2018; PPIAF, 2017; Søreide, 2006). The time and costs of the tendering process may be reduced by direct negotiation (Asian Development Bank, 2008). World Bank (2017b) and PPIAF (2017) stated that direct negotiations with a single business entity may promote corruption owing to a lack of transparency and competition, resulting in poor value for money. Furthermore, World Bank (2017b) stressed that corruption and poor monetary value have led to a ban on this method in various countries.

6.2 Purchased USP method

Once the USP is received from the private sector proponent, the public entity reviews the proposal to ensure that it aligns with the country's future infrastructure plan (Asian Development Bank, 2008; World Bank, 2017a). According to Asian Development Bank (2008), the government then compensates the initial proponent by obtaining the legal right to call competitive tenders. The original proponent can also participate in the tendering process, but no priority is given and the original proponent's offer is treated the same as the offers received from other bidders (Hodges & Dellacha, 2007). This procedure is comparable to the conventional contracting process after acquiring the legal right of the proposal by purchasing it (World Bank, 2017a).

6.3 Bonus method

In the bonus system, after the unsolicited PPP proposal is received by the government entity, which is then permitted to advance with the competitive tendering process, the original proponent receives a specified value in the form of a bonus (Hodges & Dellacha, 2007; Osei-Kyei et al., 2018). The application of additional theoretical value to the original proponent's technical or financial offer is solely for the purpose of bidding (PPIAF, 2014). However, the incentive must be reasonable in an effort to prevent other potential bidders from developing USPs (Hodges and Dellacha, 2007). If the original applicant withdraws their interest in the project or is unsuccessful in the competitive bidding process, the winning bidder must pay the first proposer back for the costs incurred during the proposal's development (Verma, 2010).

6.4 Swiss challenge method

In the Swiss challenge method, the original proposer has the right to counter-match leading or best proposals, if any, made by other bidders within a certain period of time (Hodges & Dellacha, 2007; PPIAF, 2014). It takes considerable time to come up with a counter-proposal and it stretches the period of tendering (Fernando, 2020; Osei-Kyei et al., 2018). If the first proposer's proposal is higher than or on par with the best offer made by a third party, the original proponent is selected to receive the project. If the initial proposer is unable to match the best third-party offer, the project is given to the leading third-party offeror (World Bank, 2017a). Potential tenderers for the Swiss challenge may believe that their chances of winning the offer are quite low (Hodges & Dellacha, 2007; Fernando, 2020; Ministry of Finance, 2019; Verma, 2010).

6.5 Best and final offer method

The best and final offer method is an effort to either strengthen the bonus system and the Swiss challenge method or to merge both (Osei-Kyei et al., 2018). Multiple bidding stages are a frequent characteristic of this innovation, offering a benefit for the initial proposer, who is always eligible for the last round of tendering (Hodges & Dellacha, 2007; Verma, 2010; World Bank, 2017c).

PPIAF (2014) stated that the project is tendered to solicit ideas from third parties, the offers are compared with the original proponent's offer, and the two most advantageous bids are selected. Finally, the best and final offers are called from the initial proposer and the two most advantageous bids selected, and the most economically favourable offer to the government is chosen from among these received final offers (PPIAF, 2014). In some countries, a decided bonus is granted to the original proponent in this method (Osei-Kyei et al., 2018).

6.6 Current application of tendering method for unsolicited PPP proposals

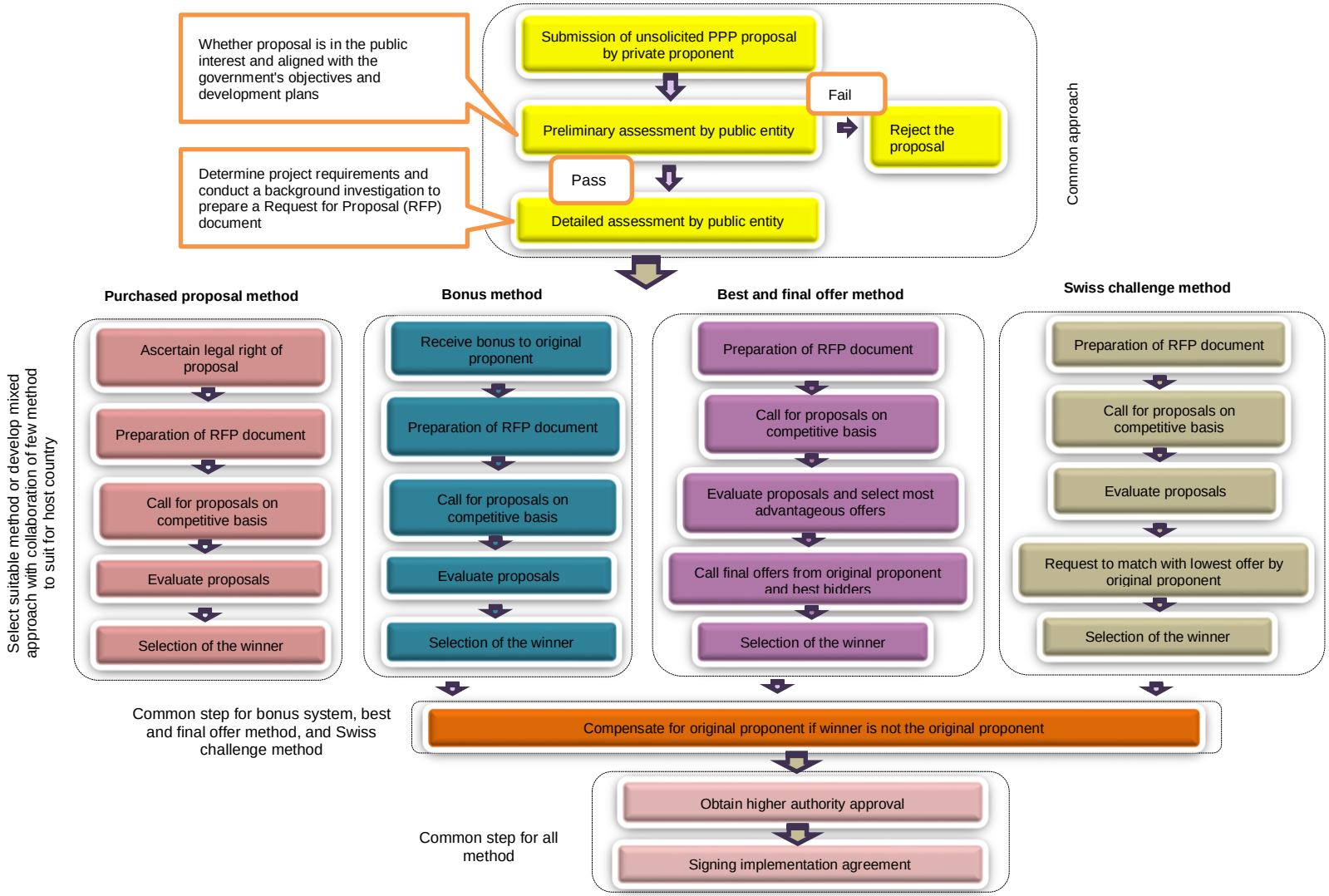
Different countries have used the Swiss challenge method, the bonus system, best and final offer method, or a mixed approach for converting unsolicited PPP proposals to competitive bids (Osei-Kyei et al., 2018; Zawawi et al., 2016). Peru and Philippines used the Swiss challenge method (PPIAF, 2014; Osei-Kyei et al., 2018); Chile, Jordan, Mexico, and South Korea used the bonus system (Hodges & Dellacha, 2007; World Bank, 2017c); Argentina and South Africa adopted the best and final offer method (Hodges & Dellacha, 2007; PPIAF, 2014); and Indonesia used a hybrid system that included the Swiss challenge method and the bonus system (PPIAF, 2014). In Sri Lanka, unsolicited PPP proposals were initially solely considered by calling competitive bids, and the original proponent was asked to submit the offer together with competitive tenders, with no additional benefits to the original proponent (Ministry of Finance and Planning, 1998). Later, unsolicited PPP proposals were allowed in Sri Lanka by direct negotiation with a specially designated expert committee (Ministry of Finance, 2011), and more recently the Swiss challenge technique was introduced to include unsolicited PPP proposals (Ministry of Finance, 2016). In the year 2019, the Swiss challenge method was abolished after a short period of its introduction, and government entities were instructed to continue with the competitive procedure without providing any further benefits to the initial proponent (Ministry of Finance, 2019).

Osei-Kyei et al. (2018) identified the common and most appropriate techniques for tendering of unsolicited PPP. According to their study, in practice, 50.9% cases used the conventional procurement method to handle unsolicited PPP proposals, whereas 14%, 10.5%, and 7% cases used the bonus system, best and final offer system, and Swiss challenge method, respectively. In contrast, 47% of respondents in their study suggested the best and final offer method as the ideal tendering procedure for turning unsolicited PPP proposals into competitive bids whereas 28.1%, 15.8%, and 8.8% respondents recommended the Swiss challenge method, bonus method, and conventional method as the best tendering techniques to entertain unsolicited PPP. According to Osei-Kyei et al. (2018), although the conventional (regular) procurement method is commonly used in procurement of unsolicited PPPs, the most recommended (suitable) method is the best and final offer method.

7 Conceptual framework for procurement of unsolicited PPP proposals

Few countries around the world have embraced the different approaches to put forward unsolicited PPP proposals for a competitive, fair, and transparent tendering method, as indicated in Section 6, whereas others are still looking for an appropriate framework to embrace unsolicited PPPs. Some countries, such as Sri Lanka, have implemented various procedures to include competitive, fair, and transparent tendering methods to procure unsolicited PPP proposals, but these systems have already been thrown out because of their inherent drawbacks. Therefore, a conceptual framework was developed, as shown in Figure 2, by taking into account different processes and tendering methods used to procure unsolicited PPPs to visualize an ideal tendering approach that is suitable for host countries.

Figure 2: Framework to develop a competitive, fair, and transparent tendering method



Source: Authors' own.

The first stage of an unsolicited PPP procurement begins with a private entity approaching a public body or line ministry with a proposal for a service or infrastructure project without getting a formal invitation from the government body, as depicted in Figure 2. Next, every unsolicited PPP proposal undergoes a preliminary evaluation to determine whether it is in the interest of the public and compatible with the goals and development plans of the government. If the project passes preliminary screening, it moves on to a detailed assessment to determine project requirements and conduct a background investigation to prepare a 'Request for Proposal' (RFP) document. If preliminary screening indicates that the project is not feasible, the proposal is rejected. Submission of an unsolicited PPP proposal to a government department or line ministry, preliminary screening, and detailed assessment are common initial steps for all tendering methods. Further, multiple procedures follow depending on the tendering method chosen.

In all methods, the preparation of the RFP document, the solicitation of offers, the evaluation of proposals, and the selection of the winner are all common steps. Ascertaining the legal right of the proposal by purchasing it via the purchased proposal method, granting a pre-defined bonus to the original proponent in the bonus method, calling final offers from the most advantageous bids and the original offer in the best and final offer method, and requesting the original proponent to match the lowest offer in the Swiss challenge method are all steps that are unique to the different methods.

In addition, if the eventual winner is not the original proponent, compensation to the original proponent is a regular step in the Swiss challenge method, the bonus system, and the best and final offer method. However, to award the contract and sign the implementation agreement, the government entity should first obtain formal approval from higher authorities in compliance with a host country's legislative framework.

8 Conclusion

This study presents the findings of a detailed analysis of previous research on unsolicited PPP tendering procedures. The systematic literature review determined that, in practice, there are two basic approaches to launching a PPP project: solicitation and unsolicitation. Unsolicited PPP proposals have grown in popularity in both developing and developed countries in recent years. USPs were banded in some countries to launch PPPs because they were frequently associated with anti-competitive behaviour. However, it was reported that unsolicited PPP proposals can offer governments the chance to tap into innovative thoughts and developments and provide a faster mode of procurement if they are managed properly. Adopting a competitive, fair, and transparent tendering procedure is one strategy for handling unsolicited PPP proposals.

Several countries have used the purchasing proposal method, Swiss challenge method, bonus system, best and final offer method, or a mixed approach, which combines a few methods, to convert USPs to competitive bids. According to Osei-Kyei et al. (2018), although the conventional procurement method is the most generally used approach in the procurement of unsolicited PPPs, the best and final offer method is the most recommended approach. Some countries are looking for a structure that allows them to secure unsolicited PPPs through competitive, fair, and transparent tendering. By considering different procedures and tendering methods used to procure unsolicited PPPs, a conceptual framework was developed and visualized in Figure 2. The framework shows that there are common approaches and unique steps in the different methods for each to have their own merits. Therefore, the conceptual framework shown in Figure 2 can be used to visualize an ideal tendering strategy that is appropriate for host countries.

9 References

Asian Development Bank. (2008). *Public–private partnership handbook*. https://www.adb.org/sites/default/files/institutional-document/31484/public-private-partnership.pdf

Aziz, A., & Nabavi, H. (2014, May 19–21). Unsolicited proposals for PPP projects: Private sector perceptions in the USA. In *Proceedings of Construction Research Congress 2014: Construction in a global network* (pp. 1189–1198), Atlanta, Georgia. https://doi.org/10.1061/9780784413517.138

Ball, R. (2011). Provision of public service infrastructure – The use of PPPs in the UK and Australia. *International Journal of Public Sector Management*, *24*(1), 5–22. https://doi.org/10.1108/09513551111099190

Ballingall, J. (2014, June 5). *PPPs: Fiscal space and investment – The United Kingdom*. Infrastructure UK. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=38831864

Burger, P., & Hawkesworth, I. (2011). How to attain value for money. *OECD Journal on Budgeting*, *11*(1), 91–146. https://doi.org/10.1787/budget-11-5kg9zc0pvq6j

Delmon, J. (2015). *Creating a framework for public-private partnership (PPP) programs: A practical guide for decision-makers*. Public–Private Infrastructure Advisory Facility. http://documents.worldbank.org/curated/en/2015/08/24948998/creating-framework-public-private-partnership-ppp-programs-practical-guide-decision-makers

Farquharson, E., Mästle, C. T., & Yescombe, E. R. (2011). *How to engage with the private sector in public–private partnerships in emerging markets*. World Bank Publications. https://documents1.worldbank.org/curated/en/995241468337913618/pdf/How-to-engage-with-the-private-sector-in-public-private-partnerships-in-emerging-markets.pdf

Fernando, P. G. (2020). Is Swiss challenge method is alternative to embrace unsolicited proposals in a competitive way. *Focus*, *10*(01), 8–11. https://iqssl.lk/docs/publications/publication-iqssl-2021-02-20-uid590.pdf

Fernando, P. G., & Chandanie, H. (2018). *PPP is one the key tools to underpin and reinforce for an economic development*. IQSSL Technical Research Proceedings. https://www.researchgate.net/publication/322712657_An_Investigation_of_the_Effects_of_Changes_Made_During_Pre-Contract_Stages_of_Water_Supply_Projects#page=55

Hodges, J. (2003). *Unsolicited proposals: The issues of private infrastructure projects*. World Bank. http://siteresources.worldbank.org/EXTFINANCIALSECTOR/Resources/282884-1303327122200/257Hodge-031103.pdf

Hodges, J., & Dellacha, G. (2007). *Unsolicited infrastructure proposals: How some countries introduce competition and transparency*. Gridlines No. 19, World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/895161468313861433/unsolicited-infrastructure-proposals-how-some-countries-introduce-competition-and-transparency

International Monetary Fund. (2006). *World Economic Outlook: Financial Systems and Economic Cycles*. https://www.imf.org/en/Publications/WEO/Issues/2016/12/31/Financial-Systems-and-Economic-Cycles

Kelly, P. (2016, April). Preparing a public–private partnership law: Observations from the international experience. *ADB East Asia Working Paper 4*. Asian Development Bank. https://www.adb.org/sites/default/files/publication/190132/eawap-04.pdf

Khallaf, R., Kang, K., & Hastak, M. (2018, April 2–4). Analysis of the use of PPPs in higher education institutions through systematic literature review. In *Proceedings of the Construction Research Congress 2018* (pp. 24–33), New Orleans, Louisiana. https://doi.org/10.1061/9780784481301.003

Klaus, F. (2011). *Public–private partnership handbook*. World Bank. http://documents.worldbank.org/curated/en/490511468331774007/Public-Private-Partnershiphandbook

Ministry of Finance. (2011). *Supplement 23 to procurement guideline, Part II*. Ministry of Finance, Sri Lanka.

Ministry of Finance. (2016). *Supplement 30 to procurement guideline, Part II*. Ministry of Finance, Sri Lanka.

Ministry of Finance. (2019). *Dealing with unsolicited proposals*. Ministry of Finance, Sri Lanka.

Ministry of Finance and Planning. (1998). *Part II – Guidelines on private sector infrastructure projects*. Ministry of Finance and Planning, Sri Lanka. https://www.treasury.gov.lk/api/file/9f9c06c1-59c4-4d7c-b43e-870c3d71803a

Neves, P., & Kim, D. J. (2017). *Managing unsolicited proposals in infrastructure: 5 key questions for governments*. World Bank. http://blogs.worldbank.org/ppps/managing-unsolicited-proposals-infrastructure-5-key-questions-governments?CID=PPP_E_PPPNewsletter_EXT

Nyagormey, J. J., Baiden, B. K., Nani, G., & Adinyira, E. (2020). Review on criteria for evaluating unsolicited public–private partnership PPP proposals from 2004 to 2018. *International Journal of Construction Management*, *22*(12), 2243–2257. https://doi.org/10.1080/15623599.2020.1783596

Okoli, C., & Schabram, K. (2010). A guide to conducting a systematic literature review of information systems research. *Sprouts: Working Papers on Information Systems*, *10*(26), 1–49. http://sprouts.aisnet.org/10-26

Osei-Kyei, R., & Chan, A. P. C. (2017). Factors attracting private sector investments in public–private partnerships in developing countries: A survey of international experts. *Journal of Financial Management of Property and Construction*, *22*(1), 92–111. https://doi.org/10.1108/JFMPC-06-2016-0026

Osei-Kyei, R., Chan, A. P. C., Dansoh, A., Ofori-Kuragu, J. K., & Owusu, E. K. (2018). Motivations for adopting unsolicited proposals for public–private partnership project implementation. *Journal of Financial Management of Property and Construction*, *23*(2), 221–238. https://doi.org/10.1108/jfmpc-06-2017-0020

Page, M. J., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., Tetzlaff, J., & Moher, D. (2020, September 14). *Updating guidance for reporting systematic reviews: Development of the PRISMA 2020 statement*. https://doi.org/10.31222/osf.io/jb4dx

Parker, D. (2009). PPP/PFI – Solution or problem? *Economic Affairs*, *29*(1), 1–5. https://onlinelibrary.wiley.com/doi/10.1111/j.1468-0270.2009.01859.x

Public–Private Infrastructure Advisory Facility. (2009). *Unsolicited proposals, Module 5: Implementing and monitoring*. http://ppiaf.org/sites/ppiaf.org/files/documents/toolkits/highwaystoolkit/6/pdf-version/5-42.pdf

Public–Private Infrastructure Advisory Facility. (2012). *Unsolicited proposals, Note 6*. http://www.castalia-advisors.com/files/Note-Six-Unsolicited-Proposals.pdf

Public–Private Infrastructure Advisory Facility. (2014). *Unsolicited proposals – An exception to public initiation of infrastructure PPPs*. http://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/PPIAF_UnsolicitedProposals_EN.pdf

Public–Private Infrastructure Advisory Facility. (2017). *Seventeen years supporting for infrastructure development*. https://documents1.worldbank.org/curated/en/283551535550381345/pdf/AR-PUBLIC-PPIAF-AR17-FINALWEB.pdf

Queiroz, C. (2005). *Launching public private partnerships for highways in transition economies*. Transport Papers Series No. TP-9. World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/459631468030579372/launching-public-private-partnerships-for-highways-in-transition-economies

Singh, P. S., & Wayal, A. S. (2019). Swiss challenge method of procurement a comparative study of state submission requirements and procedure adopted in Indian states of Maharashtra, Haryana, Madhya Pradesh, Rajasthan and Karnataka. *International Journal of Engineering Research & Technology*, *8*(10), 537–

545. https://www.ijert.org/research/swiss-challenge-method-of-procurement-a-comparative-study-of-state-submission-requirements-and-procedure-adopted-in-indian-states-of-maharashtra-haryana-madhya-pradesh-rajasthan-and-karnataka-IJERTV8IS100290.pdf

Sohrabi, C., Franchi, T., Mathew, G., Kerwan, A., Nicola, M., Griffin, M., Agha, M., & Agha, R. (2021). PRISMA 2020 statement: What's new and the importance of reporting guidelines. *International Journal of Surgery*, 88, Article 105918. https://doi.org/10.1016/j.ijsu.2021.105918

Søreide, T. (2006, September 21–23). Tender manipulation: Large firms and infrastructure contracts. In *Proceedings of the 2nd International Public Procurement Conference* (pp. 157–183). http://www.ippa.org/images/PROCEEDINGS/IPPC2/Article_8_Soreide.pdf

Takano, G. (2021). The competitive performance of public–private partnership markets. The case of unsolicited proposals in Peru. *Utilities Policy*, 72, Article 101274. https://doi.org/10.1016/j.jup.2021.101274

Telliford, G. T. (Ed.) (2009). *Public–private transportation partnerships around the world*. Nova Science Publishers.

United Nations Commission on International Trade Law. (2000). *UNCITRAL legislative guide on privately financed infrastructure projects*. United Nations. https://uncitral.un.org/sites/uncitral.un.org/files/media-documents/uncitral/en/pfip-e.pdf

United Nations Commission on International Trade Law. (2020a). *UNCITRAL legislative guide on public–private partnerships*. United Nations. https://uncitral.un.org/sites/uncitral.un.org/files/media-documents/uncitral/en/19-10872_ebook_final.pdf

United Nations Commission on International Trade Law. (2020b). *UNCITRAL model legislative provisions on public–private partnerships*. United Nations. https://uncitral.un.org/en/mlpppp

Verma, S. (2010). Government obligations in public-private partnership contracts. *Journal of Public Procurement*, *10*(4), 564–598. http://papers. ssrn.com/sol3/papers.cfm?abstract_id=1671081

World Bank. (2017a). *Guidelines for the development of a policy for managing unsolicited proposals in infrastructure projects*. http://pubdocs.worldbank.org/en/976121488983070966/Guidelines-for-the-Development-of-a-USP-Policy.pdf

World Bank. (2017b). *Public private partnerships reference guide, version 3.0*. https://ppp.worldbank.org/public-private-partnership/sites/ppp.worldbank.org/files/documents/PPP%20Reference%20Guide%20Version%203.pdf

World Bank. (2017c). *Review of experiences with unsolicited proposals in infrastructure projects*. https://thedocs.worldbank.org/en/doc/246961488983068025-0100022017/original/ExperienceReviewReportFinalDraftMarch72017.pdf

World Bank. (2021). *Private participation in infrastructure: Annual report 2021*. https://ppi.worldbank.org/content/dam/PPI/documents/PPI-2021-Annual-Report.pdf

Yun, S., Jung, W., Heon Han, S., & Park, H. (2015). Critical organizational success factors for public private partnership projects – A comparison of solicited and unsolicited proposals. *Journal of Civil Engineering and Management*, *21*(2), 131–143. https://doi.org/10.3846/13923730.2013.802715

Zawawi, M. I., Kulatunga, U., & Thayaparan, M. (2016). Malaysian experience with public–private partnership (PPP). *Built Environment Project and Asset Management*, *6*(5), 508–520. https://doi.org/10.1108/bepam-10-2015-0059

Zawawi, M. I., Rathnasinghe, A. P., & Kulatunga, U. (2022). Constraints to incorporate competition in public–private partnerships in Malaysia. *International Journal of Procurement Management*, *15*(2), 257. https://doi.org/10.1504/ijpm.2022.121148

Zhang, X. (2005). Paving the way for public–private partnerships in infrastructure development. *Journal of Construction Engineering and Management*, *131*(1), 71–80. https://doi.org/10.1061/(asce)0733-9364(2005)131:1(71)

Zheng, S., & Tiong, R. L. (2010). First public–private partnership application in Taiwan's wastewater treatment sector: Case study of the Nanzih BOT wastewater treatment project. *Journal of Construction Engineering and Management*, *136*(8), 913–922. https://doi.org/10.1061/(asce)co.1943-7862.0000196

Inclusion of marginalized communities in post-disaster phase

A literature review

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Abstract: Natural disasters disproportionately affect human lives, especially those of marginalized communities that suffer severe repercussions. These communities face numerous challenges in the aftermath of a disaster. Although today's world has embraced the concepts of resilience and inclusivity, marginalized communities are often overlooked in the aftermath of a disaster. This study intends to provide a review of the literature, both narrative and systematic, addressing the inclusion of marginalized communities during the post-disaster phase. The systematic literature review was conducted by adopting the methodology of preferred reporting items for systematic reviews and meta-analyses using the 'population, intervention, comparison, and outcome' approach. The authors were able to identify different challenges faced by marginalized communities – women, children, older people, and people with disabilities – through the systematic literature review. However, it is vital to highlight that marginalized communities are not merely victims of disasters; they also have unique capacities to contribute to the resilience of their communities. As a result, governments, in collaboration with all stakeholders, must ensure that these communities are involved in decision-making, planning, and implementation, with appropriate monetary assistance and the delivery of systems and services essential to their well-being against environmental shocks and stresses. This study recommends developing stakeholder mapping to understand stakeholder engagement with marginalized communities, exploring disaster management policies and frameworks as well as marginalized communities, identifying policy gaps and implementation barriers, and finally proposing strategies to minimize the gaps between policies and practice as ideal solutions to improve the inclusion of marginalized communities.

Keywords: inclusion, literature review, marginalized communities, post-disaster phase

1 Introduction

Globally, there has been a rise in disaster severity over the past decade, contributing to a growing number of deaths and economic and social casualties (Amaratunga et al., 2020). According to the Global Facility for Disaster Reduction and Recovery (GFDRR, 2019), the post-disaster situation is complex and challenging, and perhaps the most important challenge is to determine humanitarian needs promptly and provide lifesaving help to the people affected.

Community participation in post-disaster management programmes has become increasingly important, gaining consideration from researchers, policymakers, as well as national and international level organizations over the past few years (Chandrasekhar et al., 2014). As the community is the first to respond to any natural disaster/catastrophe, disaster management runs the risk of being ineffective without its participation (Burnside-Lawry & Carvalho, 2016). To fully understand post-disaster management-related programmes, it is also essential to understand the experiences of marginalized communities, such as women, older people, people with disabilities, and children. These groups appear to be the most vulnerable to disasters because they lack the capacity to foresee, respond to, and absorb disaster risks (Islam et al., 2020).

Although the international community has adopted the concepts of resilience and inclusion to serve them, marginalized communities are frequently ignored in post-disaster management programmes (Cretney, 2018; Mannakkara and Wilkinson, 2015). As a result, these communities have higher rates of fatalities, injuries, and economic disruption and take longer to recover. This study intends to provide a literature review, both narrative and systematic, addressing the inclusion of marginalized communities during the post-disaster phase.

2 Methodology

This study is based mainly on a thorough literature review. It is necessary to review the literature to collect current information in the field of research and pave the way for the discovery of new information (Saunders et al., 2016). The main literature for this study was gathered through a narrative literature review and a systematic literature review. The narrative literature review provided the basis for research and theoretical knowledge to meet all the research objectives. A systematic literature review was performed by adopting the methodology of preferred reporting items for systematic reviews and meta-analyses (PRISMA), which deals with the challenges faced by marginalized communities in post-disaster phases. The research question for conducting the systematic review, 'What are the challenges faced by marginalized communities in the context of the post-disaster phase?'", was developed using population, intervention, comparison, and outcome, commonly known as the PICO approach (Richardson et al., 1995). Following the PRISMA methodology, a total of 56 articles of 923 records, published from 2010 to 2021 in the Web of Science, Scopus, and Emerald Insight databases and other sources (websites, organizations, and citation searching), were considered for qualitative synthesis. The findings of both the narrative literature search and the systematic literature search are shown in Section 3.

3 Literature review

In this section, a narrative literature review and a systematic literature review are presented using the PRISMA methodology. Initially, a comprehensive background to research was established while elaborating on what post-disaster management is, how post-disaster management is achieved in three phases, and who is being more marginalized in the aftermath of disasters. Then, the challenges faced by marginalized communities in the post-disaster phase were reviewed through a systematic literature review to highlight that these communities need more assistance in recovering from the impact of disaster. Next, the need for inclusion of marginalized communities during the post-disaster phase was identified as the main outcome of the study. The findings of the literature review are presented in the following sections.

3.1 Post-disaster management

According to Jamali et al. (2019), post-disaster management aims at restoring normalcy to the affected area. Appropriate programmes are needed to achieve normalization (Malawani et al., 2020). Several activities are carried out concurrently or sequentially under post-disaster management (Ali et al., 2020). Ali et al. (2020) stated that there are no unified terms for post-disaster phases. To maintain consistency throughout the present study, the terms set out in the Sendai Framework are used when describing the post-disaster phases (United Nations Office for Disaster Risk Reduction [UNDRR], 2015). Consequently, relief, rehabilitation, and recovery have been considered the key phases of the post-disaster context.

3.1.1 Relief phase

The relief phase is the first of the post-disaster phases. According to Lloyd-Jones et al. (2006), The relief phase's scope varies depending on the disaster situation; however, the fundamental and essential aspects of this phase are premised on attending to the community's most pressing needs in the aftermath of a disaster, such as attempting to rescue victims, providing for their medical and food needs, and restoring utility services and essential infrastructure. Generally, armed troops conduct relief and rescue operations with the aid of humanitarian organizations in every region (Ali et al., 2020). However, international aid agencies such as United Nations organizations, the International Federation of Red Cross and Red Crescent Societies, and the World Health Organization step in to provide support in large-scale disasters (Tafti & Tomlinson, 2015).

3.1.2 Rehabilitation phase

According to UNDRR (2021), rehabilitation is the process of restoring the necessary resources and infrastructure needed for a community to function after a disaster. The displaced community is housed in temporary camps and shelters throughout this process, which is also known as temporary settlement. Mass feeding, injury treatment, debris cleaning, fundamental home repair, utilities, and infrastructure amenities are all included in this short-term phase. Services such as interim schools and sanitation programmes are undertaken if the restoration time is extended from weeks to months. According to Davis and Alexander (2016), the rehabilitation phase is a critical stage in the post-disaster context because it connects the relief phase to the long-term recovery phase.

3.1.3 Recovery phase

The recovery phase, which lasts a long time after a disaster, entails extensive reconstruction, development, and capacity building through structural and non-structural interventions to reduce the likelihood of future disasters. Additionally, the recovery phase is used to rebuild, re-staff, and prepare communities for sustained long-term recovery (Ali et al., 2020). However, Hsu (2016) argued that in practice post-disaster recovery is often concerned with short-term, rapid solutions rather than systemic mechanisms and their long-term implications. According to UNDRR (2017), recovery after a disaster is the most difficult role of disaster management and it is most effective when the requirements of the victims have been met and the community has returned to normalcy. However, social processes that lead to inequality and marginalization of the community can undermine this function (Kammerbauer & Wamsler, 2017).

3.2 Marginalized communities

Marginalization is a global phenomenon that has a negative effect on societies throughout the world (Mowat, 2015). Marginalization is commonly characterized as a lack of opportunities and the right of individuals or communities to take advantage of the choices available to others, often as a result of economic inequality, social exclusion, and a lack of control over political processes (Pelc, 2017).

In each mainstream community, some categories of people have been designated as vulnerable. These groups could be the poor, children, women, people with disabilities, ethnic minorities, and low-caste groups. The majority of these individuals, it has been argued, are not necessarily marginalized, despite the fact that women, older people, those with disabilities, and children are frequently marginalized due to widespread prejudice and vulnerability (Mendis et al., 2022; Pannilage, 2015; SOS Children's Villages, 2013). When considering natural disaster situations, it is well established that marginalized communities are disproportionately affected, mostly as a result of injustice and conflict legacy (Crawford & Morrison, 2020). Furthermore, these populations are still excluded in the post-disaster phase (Mendis et al., 2022).

3.3 Challenges faced by marginalized communities in the context of post-disaster

Post-disaster challenges are not borne equally by affected people. Disasters tend to hit the poorest and most marginalized demographics the hardest (Zhu & Sun, 2018). While post-disaster discussion emphasizes the role of society in promoting reconciliation, the emphasis on recovering from a disaster has overshadowed marginalized communities (Hsu, 2016). The present study identified 70 challenges faced by marginalized communities during post-disaster phases from primary data gathered from the 56 filtered articles. Among them, the 10 key challenges faced by marginalized communities during post-disaster phases are (i) development of post-traumatic stress disorder, (ii) struggle to acquire the basic necessities of life due to unequal distribution, (iii) lack of income-generating opportunities, (iv) sexual and gender-based violence, (v) lack of privacy in the camps, (vi) loss of community support and protection mechanisms, (vii) discrimination and negligence in the social system, (viii) limited accessibility to transportation, (ix) loss of financial support, and (x) not receiving required attention to medical conditions. Furthermore, women face the majority of the listed challenges. A discussion of the challenges faced by each marginalized community follows.

In a variety of situations, gender disparities prevent women and girls from accessing food, water, credit, energy, technology, educational services, health, sufficient housing, social security, and work (Alam & Rahman, 2019). Women and girls are more likely to be vulnerable to disaster-related risks and disruptions related to their livelihoods as a result of these inequalities, and they are less able to

respond to changes in post-disaster circumstances. Furthermore, women and girls face indirect consequences of disasters, such as sexual and gender-based violence, early and forced marriages, lack of livelihood and access to education, the decline of sexual and reproductive health, and changes in their workload, all of which exacerbate the gender-specific consequences of disasters (Le Masson et al., 2016; Robles & Benavidez, 2018). In recent years, governments and non-governmental organizations (NGOs) worldwide have gradually included gender frameworks in their post-disaster recovery strategies, with widespread implementation (Horton, 2012). However, the position of gender disparities in post-disaster circumstances has been less recognized (Alam and Rahman, 2014, 2019; Drolet et al., 2015; Horton, 2012).

When children's lives and welfare are jeopardized in disaster circumstances, it is critical that appropriate precautions are taken to protect them. In a post-disaster context, children's rights are generally forgotten, and this has become more pronounced in the areas of inclusion, protection, and development. Here, governments are unsuccessful and families often make the required attempts to stay safe under these circumstances (Gamini & Khalili, 2019). During post-disaster phases, it is important to recognize that children have developmental (physical and psychological) variances (UNDRR, 2017). According to Gibbs et al. (2015), there is substantial research illustrating the short- and long-term effects of disasters on children's physical, emotional, psychological, and social well-being. While there is increasing concern about the vulnerabilities and capabilities of children who have endured disasters, research on the challenges they face through post-disaster processes is sparse (Cox et al., 2017).

Although long-term health promotion for older people is crucial in the post-disaster phase, it has also been recognized that psychological assistance for people living alone is required to support their health and well-being and, as a result, their sense of belonging to a newly established community (Noro et al., 2013). Furthermore, older people, especially those living alone, are unable to develop a sense of their new society, resulting in social and health problems such as alcoholism, increased mortality, and issues of mental health (Kako & Ikeda, 2009). Although some studies have assessed the viability of initiatives that address ordinary life concerns in the post-disaster setting (Akiyama et al., 2018), little attention has been paid to the challenges faced by older people in the post-disaster phase (Akiyama et al., 2018).

People with disabilities are negatively affected by disasters (Stough et al., 2017a), yet empirical research on the challenges faced by them is limited (Phibbs et al., 2014). During the disaster relief phase, they find evacuation routes and public shelters difficult or even unavailable; necessary healthcare and shelter facilities are frequently insufficient; and they are frequently disregarded in rehabilitation and recovery plans (Priestley & Hemingway, 2007; Stough et al., 2016). Furthermore, people with disabilities are more likely to be disadvantaged or unemployed, economically marginalized, removed from decision-making systems, and live in vulnerable conditions with insufficient resources and restricted access to basic services (Twigg et al., 2018). In addition, they evidence specialized mental health needs (Stough, 2009; Stough et al., 2017b), and require more intensive case management in the post-disaster context (Stough et al., 2010).

Multiple factors affect marginalization, and individuals may be part of more than one marginalized category at risk in a post-disaster situation. As an example, this intersectionality applies to being an individual with a disability, who is also a part of another dimension of perceived marginalization, such as a child, older person, or female gender. It is the intertwined features that may contribute to more marginalization, inequality, or problems in disaster situations (Bennett, 2020). However, very few studies have been carried out on these intersectionalities in the post-disaster context.

3.4 Need for inclusion of marginalized communities during the post-disaster phase

Inclusivity is a fundamental human right that applies to all people regardless of age, ethnicity, gender, class, or disability (Cordaid & and Partners for Resilience, 2020). Inclusion means that both individuals and communities contribute and lead thoroughly and meaningfully in the pre-and post-disaster processes. It also encourages the equality of rights and opportunities for all in the face of risk, as well as responding to the varied characteristics, capabilities, and vulnerabilities of all (GFDRR, 2019). Inclusion is seen as a comprehensive solution to developing a support structure geared towards creating more sustainable societies that work together to manage the effects of disasters (Cordaid & and Partners for Resilience, 2020). According to Zayas et al. (2017), although the term 'inclusion' is becoming popular in post-disaster management, establishing inclusion has proven to be a very difficult endeavour as challenges to doing so are intertwined with many other types of social organizations and relationships. In such an environment, marginalized communities seem to be the most vulnerable to disruptions and distress because they are unable to expect, respond, and absorb risk from disasters (Bahadur et al., 2015). Disasters further intensify socioeconomic disparities and current wealth dynamics, leaving the more marginalized to be most likely to be 'left behind' (Diwakar et al., 2019). Therefore, governments must make sure that those who are marginalized during post-disaster situations are included in decision-making and that there is enough budget for and distribution of services and systems to support people's health (Mendis et al., 2020). This is critical to help marginalized communities develop resilience and ensure that they have the capacity to plan for, deal with, and adapt to potential disaster risks (Manuel et al., 2018).

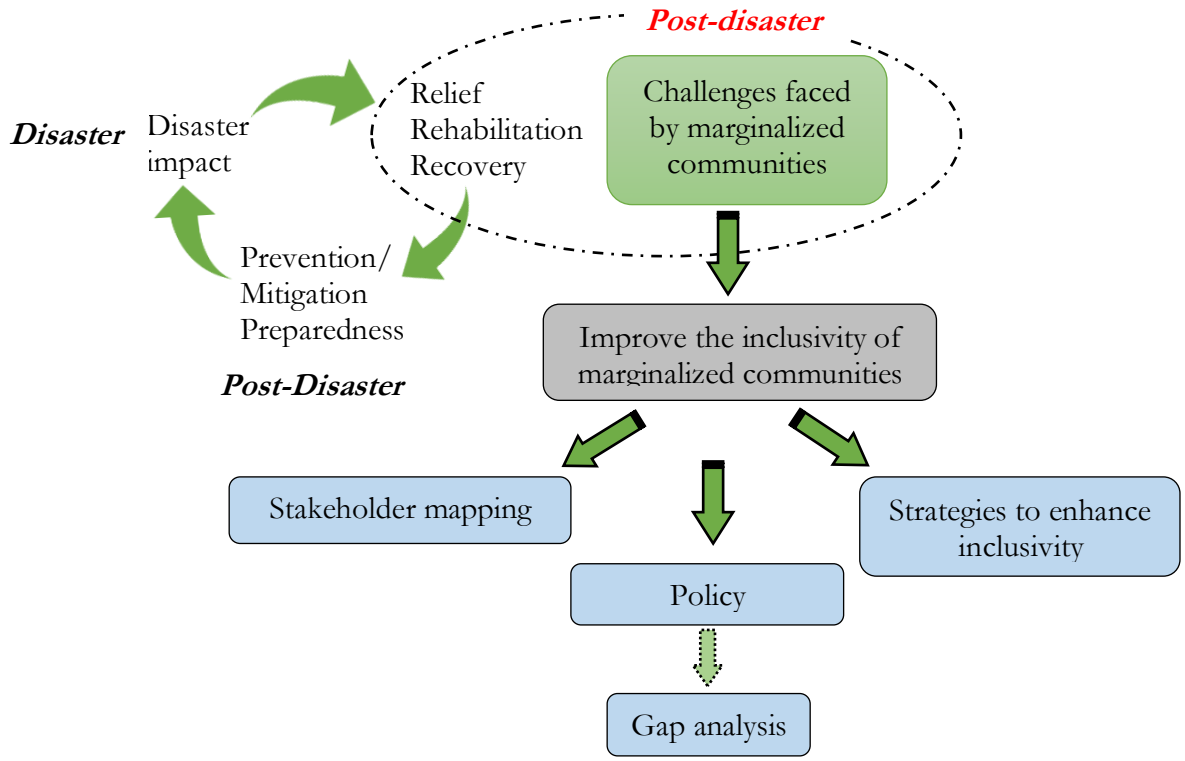
Removing the undue burden placed on marginalized communities as a result of inequitable allocation of vital capital as well as growing equality and social justice are key fundamental values of social resilience (Plough et al., 2013). Rather than relying exclusively on what reduces people's potential to minimize their vulnerability, policymakers must prioritize recognizing people's capacity to withstand and rebound from disasters as well as improving the overall resilience of individuals, communities, and systems (Maurya, 2019). Although inclusive disaster management is still far from fully realized, there are areas of interaction where inclusion can be advanced and conventional approaches to disaster preparedness and response can be changed to become more sensitive to the needs, conditions, and abilities of all people (Zayas et al., 2017).

Jovita (2018) claimed that addressing the concerns of marginalized communities requires actions not just on the part of the government but also on the part of other stakeholders. Local authorities in any country should consider particular communities that are often left out of planning discussions. Furthermore, it is to be anticipated that the same individuals will be less likely to participate in the disaster's aftermath (Hamideh, 2020). Before a disaster, there are formal and informal networks that exist in society through charities, NGOs, and different forms of advocacy groups. These social institutions and networks have relationships and confidence in their participants and they know who is at risk of marginalization after a disaster. Recovery planners should collaborate with these existing networks to reach marginalized communities, a strategy that has also been implemented in other planning efforts (Kondo, 2012). As a result, it can be concluded that it is critical to develop interaction among all of these stakeholders to increase the involvement of marginalized populations throughout the post-disaster management process. Without actively involving marginalized populations through integrated policies, physical removal and a history of mistrust severely limits those people's voices (Hamideh, 2020). Therefore, it is critical to understand the current global and local policies/frameworks that regulate post-disaster processes, how they take into account the concerns of marginalized populations, and how these might be leveraged to promote inclusivity throughout the post-disaster setting.

4 Conceptual framework

The conceptual framework was developed based on the literature synthesis, which covers post-disaster phases, challenges faced by marginalized communities, stakeholders, and policy analysis. This study only presents the disaster phases and challenges explored. To address the challenges, the stakeholders who are involved in decision-making related to marginalized communities will be studied. In addition, policies that can support the inclusion of marginalized communities will be explored and the gap between such policies and implementation will be analysed. Suitable strategies will be proposed to minimize the policy implementation gap. The conceptual framework of this research, as shown in Figure 1, has been developed based on these key points.

Figure 1: Conceptual framework



Source: Authors' own.

The conceptual framework guides how to enhance the inclusion of marginalized communities in the post-disaster phase.

5 Conclusion and way forward

It is increasingly recognized that disasters take a disproportionate toll on affected populations, often with the most marginalized bearing the greatest impacts of disasters. Therefore, there should be explicit consideration of marginalized groups in policy preparation for post-disaster management. To guarantee an equitable and successful response, it is also crucial to comprehend why the inclusion of so-called marginalized community policy and practice during post-disaster phases is essential. Without taking this into account, these communities frequently experience higher rates of fatalities, injuries, and financial losses, as well as slower recovery times. Marginalized communities can be helped during disasters using data, communication, strategy, and policy-based

evaluation and decisions. As a way forward from this study, in the future, stakeholder mapping needs to be carried out to understand stakeholder engagement with marginalized communities to improve inclusion during the post-disaster phase. Also, policy gaps need to be identified and appropriate strategies formulated to minimize the gaps between policies and practice to enhance the inclusivity of marginalized communities during the post-disaster phase.

6 References

Akiyama, T., Gregorio, E. R., & Kobayashi, J. (2018). Youth sports activity and young people's well-being after a disaster: A trial with the mastery approach to coaching (MAC) in the Philippines. *BMC Research Notes*, *11*, Article 747. https://doi.org/10.1186/s13104-018-3860-1

Alam, K., & Rahman, M. H. (2014). Women in natural disasters: A case study from southern coastal region of Bangladesh. *International Journal of Disaster Risk Reduction*, *8*, 68–82. https://doi.org/10.1016/j.ijdrr.2014.01.003

Alam, K., & Rahman, M. H. (2019). Post-disaster recovery in the cyclone Aila affected coastline of Bangladesh: women's role, challenges and opportunities. *Natural Hazards*, *96*(3), 1067–1090. https://doi.org/10.1007/s11069-019-03591-7

Ali, R. A., Mannakkara, S., & Wilkinson, S. (2020). Factors affecting successful transition between post-disaster recovery phases: A case study of 2010 floods in Sindh, Pakistan. *International Journal of Disaster Resilience in the Built Environment*, *11*(5), 597–614. https://doi.org/10.1108/IJDRBE-03-2020-0016

Amaratunga, D., Malalgoda, C., Haigh, R., & De Silva, A. (2020). *How do we organise for disaster risk reduction and resilience? A study on disaster reduction and management governance profile of Sri Lanka*. University of Huddersfield. https://huddersfield.box.com/s/zwtx3jrn78gmobm62zcxgob8o875qvwa

Bahadur, A., Peters, K., Wilkinson, E., Pichon, F., Gray, K., & Tanner, T. (2015). *The 3As: Tracking resilience across BRACED*. https://cdn.odi.org/media/documents/9812.pdf

Bennett, D. (2020). Five years later: Assessing the implementation of the four priorities of the Sendai framework for inclusion of people with disabilities. *International Journal of Disaster Risk Science*, *11*(2), 155–166. https://doi.org/10.1007/s13753-020-00267-w

Burnside-Lawry, J., & Carvalho, L. (2016). A stakeholder approach to building community resilience: Awareness to implementation. *International Journal of Disaster Resilience in the Built Environment*, *7*(1), 4–25. https://doi.org/10.1108/IJDRBE-07-2013-0028

Chandrasekhar, D., Zhang, Y., & Xiao, Y. (2014). Non-traditional participation in disaster recovery planning: Cases from China, India, and the United States. *Journal of the American Planning Association*, *80*(4), 373–384. https://doi.org/10.1080/01944363.2014.989399

Cordaid and Partners for Resilience. (2020). *Step-by-step guide to inclusive resilience*. https://www.preventionweb.net/files/71675_716542020marchpfrinclusiontoolkit.pdf

Cox, R. S., Scannell, L., Heykoop, C., Tobin-Gurley, J., & Peek, L. (2017). Understanding youth disaster recovery: The vital role of people, places, and activities. *International Journal of Disaster Risk Reduction*, *22*, 249–256. https://doi.org/10.1016/j.ijdrr.2017.03.011

Crawford, G., & Morrison, C. (2020). Community-led reconstruction, social inclusion and participation in post-earthquake Nepal. *Development Policy Review*, *39*(4), 548–568. https://doi.org/10.1111/dpr.12512

Cretney, R. M. (2018). Beyond public meetings: Diverse forms of community-led recovery following disaster. *International Journal of Disaster Risk Reduction*, *28*, 122–130. https://doi.org/10.1016/j.ijdrr.2018.02.035

Davis, I., & Alexander, D. (2016). *Recovery from disaster* (1st ed.). Routledge. https://doi.org/10.4324/9781315679808

Diwakar, V., Lovell, E., Opitz-Stapleton, S., Shepherd, A., & Twigg, J. (2019, March 14). *Child poverty, disasters and climate change: Examining relationships and assessing implications over the life course of children* [Research report]. https://odi.org/en/publications/child-poverty-disasters-and-climate-change-investigating-relationships-and-implications-over-the-life-course-of-children/

Drolet, J., Dominelli, L., Alston, M., Ersing, R., Mathbor, G., & Wu, H. (2015). Women rebuilding lives post-disaster: Innovative community practices for building resilience and promoting sustainable development. *Gender and Development*, *23*(3), 433–448. https://doi.org/10.1080/13552074.2015.1096040

Gamini, H., & Khalili, H. A. (2019). Resettlement challenges for children after disasters (case study): Bam city. In A. Asgary (Ed.), *Resettlement challenges for displaced populations and refugees* (pp. 141–152). Springer. https://doi.org/10.1007/978-3-319-92498-4_10

Gibbs, L., Block, K., Harms, L., MacDougall, C., Baker, E., Ireton, G., Forbes, D., Richardson, J., & Waters, E. (2015). Children and young people's wellbeing post-disaster: Safety and stability are critical. *International Journal of Disaster Risk Reduction*, *14*(2), 195–201. https://doi.org/10.1016/j.ijdrr.2015.06.006

Global Facility for Disaster Reduction and Recovery. (2019). *Joint communique on inclusion for resilient recovery*. World Reconstruction Conference 4, 13–14 May, Geneva, Switzerland. https://www.gfdrr.org/en/WRC4/communique

Hamideh, S. (2020). Opportunities and challenges of public participation in post-disaster recovery planning: Lessons from Galveston, TX. *Natural Hazards Review*, *21*(4), 1–16. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000399

Horton, L. (2012). After the earthquake: Gender inequality and transformation in post-disaster Haiti. *Gender & Development*, *20*(2), 295–308. https://doi.org/10.1080/13552074.2012.693284

Hsu, M. (2016). Lost, found and troubled in translation: Reconsidering imagined indigenous 'communities' in post-disaster Taiwan settings. *AlterNative: An International Journal of Indigenous Peoples*, *12*(1), 71–85. https://doi.org/10.20507/AlterNative.2016.12.1.6

Islam, E., Wahab, H. A., & Benson, O. G. (2020). Structural and operational factors as determinant of meaningful community participation in sustainable disaster recovery programs: The case of Bangladesh. *International Journal of Disaster Risk Reduction*, *50*, Article 101710. https://doi.org/10.1016/j.ijdrr.2020.101710

Jamali, M., Nejat, A., Ghosh, S., Jin, F., & Cao, G. (2019). Social media data and post-disaster recovery. *International Journal of Information Management*, *44*, 25–37. https://doi.org/10.1016/j.ijinfomgt.2018.09.005

Jovita, H. D. (2018). *Cross-sector collaboration in region X: Philippines' disaster management* [Thesis, Universitas Muhammadiyah Yogyakarta]. UMY Research Repository. http://repository.umy.ac.id/handle/123456789/32810

Kako, M., & Ikeda, S. (2009). Volunteer experiences in community housing during the Great Hanshin-Awaji Earthquake, Japan. *Nursing and Health Sciences*, *11*(4), 357–359. https://doi.org/10.1111/j.1442-2018.2009.00484.x

Kammerbauer, M., & Wamsler, C. (2017). Social inequality and marginalization in post-disaster recovery: Challenging the consensus? *International Journal of Disaster Risk Reduction*, *24*(411–418). https://doi.org/10.1016/j.ijdrr.2017.06.019

Kondo, M. C. (2012). Immigrant organizations in pursuit of inclusive planning: Lessons from a municipal annexation case. *Journal of Planning and Educational Research*, *32*(3), 319–330. https://doi.org/10.1177/0739456X11431574

Le Masson, V., Lim, S., Budimir, M., & Podboj, J. S. (2016). *Disasters and violence against women and girls: Can disasters shake social norms and power relations?* Asian Development Bank. https://www.odi.org/sites/odi.org.uk/files/resource-documents/11113.pdf

Lloyd-Jones, T., Theis, M., Kalra, R., & Mulyawan, B. (2006). *Mind the gap! Post-disaster reconstruction and the transition from humanitarian relief*. Royal Institution of Chartered Surveyors (RICS). https://www.preventionweb.net/files/9080_MindtheGapFullreport1.pdf

Malawani, A. D., Nurmandi, A., Purnomo, E. P., & Rahman, T. (2020). Social media in aid of post-disaster management. *Transforming Government: People, Process and Policy*, *14*(2), 237–260. https://doi.org/10.1108/TG-09-2019-0088

Mannakkara, S., & Wilkinson, S. J. (2015). Supporting post-disaster social recovery to build back better. *International Journal of Disaster Resilience in the Built Environment*, *6*(2), 126–139. https://doi.org/10.1108/IJDRBE-06-2013-0019

Manuel, M., Grandi, F., Manea, S., Kirbyshire, A., & Lovell, E. (2018). *'Leave no one behind' index 2018*. https://odi.org/en/publications/leave-no-one-behind-index-2018/

Maurya, V. (2019). Natural disasters, psychological well-being and resilience: Concerns related to marginalized groups. *International Journal of Research and Analytical Reviews*, *6*(1), 270–275.

Mendis, A. P. K. D., Disaratna, V., Thayaparan, M., & Kaluarachchi, Y. (2022). Policy-level consideration on marginalised communities in the post-disaster context: A desk study. In Y. G. Sandanayake, G. S., & K. G. A. S. Waidyasekara (Eds.), *Proceedings of the 10th World Construction Symposium* (pp. 668–681). https://doi.org/10.31705/WCS.2022.54

Mendis, A. P. K. D., Thayaparan, M., & Kaluarachchi, Y. (2020, November 6–9). Gender and disability inclusion in post-disaster rebuilding 'Build Back Better' programmes in Sri Lanka: A literature review. *13th FARU International Research Conference* (pp. 81–88), University of Moratuwa, Sri Lanka. https://faru.uom.lk/Documents/FARU Proceedings 2020.pdf

Mowat, J. G. (2015). Towards a new conceptualisation of marginalisation. *European Educational Research Journal*, *14*(5), 454–476. https://doi.org/10.1177/1474904115589864

Noro, C., Hibino, N., & Nakamura, Y. (2013). Disaster recovery supporter's understanding of the living environment of older people who live in rural area. *Japan Nursing Science Society Conference Journal*, *33*(325).

Pannilage, U. (2015). Excluding the worthy: The need of marginalized groups in the decision-making process. *Social Sciences and Humanities Review*, *2*(2). https://hss.ruh.ac.lk/ejournal vol03/publications/volume02/worthy.pdf

Pelc, S. (2017). Marginality and marginalization. In R. Chand, E. Nel, & S. Pelc (Eds.), *Societies, social inequalities and marginalization: Marginal regions in the 21st century* (pp. 13–28). Springer.

Phibbs, S., Good, G., Severinsen, C., Woodbury, E., & Williamson, K. (2014). What about us? Reported experiences of disabled people related to the Christchurch earthquakes. *Procedia Economics and Finance*, *18*, 190–197. https://doi.org/10.1016/S2212-5671(14)00930-7

Plough, A., Fielding, J. E., Chandra, A., Williams, M., Eisenman, D., Wells, K. B., Law, G. Y., Fogleman, S., & Magana, A. (2013). Building community disaster resilience: Perspectives from a large urban county department of public health. *American Journal of Public Health*, *103*(7), 1190–1197. https://doi.org/10.2105/AJPH.2013.301268

Priestley, M., & Hemingway, L. (2007). Disability and disaster recovery: A tale of two cities? *Journal of Social Work in Disability & Rehabilitation*, *5*(3–4), 23–42. https://doi.org/10.1300/J198v05n03_02

Richardson, W. S., Wilson, M. C., Nishikawa, J., & Hayward, R. S. (1995). The well-built clinical question: A key to evidence-based decisions. *ACP Journal Club*, *123*(3), 12–13. https://doi.org/10.7326/ACPJC-1995-123-3-A12

Robles, C. P. Q., & Benavidez, M. (2019). *Gender equality and women's empowerment in disaster recovery*. https://www.gfdrr.org/sites/default/files/publication/gender-equality-disaster-recovery.PDF

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research methods for business students* (7th ed.). Pearson Education Limited.

SOS Children's Villages. (2013). *Protecting the most marginalised children and families. SOS Children's Villages Post-2015 think piece on social protection*. https://www.sos-childrensvillages.org/getmedia/752e9dd7-d875-4492-8852-b323d3a2d627/Post2015-Think-Piece-SocialProtection_reduced.pdf

Stough, L. M. (2009). The effects of disaster on the mental health of individuals with disabilities. In Y. Neria, S. Galea, & F. H. Norris (Eds.), *Mental health and disasters* (pp. 264–276). Cambridge University Press. https://doi.org/10.1017/CBO9780511730030.015

Stough, L. M., Ducy, E. M., & Holt, J. M. (2017a). Changes in the social relationships of individuals with disabilities displaced by disaster. *International Journal of Disaster Risk Reduction*, *24*, 474–481. https://doi.org/10.1016/j.ijdrr.2017.06.020

Stough, L. M., Ducy, E. M., & Kang, D. (2017b). Addressing the needs of children with disabilities experiencing disaster or terrorism. *Current Psychiatry Reports*, *19*(4), 24. https://doi.org/10.1007/s11920-017-0776-8

Stough, L. M., Sharp, A. N., Decker, C., & Wilker, N. (2010). Disaster case management and individuals with disabilities. *Rehabilitation Psychology*, *55*(3), 211–220. https://doi.org/10.1037/a0020079

Stough, L. M., Sharp, A. N., Resch, J. A., Decker, C., & Wilker, N. (2016). Barriers to the long-term recovery of individuals with disabilities following a disaster. *Disasters*, *40*(3), 387–410. https://doi.org/10.1111/disa.12161

Tafti, M. T., & Tomlinson, R. (2015). Best practice post-disaster housing and livelihood recovery interventions: Winners and losers. *International Development Planning Review*, *37*(2). https://doi.org/10.3828/idpr.2015.14

Twigg, J., Kett, M., & Lovell, E. (2018). *Disability inclusion and disaster risk reduction: Overcoming barriers to progress* [ODI Briefing Note]. https://odi.org/en/publications/disability-inclusion-and-disaster-risk-reduction-overcoming-barriers-to-progress/

United Nations Office for Disaster Risk Reduction. (2015). *The Sendai framework for disaster risk reduction, 2015–2030*. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

United Nations Office for Disaster Risk Reduction. (2017). *Build back better: In recovery, rehabilitation and reconstruction*. www.unisdr.org/files/53213_bbb.pdf

United Nations Office for Disaster Risk Reduction. (2021). *UNDRR terminology*. www.unisdr.org/we/inform/terminology#letter-r

Zayas, J., Garcia, J. C., Lacsamana, L., Garcia, F. D., & Alburo-Cañete, K. Z. (2017). *Build back better: Making inclusion work in disaster recovery in the aftermath of Typhoon Haiyan*. Women with Disability Leap to Economic and Social Progress. https://www.preventionweb.net/files/submissions/65859_buildbackbettermakinginclusionworkindisasterrecoveryintheaftermathoftyphoonhaiyan.pdf

Zhu, X., & Sun, B. (2018). Recognising and promoting the unique capacities of the elderly. *International Journal of Emergency Management*, *14*(2), 137–151. https://doi.org/10.1504/IJEM.2018.10011572

The impact of the COVID-19 pandemic on research in built environment education

A bibliometric review

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Abstract: The COVID-19 pandemic has disrupted the education sector, including in the built environment, and has precipitated a pedagogical shift to e-learning. This has affected educational outcomes due to challenges faced by educators and students, including access to technology and connectivity and lack of practical training. Broad adaptation has been required to maintain resilience in educational outcomes. Research is an important tool in informing potential adaptation measures towards mitigating the impact of the pandemic and other external disturbances. The research aim was to provide insight into the extent to which research on built environment education may potentially support adaptation in related educational practices in response to the COVID-19 pandemic. The study objectives included determining the effect of the pandemic on research in built environment education and delineating the pandemic-related research themes incorporated in the related research body. A bibliometric review method was adopted, which included the analysis of Scopus-indexed publications through the application of the VOSviewer (v1.6.17) software. Findings indicated that the focus of built environment education research is increasingly shifting towards wide-ranging themes applicable to the interrelationship between the pandemic and educational outcomes. This may be linked to the impact and effect of the pedagogical shift from in-person teaching methods to e-learning, which has garnered research interest in related themes. The findings may provide insight into the potential of research to support adaptation. In the context of this study, this may be relevant to educational practices in the form of online teaching strategies and related educator development approaches.

Keywords: built environment education, COVID-19, bibliometric review, adaptation, resilience

Acknowledgements: We are grateful to the anonymous reviewers for their valuable feedback, which has aided in improving the quality of this study presentation.

1 Introduction

The COVID-19 pandemic has affected the daily activities of populations around the world. Government regulations have sought to limit social contact and the subsequent spreading of the virus (Riiser et al., 2021). The pandemic and associated interventions have had a significant impact on the global economy, including reduced trade and disrupted supply chains (Park et al., 2020a), adverse effects on a diverse range of sectors (Lin & Falk, 2021), and downturns in factor markets (Maliszewska et al., 2020). In addition, the pandemic has had a profound impact on education, including disruptions of teaching and learning activities with specific reference to a pedagogical shift to e-learning approaches (Mseleku, 2020). In addition to the infrastructure challenges of these changes perpetuated (with reference to information and communication technology facilities, access to the internet, and devices to access online functionalities), there are also psychological effects associated with increased workloads for staff and students and the inequality fostered through unevenly dispersed access to online modalities (Popoola et al., 2022). The pandemic impact is also relevant to education in the built environment; where necessary in-person activities such as studio work (Peimani & Kamalipour, 2022), site visits, and practical training have been restricted due to the limitations on physical interaction.

The disturbance manifesting from the pandemic affected diverse educational outcomes (Joshi et al., 2020), including teaching and learning approaches, content access functions, and assessment and evaluations. Maintaining resilience of educational outcomes and considering the teaching and learning conditions perpetuated by the pandemic have highlighted the need for rapid adaptation by stakeholders in built environment education (Peimani & Kamalipour, 2022), including from educators, students, and related support functions at the relevant institutions. The absence of said resilience and the ability to recover and respond to an external disruption (i.e. the pandemic) may have affected – and continue to affect – the achievement of educational outcomes in diverse contexts. A prominent tool in the identification and development of measures towards adaptation in support of resilience, regardless of sector or envisioned outcome, is research and the related knowledge it expounds to be implemented by stakeholders and practitioners. Inherent hereto is the relationship between research and practice, with the former able to inform and guide the latter in line with shared objectives (Gray et al., 2014). Targeted research has the ability to guide adaptation in a sector through delineating related interventions by sectoral agents towards this end (Pretorius et al., 2021).

In the context of built environment education, this study further explored the relationship between research, practice, and adaptation to support resilience in the education sector in the context of the impact of the COVID-19 pandemic. The research aim of this study was to provide insight into the extent to which research on built environment education may potentially support adaptation in related educational practices in response to the COVID-19 pandemic. To achieve this aim, two objectives guided this study: (i) to analyse the effect of the pandemic on research in built environment education, and (ii) to delineate the pandemic-related research themes incorporated in the related research body. These objectives allow for an informed discussion on the extent to which research in built environment education has changed as a result of the COVID-19 pandemic, in addition to providing insight into how new research may be supportive of the associated adaptation of practices in the education sector in response to the pandemic. In this regard, a bibliometric review of secondary sources in the form of existing literature and applicable publications was undertaken using the VOSviewer (v1.6.17) software. There is currently limited literature on how the pandemic has altered research on education and on the built environment, but also in terms of built environment education specifically. This is the research gap this study sought to contribute to, anchored in the potential of research to support adaptation of practices in the education sector in response to the pandemic. The study exploration is provided through

an overview of relevant literature themes, a discussion of the research methodology, the findings and discussion, as well as the conclusion.

2 Literature review

The literature review consists of an overview of the impact of the pandemic on education, and specifically on built environment education, the concepts of adaptation and resilience in education, and the relationship between research and practice.

2.1 Impact of the pandemic on education

The collective summary of the impact of the pandemic on education was the global temporary closure of schools (Chaabane et al., 2021) and disruption to traditional teaching and learning approaches that led to the migration to online education. Mahdy (2020) reported that most institutions of higher learning across the globe either postponed or cancelled schooling activities to manage the pandemic vulnerabilities. In fact, it was identified that despite embracing online teaching, many students in disciplines such as veterinary medicine perceived that sustainable teaching is subjective under such conditions. It was argued that learners reported difficulty in fulfilling the veterinary competencies via the emergency online education. This posits on the writing by Alsoufi et al. (2020) that the pandemic has limited education feasibility and adequacy. The example was given in the medical clerkship and clinical ward training associated with medical education that is disrupted and limited by the pandemic. He et al. (2020) argued for the physical and psychosocial shocks that may result from the pandemic on resident medical learners.

According to Akyildiz (2020), the uncertainty of the education calendar due to the pandemic cannot be downplayed. The author mentioned that while there were reported cases of anxiety, despair, and boredom among students, the pandemic has resulted in lack of interaction and communication, leading students to isolation and problems about exams, traditional educational habits, learning tasks and assignments, and time management. Martin (2020) buttressed on this that the online teaching owing to the pandemic limits interaction with academic staff and peers, resulting in isolation, changes in assessment, and lack of engagement, all of which resulted in reduced learning and teaching motivation. Although Ilieva-Sinigerova (2020) stated that about 65% of students in a sports programme actively participated in education and were generally satisfied with online teaching owing to the pandemic. For the few inactive students, the impact of the pandemic as mentioned by Onyema et al. (2020) may include learning disruptions, decreased access to education and research facilities, job losses, and increased student debt.

2.2 Impact of the pandemic on built environment education

The footprint of the COVID-19 pandemic on all sectors of the economy remains evident. Iterating the effect of the pandemic on the built environment, Cheshmehzangi (2021) reported that the pandemic has negatively affected learning and training in architecture, interior and urban design, and urban planning disciplines. Contributing to the argument, Tleuken et al. (2022) argued for student performance and satisfaction in the built environment during the pandemic. The authors examined the limitation in learning comfortability, ease of remote education, and technologies associated with built environment learning and training as an educational negativity that resulted from the pandemic. It was posited that the pandemic as a social factor is a limitation for positive and improved performance of students in the built environment. Gui et al. (2021) highlighted the relationship between built environment learning and learning outcomes and found that the characteristics of learners (student demographic profile, and background) together with the

learning environment positively influenced outcomes of online learning. Learners in the built environment tend to demand extra learning support owing to the challenges of learning online. This is because learners perceived a lack of discussion of ideas and personal goals with their lecturers in online educational practices (Gui et al., 2021, p. 10), suggesting that the pandemic remains a driver of built environment learning inequality and below par learning experience.

According to Larsson et al. (2020), the pandemic as a complex educational and social issue remains unresolved because of forced learning migration adaptation from face-to-face teaching to remote teaching. Uyaroğlu (2021) reported on the acid test of the resilience of built environment education in the face of the pandemic. The author mentioned that the pandemic led to a shock in architecture education curriculum and an urgent adaptation to the distance education process, which resulted in changing the course curricula in parallel with the emergence of new teaching and learning strategies, especially in applied programmes such as interior architecture. Uyaroğlu (2021) argued that the pandemic has limited learning methods and process owing to the cancellation of the traditional face-to-face education because of the pandemic. Similar disruptions of teaching and learning approaches were experienced in other built environment fields, including engineering (Park et al., 2020b; Asgari et al., 2021) and quantity surveying (Leong, 2022). Buttressing on the restrictions on face-to-face teaching in the built environment education sector, Jin et al. (2021) emphasized the need for the integrative digitalization-based pedagogy in the built environment. This is because, technology serves a resilient and adaptive tool to the pandemic.

2.3 Contextualizing adaptation and resilience in education

Owing to the diverse impact of the pandemic on education – including in the built environment – rapid adaptation has been required (Yasa & Wirwan, 2021) to ensure resilience in educational outcomes. Resilience refers to the ability of a system to maintain its function and productivity in the event on an external disturbance (Tan et al., 2020). This is determined by the ability of the system to absorb the initial impact of the shock and to subsequently foster the needed changes to regain what was 'lost' during the initial impact. The latter connects with the notion of adaptation inherent to resilience, where the system seeks to ensure that previous output levels are regained and maintained at comparable levels and that the vulnerability of the system is reduced in the face of potential future disturbances (Pretorius et al., 2017). In the context of this study, the system is built environment education and potential outputs to be maintained (or improved) may refer to the various outcomes associated with educational activities, particularity teaching and learning.

As discussed, adaptation in this context has primarily been necessitated by the shift to online teaching and learning, away from physical, in-person approaches (Bento et al., 2021). This represents a profound change in teaching pedagogy (Peimani & Kamalipour, 2022), one which has required significant alterations in related teaching and learning practices to maintain educational outcomes and related resilience. Adaptation and change of pedagogies in the face of disruption has been studied by King et al. (2021, p. 174), who stated that is it imperative that educational stakeholders 'adapt to abrupt changes and disruptive transformations caused by emergency situations'. In addition, Ellerton (2016) studied pedagogical changes in the context of disruptive technology, while Evans (2022) incorporated the dual impact of the COVID-19 pandemic and new technology in catalysing change in teaching approaches. The manner in which practices have changed and adapted in the face of the pandemic and as a result of COVID-19 shock is what guided and informed the current research. This is in line with Pretorius et al. (2021), who stated that a central objective of resilience research is to delineate how practice must change and adapt to mitigate the effects of external disturbances.

2.4 Relationship between research, practice, and resilience

There is a profound relationship between research and practice, with the former being able to foster change and adaptation in the latter in line with predetermined and shared objectives. Rogers (2004), as referenced in Gray et al. (2014, p. 726), stated that a core dimension of the relationship between research and practice is 'the appropriation of theory [i.e. research] through use and adaptation in design practice'. This flow of knowledge and information from research to practice is referred to as a 'trickle-down' effect (Gray et al., 2014). To ensure this trickle-down effect – and thus for research to influence and inform practice – Kennedy (1997) stated that research should be persuasive, relevant, and accessible to the practitioner on all fronts (including writing and language use). In addition, the system in which the research is applied should be amendable to change and provide an environment conducive to adaptation in light of new findings, approaches, and interventions as delineated by research. The study by Kennedy (1997) noted that the absence of said factors deter adaptation of practice through research. Barriers to the uptake of research into practice is critically studied by Almeida and Báscolo (2006), who stated that, in the context of policymaking, research ought to be aligned with the objectives of practice or risk being irrelevant for implementation. Researchers need to consider how practitioners, whether individual stakeholders or institutions, engage with research outcomes (Pretorius et al., 2022).

Gray et al. (2014, p. 726) supported the potential of the 'dynamic relationship between theory and practice', noting that research ought to address everyday problems and challenges of practitioners, and offer tangible and suitable solutions in the appropriate contexts. This ability to mitigate presiding challenges in practice is a central advantage and factor in supporting the effective transfer of knowledge from research to practice (Chen et al., 2012). 'Alliancing', that is, the development and support of partnerships among stakeholders relevant to research and practice, is an effective way to enhance and strengthen this relationship (Chen et al., 2012). Practice informed by the application of research is paramount in the context of education. According to Nelson and Campbell (2017, p. 127), 'evidence-informed [education institutions] are an essential feature of effective education systems'. The foundation of this relationship is the ability of research to inform and stimulate adaptation in the context of programmes and curricula, the structure of and approaches inherent to educator development interventions, and educator engagement with research, in terms of consumption and production (BERA, 2014).

Research has the potential to foster change and relevant adaptation in practice in line with delineated and communicated objectives. Accordingly, this study explored the extent to which current research may potentially be supportive of adaptation in educational practices in the built environment, in the context of resilience.

3 Research methodology

The method adopted in this study was a bibliometric review. This constituted the central data collection and analysis instrument. The method involved a quantitative, and thus replicable, appraisal of literature applicable to the research aim. This instrument was utilized to triangulate evidence from current publications. Within this process, the Scopus-indexed publications database was utilized, from which applicable secondary literature data were exported. These data constituted the body of literature of a specified theme that was delineated using certain keywords identified in the publications' title, abstract, or stipulated keywords. To achieve the objectives of this study, bibliometric reviews of two datasets were undertaken. The first focused on the education in the built environment, with the body of literature delineated using the keywords 'education' (or 'teaching' or 'learning') and 'built-environment' (or 'built environment'). The second incorporated

research on the pandemic, with the keywords 'education' (or 'teaching' or 'learning'), 'built-environment' (or 'built environment'), and 'pandemic' (or 'COVID-19' or 'coronavirus'). These datasets were further curated by limiting included publications to fields related to the built environment, including environmental science, engineering, earth and planetary science, and social science.

Central to the data analysis was the application of the VOSviewer (v1.6.17) software (Van Eck & Waltman, 2022). The collected datasets were further analysed to, first, determine occurrences and linkages of keywords and themes within the delineated research bodies. Second, the VOSviewer software was also used to present the findings through network and overlay visualizations. Through the application of a network visualization approach, clusters of research inherent to the body of literature were identified. The items in the research clusters displayed significant interrelationship, to a greater degree than with exogenous keywords – that was the basis of their demarcation (Van Eck & Waltman, 2022). In addition, an overlay visualization approach was utilized to determine how the research body on built environment education during the pandemic had changed over time by being able to identify previous, current, and emerging research themes (Van Eck & Waltman, 2022).

4 Findings

This section provides an overview of the findings inherent to the bibliometric review. In line with the discussion on the research methodology, this section consists of two parts: (i) the effects of the pandemic on built environment education research and (ii) pandemic-related fields explored in built environment education research. These represent the two bodies of knowledge used in the analysis.

4.1 Effects of the pandemic on built environment education research

In determining the effects of the pandemic on built environment education research, related research published from 2017 to 2021 was analysed. This delineated a time-series that highlights the broad research themes and trends (and changes thereto) over time. In the broad body of literature, there was some mention of pandemic-related themes (i.e. 'coronavirus', 'COVID-19', 'pandemic', etc). This was quantified by (i) the number of times they occurred (i.e. occurrences) and (ii) the extent of the linkages with other keywords in the delineated publications (i.e. total link strength) (Van Eck & Waltman, 2022). In this case, their combined number of occurrences were 30 and total link strength was 674.

Table 1 provides an overview of these two variables, with data points from 2020 – when the pandemic (and this related research) commenced – and 2021.

Table 1: Occurrences and total link strength of pandemic-related keywords

Year	Occurrences	Total link strength	Total link strength of body of literature (%)
2020	11	303	0.53
2021	19	371	0.86
Total	30	674	—

Source: Authors' own.

Evidently, research on pandemic-related themes in the context of built environment education research had increased from 11 occurrences in 2020 to 19 in 2021, whereas total link strength had risen from 303 in 2020 to 371 in 2021. Year-on-year, occurrences of pandemic-related keywords thus increased by 73% and total link strength increased by 22%. Although research on related themes was limited in comparison to other keywords such as 'machine learning' (133 occurrences and 2,728 total link strength) and 'sustainable development' (123 occurrences and 2,043 total link strength), a growing number of publications focused on pandemic keywords and themes. An additional variable listed in Table 1 is the percentage of the total link strength of the body of literature that pandemic-related themes represented. This was strengthened from 0.53% in 2020 to 0.86% in 2021, representing a growth of 62%.

Although these findings provide some understanding of the growing prominence of pandemic-related research in the delineated body of literature, the review provides limited insight into the specific subthemes investigated in these publications (e.g. research on novel education topics catalysed by the pandemic), and thus the extent to which research may be potentially informing adaptation in teaching and learning practice to ensure resilience in educational outcomes.

4.2 Pandemic-related themes explored in built environment education research

This section used an adjusted dataset as well as network and overlay visualization approaches to identify the topics of research that have been catalysed by the pandemic within the context of built environment education. To achieve this more focused objective, the dataset itself was delineated using keywords directly relevant to the pandemic ('pandemic' or 'COVID-19' or 'coronavirus'), in addition to being individual datapoints as in Section 4.1. Accordingly, Table 2 illustrates the ten most prominent keywords inherent to the applicable research body.

Table 2: Keywords, occurrences, and linkages in research body

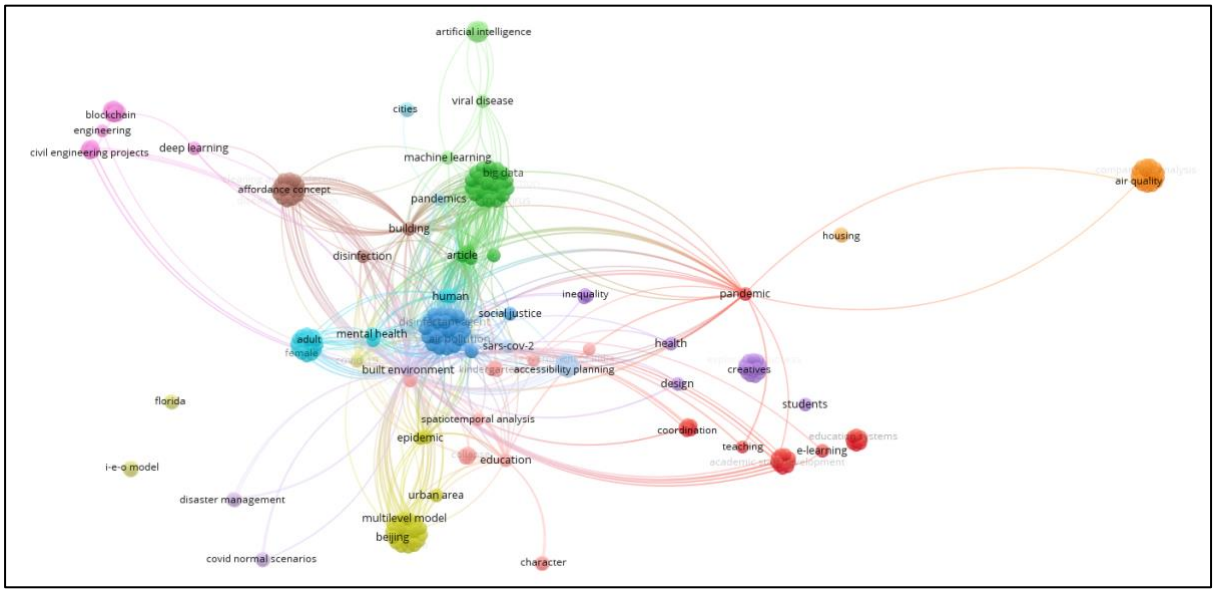
Keyword(s)	Occurrences	Total link strength
Human, humans	8	230
Pandemic, pandemics	10	215
Built environment	12	213
Coronavirus, coronavirus disease	7	191
COVID-19	10	190
Education	6	102
Environmental effect	2	79
Machine learning	4	77
Epidemic	2	71
Social environment	2	71

Source: Authors' own.

From this review, it is evident that there were 280 keywords that occurred at least once in the delineated publications. As indicated in Table 2, the most prominent keywords included 'human' (and 'humans'), 'pandemic' (and 'pandemics'), 'built environment', 'COVID-19', and 'coronavirus' (and 'coronavirus disease'). The total link strength of each of the mentioned keywords was above 190. Other prominent keywords included 'education', 'environmental effect', 'machine learning', 'epidemic', and 'social environment'.

The various research clusters and their linkages are shown in Figure 1, which represents the network visualization.

Figure 1: Clusters and linkages in research body



Source: Authors' own, using VOSviewer (v1.6.17) software.

From the 16 clusters in total, four primary clusters can be identified based on the quantity and interrelationship of keywords. *Education* was the most prominent cluster with 30 items, including keywords such as 'academic staff development', 'e-learning', 'education systems', 'teaching and learning', 'online teaching', and 'teaching strategies'). The *environment* cluster consisted of 29 keywords, including, inter alia, 'environmental design', 'environmental effect', 'disease spread', 'neighbourhood', 'land use', and 'urbanization'). The *social* and *economic* clusters each consisted of 26 keywords, the latter with items such as 'child development', 'food insecurity', 'health disparity', 'resource development', 'pesticide', and 'social interaction', and the former with 'employment', 'urban area/geography/planning/public security', 'shelters', 'property management', and 'community development'.

The *education* cluster in the research body on built environment education during the pandemic consisted of four subgroups, each focusing on an important component of the main cluster, namely (i) *learning* (keywords such as 'coordination', 'subject coordination', 'online', 'post-pandemic'); (ii) *teaching*, with focus on pedagogy ('online teaching', 'e-learning', 'online contents'), application ('academic staff development' 'teaching strategy', 'tools and technologies', 'electronic assessments', 'student engagement'), and context ('institutional contexts', 'innovation process'); (iii) *education systems*, which focused on 'learning experiences', 'interactive technology', 'virtual learning community', 'personal contacts', and 'sustainable educations'; and (iv) *pandemic*. It was this last keyword that fostered intra-cluster connectivity among the otherwise isolated subgroups, with *pandemic* and *teaching* constituting the strongest research connection within the *education* cluster. The *pandemic* subgroup also connected the broader *education* cluster and its three research subgroups with the primary *environment*, *social*, and *economic* clusters. In terms of inter-cluster linkages, all *education* subgroups were linked with the *built environment* cluster, with the exception of *education systems*. The primary artery between the *education* cluster and the rest of the delineated research body on built environment education was the linkage between the *built environment* cluster, the *pandemic* subgroup, and themes relating to pedagogical approaches inherent to online teaching and learning.

As research on the pandemic commenced in 2020, the overlay visualization was applied to identify which keywords and themes had gained research prominence during the initial and subsequent months. When considering the primary clusters, it was evident that the *social* cluster and its inherent research themes were the subject of the initial publications, focusing primarily on 'coronavirus infections', 'disease spread', and 'risk factor'. The *built environment* gained research focus, with initial topics that included 'cleaning and disinfection', 'disease transmission', and 'risk assessment'. These initial themes became increasingly connected with topics on 'education' during the 'pandemic'. The *social* and *environment* clusters constituted emerging themes in this built environment education research body, which included keywords mentioned in the discussion on the primary research clusters. Within the *education* cluster, the earliest research was done on the primary pedagogical change due to the pandemic: transitioning to an online teaching environment. From there, research in this cluster had extended towards the *pandemic* subgroup, with themes inherent to the *learning* and *education systems* subgroups identified as emerging topics in the research body.

5 Discussion

The findings of the two analyses indicate that (i) research on the relationship between the pandemic and built environment education was increasing in prominence, and (ii) certain key themes were explored subsequent to the initial impact of the pandemic. These findings constitute important considerations and study, as they illustrate that the relevant body of literature was growing in size, and the diversity of research themes might improve the breadth of evidence to inform the various relevant actions of education practitioners in this context. These findings also include that a prominent focus of current research was on changes to teaching approaches due to the pandemic. Specific references here included changing pedagogies (to e-learning), and, importantly, adaptation in the approaches to academic staff development, teaching strategies, and the available tools and technologies within this altered education landscape. While research focus was on the adaptation of teaching (and thus educator) approaches, there was also reference to the impact of the pandemic and related changes on students. Themes relating to learning experiences, interactive technology, and personal contact were investigated, in addition to wider societal themes such as the related socio-economic and environment effects.

As discussed in the literature review (Section 2.4), Nelson and Campbell (2017) indicated that research has the potential to influence adaptation in education practice in three ways: (i) the alteration of programme and curricula content, (ii) changing the structure and approaches to educator development initiatives, and (iii) shifting educator engagement with research. In the context of the pandemic, the findings of the study may indicate that the most prominent of these was adaptation in educator development initiatives. This is due to the central factor that catalysed the pandemic shock on education, namely, the shift to online teaching and learning. Accordingly, this had increased the need for research to inform the required adaptation of teaching and learning approaches from physical, in-person methods to those centred on e-learning, and thus the adaptation of the structure of educator development initiatives that sought to empower educators in these new methods. Furthermore, it was found that current research, due to its growing extent and its focus on diverse themes relating to teaching and learning and the associated online transition, might potentially inform and guide adaptation of certain core aspects of built environment education functionalities, with specific reference to the structure and approaches of educator development and related initiatives coordinated by institutions. This may subsequently support the continued resilience of educational outcomes within the lingering milieu of the pandemic and its effects, while also potentially reducing vulnerability to future external disturbances.

6 Conclusion

The COVID-19 pandemic has had a profound impact on education research in the built environment. From the literature review, it is apparent that the pandemic brought about the temporary closure of education institutions and a pedagogical shift to online teaching and learning. This significantly affected educational outcomes, due to challenges related to access to required technological devices, the missing practical elements to teaching and learning inherent to education in built environment fields, and the psychological toll associated with the online format and pandemic-related socio-economic effects.

The aim of this study was to provide insight into the extent to which research on built environment education may potentially support adaptation in related educational practices in response to the COVID-19 pandemic. Evident from the bibliometric review is that built environment education research is increasingly focused on diverse themes relating to the interrelationship between the pandemic and educational outcomes. This may be indicative of the extent of the impact and effect of the pedagogical shift from face-to-face teaching approaches to the online paradigm, which has necessitated further research enquiry. In further analysing the specific subthemes explored by researchers, it is apparent that the initial transition was driven by the mentioned pedagogical shift: the online teaching environment. This includes research on teaching strategies and academic staff development in the face of e-learning. This may have laid the foundation for more nuanced research, including learning experiences in utilizing interactive technology within a virtual learning community to foster sustainable and resilient education within the context of the pandemic.

The study has contributed to the growing body of literature on the broad impact of the COVID-19 pandemic on education, with specific focus on its effect on education research in the built environment.

It has further contributed to existing literature on the potential of research in informing adaptation in education practice. The possible role of emerging research outcomes in informing education practitioners and institutions on best practices are identified from the findings of this study. Relevant here is technology application, teaching approaches and strategies, educator development interventions, and assessment approaches. While applied to the built environment and in the context of the COVID-19 pandemic, the findings of this study may be further indicative of the role of research in potentially fostering adaptability towards long-term resilience in other educational realms and sectors of society, in the face of diverse potential future disturbances.

These contributions should be considered in light of the limitations of this study. This includes that the methodology applied does not incorporate a detailed qualitative review of the content of the delineated publications. In addition, the secondary data used in the study is limited to the Scopus database. Future research should aim to overcome these limitations. Furthermore, to support this study's aim and contribute to existing literature, future research ought to focus on gaining the insight of practitioners and institutions in the education sector on their utilization and implementation of research outputs in their respective activities to improve educational outcomes, both in general and in the context of fostering resilience. In addition to this, insight ought to be gained on the underlying factors that influence the uptake – or otherwise – by education practitioners of adaptive measures expounded by related research, in line with the factors of persuasiveness, accessibility, and relevance inherent to the framework of Kennedy (1997; see Section 2.4).

7 References

Akyildiz, S. T. (2020). College students' views on the pandemic distance education: A focus group discussion. *International Journal of Technology in Education and Science*, *4*(4), 322–334. https://doi.org/10.46328/ijtes.v4i4.150

Almeida, C., & Báscolo, E. (2006). Use of research results in policy decision-making, formulation, and implementation: A review of the literature. *Cad Saúde Pública*, *22*, S7–S19. https://doi.org/10.1590/S0102-311X2006001300002

Alsoufi, A., Alsuyihili, A., Msherghi, A., Elhadi, A., Atiyah, H., Ashini, A., Ashwieb, A., Hasan, M., Abdudabuos, S., Alameen, H., Abokhdir, T., Anaiba, M., Nagib, T., Shuwayyah, A., Benothman, R., Arrefae, G., Alkhwayildi, A., Alhadi, A., Zaid, A., & Elhadi, M. (2020). Impact of the COVID-19 pandemic on medical education: Medical students' knowledge, attitudes, and practices regarding electronic learning. *PLOS ONE*, *15*(11), 1–20. https://doi.org/10.1371/journal.pone.0242905

Asgari, S., Trajkovic, J., Rahmani, M., Zhang, W., Lo, R. C., & Sciortino, A. (2021). An observational study of engineering online education during the COVID-19 pandemic. *PLOS ONE*, *16*(4), Article e0250041. https://doi.org/10.1371/journal.pone.0250041

Bento, F., Bottino, A.G., Pereira, F.C., de Almeida, J.F., & Rodrigues, F.G. (2021). Resilience in higher education: A complex perspective to lecturers' adaptive processes in response to the COVID-19 pandemic. *Education Sciences*, *11*(9), Article 492. https://doi.org/10.3390/educsci11090492

BERA. (2014). *The role of research in teacher education: Reviewing the evidence. Interim Report of the BERA–RSA Inquiry*. https://www.thersa.org/globalassets/pdfs/reports/bera-rsa-interim-report.pdf

Chaabane, S., Doraiswamy, S., Chaabna, K., Mamtani, R., & Cheema, S. (2021). The impact of COVID-19 school closure on child and adolescent health: A rapid systematic review. *Children*, *8*(45), 1–17. https://doi.org/10.3390/children8050415

Chen, G., Zhang, G., Xie, Y. M., & Jin, X. H. (2012). Overview of alliancing research and practice in the construction industry. *Architectural Engineering and Design Management*, *8*(2), 103–119. https://doi.org/10.1080/17452007.2012.659505

Cheshmehzangi, A. (2021). Revisiting the built environment: 10 potential development changes and paradigm shifts due to COVID-19. *Journal of Urban Management*, *10*(2), 166–175. https://doi.org/10.1016/j.jum.2021.01.002

Ellerton, P. (2016, June). *The educational community of inquiry as disruptive pedagogy* [Paper presentation]. Proceedings at the North American Association for Community of Inquiry Conference, New Jersey, New York.

Evans, D. J. R. (2022). Has pedagogy, technology, and COVID-19 killed the face-to-face lecture? *Anatomical Sciences Education*, *15*, 1145–1151. https://doi.org/10.1002/ase.2224

He, K., Stolarski, A., Whang, E., & Kristo, G. (2020). Addressing general surgery residents' concerns in the early phase of the COVID-19 pandemic. *Journal of Surgical Education*, *77*(4), 735–738. https://doi.org/10.1016/j.jsurg.2020.04.003

Gray, C. M., Stolterman, E., & Siegel, M. A. (2014, June 21–25). Reprioritizing the relationship between HCI research and practice: bubble-up and trickle-down effects. In *Proceedings of the Conference on Designing Interactive Systems (DIS'14)* (pp. 725–734), Vancouver, Canada. https://doi.org/10.1145/2598510.2598595

Gui, H., Wong, S., Ahmad Zaini, A., & Goh, N. (2021). Online learning amidst COVID-19 pandemic – explicating the nexus between learners' characteristics, their learning environment and the learning outcomes in built environment studies. *Interactive Learning Environments*, 1–12. https://doi.org/10.1080/10494820.2021.1978504

Ilieva-Sinigerova, S. (2020). The impact of pandemic into sport statistics learning – students' opinion. *Pedagogy*, *92*(7s), 302–311.

Jin, R., Adamu, Z., Chohan, N., & Kangwa, J. (2021, September 5–7). *A critical analysis of collaborative and disruptive digital-driven built environment education* [Paper presentation]. Proceedings of the Association of Researchers in Construction Management (ARCOM), Manchester.

Joshi, A., Vinay, M., & Bhaskar, P. (2020). Impact of coronavirus pandemic on the Indian education sector: perspectives of teachers on online teaching and assessments. *Interactive Technology and Smart Education, 18*(2), 205–226. https://doi.org/10.1108/ITSE-06-2020-0087

Kennedy, M. M. (1997). The connection between research and practice. *Educational Researcher*, *26*(7), 4–12. https://doi.org/10.3102/0013189X026007004

King, I., Saxena, C., Pak, C., Lam, C., & Cai, H. (2021). Rethinking engineering education: Policy, pedagogy, and assessment during the crises. *IEEE Signal Processing Magazine*, *38*, 174–184. https://doi.org/10.1109/MSP.2021.3059243

Larsson, N. (Ed.), Giancarlo Mangone, G., Kujawski, W., Delcourt, H., Leighton, L., Berchtold, M., Foliente, G. C., Larsson, G. C., Issa, M. H., Hierlihy, B., Salat, S., & Fadli, F. (2020, June 22). *Pandemics and the built environment*. International Initiative for a Sustainable Built Environment (iiSBE). https://aibc.ca/wp-content/uploads/2020/06/Pandemics-and-the-Built-Environment-22June20.pdf

Leong, D. C. P. (2022). Curriculum change management amidst pandemic crisis: Comparative study of academic leadership in quantity surveying program. *Malaysian Journal of Social Sciences and Humanities*, *7*(4), Article e001464. https://doi.org/10.47405/mjssh.v7i4.1464

Lin, X., & Falk, M. T. (2021). Nordic stock market performance of the travel and leisure industry during the first wave of COVID-19 pandemic. *Tourism Economics*, *28*(5), 1–18. https://doi.org/10.1177/1354816621990937

Mahdy, M. A. (2020). The impact of COVID-19 pandemic on the academic performance of veterinary medical students. *Frontiers in Veterinary Science*, *7*, Article 596391. https://doi.org/10.3389/fvets.2020.594261

Maliszewska, M., Mattoo, A., & Van Der Mensbrugghe, D. (2020). The potential impact of COVID-19 on GDP and trade: A preliminary assessment. *WB Policy Research Working Paper* 9211, April. World Bank Group. https://doi.org/10.1596/1813-9450-9211

Martin, L. (2020). *Foundations for good practice: The student experience of online learning in Australian higher education during the COVID-19 pandemic*. Tertiary Education Quality and Standards Agency, Australian Government. https://www.teqsa.gov.au/sites/default/files/student-experience-of-online-learning-in-australian-he-during-covid-19.pdf?v=1606953179

Mseleku, Z. (2020). A literature review of e-learning and e-teaching in the era of COVID-19 pandemic. *International Journal of Innovative Science and Research Technology*, *5*(10), 588–597.

Nelson, J., & Campbell, C. (2017). Evidence-informed practice in education: Meanings and applications. *Educational Research*, *59*(2), 127–135. https://doi.org/10.1080/00131881.2017.1314115

Onyema, E., Eucheria, N., Obafemi, F., Sen, S., Atonye, F., Sharma, A., & Alsayed, A. (2020). Impact of coronavirus pandemic on education. *Journal of Education and Practice*, *11*(13), 108–121.

Park, C. Y., Kim, K., Roth, S., Beck, S., Kang, J. W., Tayag, M. C., & Griffin, M. (2020a). Global shortage of personal protective equipment amid COVID-19: Supply chains, bottlenecks, and policy implications. *ADB Briefs*, 130(April), 1–10. https://doi.org/10.22617/BRF200128-2

Park, J. J., Park, M., Jackson, K., Vanhoy, G. (2020b). Remote engineering education under COVID-19 pandemic environment. *Open Journals in Education*, *5*(1), 160–166. https://doi.org/10.32674/jimphe.v5i1.2811

Peimani, N., & Kamalipour, H. (2022). The future of design studio education: student experience and perception of blended learning and teaching during the global pandemic. *Education Sciences*, *12*(2), 1–13. https://doi.org/10.3390/educsci12020140

Popoola, A., Pretorius, O., Blamah, N., Chipungu, L., & Magidimisha-Chipungu, H. (2022, February 17–22). In the middle of the pandemic: Experiences for built environment education. In W. M. Shahzad, E. O. Rasheed, & J. O. B. Rotimi (Eds.), *Proceedings of 7th New Zealand Built Environment Research Symposium (NZBERS)*, Massey University, Albany, New Zealand.

Pretorius, O., Drewes, E., & Van Aswegen, M. (2017). Fostering a resilient regional economy in the SADC through regional integration. *Regional Science Policy & Practice*, *9*(3), 217–228. https://doi.org/10.1111/rsp3.12102

Pretorius, O., Drewes, E., van Aswegen, M., & Malan, G. (2021). A policy approach towards achieving regional economic resilience in developing countries: Evidence from the SADC. *Sustainability*, *13*(5), 1–21. https://doi.org/10.3390/su13052674

Pretorius, O., Drewes, J. E., Gumbo, T. (2022). Evidence to inform resilience policy in the SADC: Current limitations and future research areas. *World*, *3*, 449–469. https://doi.org/10.3390/world3030024

Riiser, K., Richardsen, K. R., Haraldstad, K., Helseth, S., & Torbjornsen, A. (2021). *'It's hard to keep a distance when you're with someone you really care about': A qualitative study of adolescents' pandemic-related health literacy and how COVID-19 affects their lives.* https://doi.org/10.1101/2021.06.17.21257667

Rogers, Y. (2004). New theoretical approaches for HCI. *Annual Review of Information Science and Technology*, *38*(1), 87–143. https://doi.org/10.1002/aris.1440380103

Tan, J., Hu, X., Hassink, R., & Ni, J. (2020). Industrial structure or agency: What affects regional economic resilience? Evidence from resource-based cities in China. *Cities*, *106*, Article 102906. https://doi.org/10.1016/j.cities.2020.102906

Tleuken, A., Turkyilmaz, A., Unger, K., Tokazhanov, G., El-Thalji, I., Mostafa, M., Mert, G., & Karaca, F. (2022). Which qualities should built environment possess to ensure satisfaction of higher-education students with remote education during pandemics? *Building and Environment*, *207*, Article 108567. https://doi.org/10.1016/j.buildenv.2021.108567

Uyaroğlu, İ. D. (2021). Resilience in interior architecture education: Distance universal design learning in the COVID-19 pandemic. *Journal of Design for Resilience in Architecture and Planning*, *2*(2), 234–249. https://doi.org/10.47818/DRArch.2021.v2i2022

Van Eck, N., & Waltman, L. (2022). *VOSviewer manual*. https://www.vosviewer.com/getting-started

Yasa, I. W. P., & Wirawan, I. G. M. A. S. (2021, September 9). High school learning problems during the COVID-19 pandemic. In *Proceedings of the 3rd International Conference on Law, Social Sciences, and Education (ICLSSE 2021)*, Singaraja, Bali, Indonesia.

Resilience in Research and Practice are the proceedings of the International Postgraduate Conference held at the University of Salford from the 4th to the 6th of April, 2022.
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University of Salford, 2023
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ISBN: 978-1-912337-64-4

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