A principal component analysis of sustainable building construction features for project delivery in South Africa

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Abstract

Purpose – Successful project delivery for sustainable building construction (SBC) has been linked to certain features. Previous studies have emphasised the need to improve SBC practice in South Africa. The purpose of this study is to explore the SBC features for project delivery in South Africa.

Design/methodology/approach – A structured questionnaire elicited the primary data from 281 built environment professionals, mainly in South Africa's Gauteng province. Descriptive and inferential statistics were used for the data analysis. This study used the principal component analysis technique to ascertain the principal SBC features.

Findings – Three components of SBC features, namely, sustainable resource use and compliance, sustainable waste minimisation and recycling and sustainable designs and materials, were developed from the principal component analysis. The factor loadings of the constituent variables ranged from 0.570 to 0.836. The reliability of each component was evaluated, and the results were 0.966, 0.931 and 0.913.

Practical implications – The revelations from this study will aid the decision-making of the relevant stakeholders towards establishing improvement initiatives and mitigating the reluctance to shift from conventional building methods and poor knowledge sharing of SBC benefits.

Originality/value – This is one of the most recent South African studies that sheds light on the components of a successful SBC deployment. The findings of this study added to knowledge by confirming three

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fundamental features of SBC. This study recommends adequately considering the principal features for successful SBC project delivery in South Africa.

Keywords Sustainable building construction, Green building, Features, Principal component analysis, South Africa

Paper type Research paper

1. Introduction

Sustainable building construction (SBC) is the answer to curb the significant threat and deleterious effects of the conventional activities of the construction industry towards the climate, environment, human health and national economies (Krizmane *et al.*, 2016; Omopariola *et al.*, 2022). The construction industry is one of the most resource-intensive industries using raw materials, water and energy and is a significant contributor to environmental pollution, ozone layer depletion and waste (Willar *et al.*, 2020). Globally, the construction industry consumes about 40%–50% of the world's raw materials and 40%–45% of energy (Tabassi *et al.*, 2016; Murtagh *et al.*, 2020).

The construction industry activities in South Africa are not without an effect on the environment and natural resources. Despite ongoing efforts to improve construction practices in South Africa, the industry faces significant challenges, particularly concerning sustainability and project delivery (Bowen *et al.*, 2014). There is pressure to deliver green buildings in South Africa, considering the challenges such as climate change, the energy crisis and ongoing water shortages (Simpeh *et al.*, 2023). In South Africa, building construction at least leads to 23% of greenhouse gas (GHG) emissions, while emissions from its material production account for 18 mt CO_2 annually, accounting for about 4% of the total CO_2 emissions (Simpeh and Smallwood, 2020). Similarly, buildings consume about 23% of electricity and an additional 5% is used to manufacture construction products in South Africa (Emere *et al.*, 2023). Solid waste production is estimated to be 42 million cubic meters yearly in South Africa, with most of this waste produced in Gauteng province (Aboginije *et al.*, 2020). SBC is required to mitigate the negative environmental impacts of building construction and ensure that social and economic objectives are met (Häkkinen *et al.*, 2016). SBC is defined as the construction of buildings in a sustainable and green way (Tabassi *et al.*, 2016). Green and sustainable are terms that connote ecological mindfulness. Besides, SBC aims to meet environmental, social and economic objectives. The consciousness of a sustainable built environment encourages the creation of designs that better serve community members' needs, accommodate, improve occupant comfort and health and increase employee productivity (Kwofie *et al.*, 2020; Omopariola *et al.*, 2022). Hence, incorporating SBC principles will transform the construction industry, increase the number of green buildings (Omopariola *et al.*, 2022) and positively contribute to achieving sustainable development goals (SDGs).

Although there is a great need to adopt SBC in developing countries and South Africa, it has yet to receive sufficient attention in practice (Simpeh and Smallwood, 2020; Emere *et al.*, 2023). The South African construction industry (SACI) is generally slow in adopting green and sustainable building principles (Simpeh and Smallwood, 2020). Also, adoption is still in the infancy stage among property developers and clients compared to developed countries (Masia *et al.*, 2020). There has been a reluctance to shift from conventional building construction methods (Aghimien *et al.*, 2019) and a lack of demand for sustainable buildings/products (Marsh *et al.*, 2021). Conventional building methods often result in environmental degradation, excessive energy consumption and waste, undermining the country's sustainability goals (Ofori, 2019). Concurrently, project delivery often suffers from inefficiencies such as cost overruns, delays and quality issues (Windapo and Cattell, 2013). Considering the challenges of the construction industry and the problems associated with conventional building methods, there is an urgent need to adopt SBC in South Africa. SBC is characterised by certain features for successful project delivery (Olanipekun *et al.*, 2017). Hence, the current study explores the critical features for effectively implementing and delivering SBC projects. The hypothesis was that the discussed features positively affect SBC in South Africa. Besides, in South Africa, literature is still in the dark about which features are most crucial for effectively implementing SBC. Notably, studies have yet to explore the principal SBC features in SACI. Hence, this study seeks to fill this gap by using the principal component analysis (PCA) technique to reveal the principal features of SBC for effective implementation in South Africa.

2. Literature review

2.1 Adoption of sustainable building construction in South Africa

The number of green and sustainable buildings in South Africa's building stock is minimal, as is their contribution to the country's construction market (Simpeh *et al.*, 2023). There is a great need to switch from traditional construction methods to those that align with green building principles and concepts, including adopting green features in SACI (Owoha *et al.*, 2022). Sinha (2009) affirmed that features like energy efficiency need to be addressed more in most building practices in South Africa, including the overall neglect of green building principles. Nevertheless, the worldwide adoption of green buildings has increased awareness of green building features and projects in SACI compared to other African countries (Owoha *et al.*, 2022).

South Africa is argued to have one of the fastest-growing green building markets that will expand professionally and technologically further (Dodge Data and Analytics [DDA], 2018). The number of construction firms that integrate green building practices into their business was predicted to rise from 28% to 48% in 2018 and 2021, respectively (Owoha *et al.*, 2022). Besides, according to DDA (2018), South Africa has the highest green share for retrofitting existing buildings, with 49% more than the global average (37%) for green retrofits. Furthermore, between 2015 and 2019, the country certified 100 and 500 Green Star SA-rated buildings, respectively (GBCSA, 2019; Owoha *et al.*, 2022). This suggests that the adoption rate is improving progressively.

However, the industry has significant impediments to fully adopting green/sustainable building practices. There are prevailing problems encountered in implementing SBC practices in South Africa. These problems include a lack of knowledge and awareness of the methods and technologies, limited information that will allow practical implementation of practices, absence of dependable exact cost data/information, inadequate communication on strategies, limited understanding from clients/stakeholders on the benefits and perceived high cost of sustainable building materials (Saad, 2016; Aigbavboa *et al.*, 2017; Mashwama *et al.*, 2020; Marsh *et al.*, 2021). Other challenges include the use of expensive technologies, lack of effective enforcement and mobilisation of resources to support technological changes, reluctance to shift from the conventional methods and lack of client's/stakeholders' interest (Saad, 2016; Aghimien *et al.*, 2019; Marsh *et al.*, 2021). Furthermore, there is a lack of team integration among stakeholders, limited government involvement and poor knowledge sharing among the public/clients on the benefits of SBC project delivery (Aghimien *et al.*, 2019; Simpeh *et al.*, 2023). Interestingly, these problems are common in other developing and African countries (Ametepey *et al.*, 2015).

2.2 Sustainable building construction implementation

Building sustainably is in increasing demand and essential to ensure that the depletion of resources is mitigated. The practice of SBC alludes to different strategies, tools and techniques used to implement building projects that are less harmful to the environment, reduce/prevent waste production, increase waste management (reuse of waste in the production of building material), advantageous to the society and profitable to the company (Willar *et al.*, 2020). To complete a project successfully, SBC calls for adjustments to attitudes, paradigms, procedures and systems and finding answers to issues (Oke *et al.*, 2017). The following briefly discusses the SBC features.

2.2.1 Sustainability indicators in project briefs. Early identification of the project's primary sustainability goals and objectives is crucial (Wang and Adeli, 2014). These could be lowering carbon emissions, conserving natural resources, advancing social equity or strengthening the local economy (Tupenaite *et al.*, 2017; Intuitix, 2023). It is necessary to decide on the project's key performance metrics. Metrics like GHG emissions, water use, waste production or social and economic effects are examples of key indicators (Wang and Adeli, 2014; Intuitix, 2023).

2.2.2 Sustainable and efficient designs. Sustainable design considers the whole life cycle of a building and investigates approaches to decreasing the adverse environmental effects of building activities (Efthymiou *et al.*, 2010). Wang and Adeli (2014) emphasised the essence of sustainable, efficient designs to ensure that the economic, social and ecological objectives are met. Similarly, sustainable design initiatives seek to transmute structural developments into more environmentally conscious building designs and eventually enhance the quality of life (Wang and Adeli, 2014). It also accommodates using modern building techniques such as building information modelling (BIM) and value management. BIM, for example, optimises design and integrated project delivery (Wong and Fan, 2013). It also improves quality and reduces time and cost (Gurung, 2020).

2.2.3 Sustainable structural materials. Using sustainable structural materials minimises environmental impacts, reduces the use of resources, is cost-effective and poses no or low human health risks (Hussain and Kamal, 2015). Sustainable structural materials include timber and alternative lumber, composite bricks, composite blocks, cementitious materials, reinforced concrete/masonry alternatives and so on (Wang and Adeli, 2014; Kumar *et al.*, 2015). For instance, Wang and Adeli (2014) recommend wood to be used as a reuse and innocuous item in low-rise buildings. Likewise, Austin Energy (2013) confirmed using alternative lumber made of recycled materials, such as composite or plastic lumber (a recyclable material made of virgin or waste plastic), to receive increasing applications, especially for outdoor decks. Besides, alternative lumber can cost less in the long run, as it requires little maintenance during its lifetime (Wang and Adeli, 2014). Furthermore, Kumar *et al.* (2015) identified cellular lightweight concrete blocks as an alternative to conventional bricks/blocks.

2.2.4 Usage of biodegradable materials. According to Rautray *et al.* (2019), sugarcane bagasse, lime, stone dust and water can be combined to produce lightweight bio-bricks for non-load-bearing walls with excellent heat and sound insulation. Likewise, sewage sludge and fly ash have been advocated as suitable replacements for clay in brick production (Taki *et al.*, 2020). Furthermore, Lawrence (2015) proposed using bio-based renewable materials to reduce the embodied energy of buildings and in-use energy demand. Besides, as recycled materials still use significant energy, bio-based materials offer a viable substitute for environmental sustainability (Adebowale and Agumba, 2023).

2.2.5 Decrease in generating waste. This concerns reducing waste at the source or before ultimate disposal (Chadar and Chadar, 2017). In addition, it entails considering and applying the essential solid waste management concepts at every stage of the process, from material design to final material usage (Ugwu *et al.*, 2021). This necessitates adopting lean techniques and industrialised building systems (Hussin *et al.*, 2013). Reducing construction waste and improving material estimation are two benefits of assembling building components after they have been separated from the site (Jackson, 2023).

2.2.6 Promotion of waste material recyclability. This entails promoting the conversion of waste materials into alternative forms by reprocessing before their use (Ugwu *et al.*, 2021). Shifting to a circular economy in buildings requires recycling resources (Jackson, 2023). Adopting recycling procedures allows materials to be recycled into new goods or components rather than discarded at the end of their life cycle. Recycling lessens the need for energy, protects our resources and lessens pollution from material extraction (Ugwu *et al.*, 2021; Jackson, 2023).

2.2.7 Usage of waste in making construction materials. Agro-waste materials have been discovered to be beneficial in making construction materials. For example, agro-wastes like rice husk-bark ash, coal combustion fly ash and bagasse ash, were advantageous for making cementitious materials as suitable alternatives to Portland cement (Yang *et al.*, 2019).

2.2.8 Energy consumption minimisation. The operating energy of a building plus the embodied energy of the building materials and construction make up the building's life cycle energy (Karimpour *et al.*, 2014). Using low embodied energy materials, designing a lightweight/efficient structure to minimise material consumption, using recycled/reusable materials, renovating buildings rather than demolishing them and using locally sourced materials are some of the methods mentioned in the literature to reduce the embodied energy of buildings (Karimpour *et al.*, 2014; Adebowale and Agumba, 2023).

2.2.9 Consideration of supplementary energy systems. Generating energy has been a great challenge considering the increasing global population and expanding communities that put demands on energy supply, especially electricity, for their needs (De Amorim *et al.*, 2018). There is a great need to provide alternative energy supplies that are environmentally friendly, efficient and healthy for society (Rabaia *et al.*, 2021). A few ecologically friendly and efficient replacements for the conventional energy market have been discovered, including renewable energy sources. One of the cheapest energy sources is solar energy (thermal and photovoltaic), used mainly in buildings (Rabaia *et al.*, 2021).

2.2.10 Usage of renewable resources. Biomass burners and solar thermal collectors are typical low-energy active renewable technologies (Karimpour *et al.*, 2014). Literature suggests switching to renewable energy sources can lead to zero-energy buildings (Karimpour *et al.*, 2014). These houses use renewable technologies, such as solar thermal, photovoltaic and wind turbines, to lower the annual energy requirements for heat and power (Bruno, 2011; Karimpour *et al.*, 2014).

2.2.11 Minimisation of pollution and greenhouse gas emissions. The International Energy Agency advocates for substantial reductions in CO_2 emissions in building construction to limit global warming to below 2°C (IEA, 2020). Building materials and their production play a significant role in GHG emissions, underscoring the importance of sustainable practices or choosing sustainable options (Adebowale and Agumba, 2023).

2.2.12 Usage of materials with low carbon footprint. The construction industry, especially the building sector, must function at net-zero carbon by 2050 by the worldwide Paris Agreement on Climate Change, to which South Africa is a signatory (Green Directory, 2021). Many low-carbon footprint building materials are available for small- and large-scale construction projects. Typical building materials with a low carbon footprint and less environmental harm include bamboo, rammed earth, recycled steel and complementary cementing materials (Adebowale and Agumba, 2023).

2.2.13 Consideration of the project's effect on air, soil and water. Assessing the implications of construction activities, especially on air, soil and water, for mitigation is crucial. Increased dust particles in the atmosphere because of grading, filling, removals and other construction activities are some of the effects of construction on air quality (Cheriyan and Choi, 2020). Vehicle and construction equipment emissions may also influence the quality of the air. Similarly, large-scale projects typically involve significant land disturbance, including vegetation removal and topographical reconfiguration, which increase the soil's susceptibility to erosion (Rahman and Esa, 2014). Furthermore, water quality is crucial to the economy, ecology, aesthetics and recreation. Water quality changes can impact the water's aesthetic appeal or even make some uses impossible (Rahman and Esa, 2014).

2.2.14 Water usage minimisation. Water conservation tactics and technologies are frequently disregarded components of a whole-building design plan (Ilha *et al.*, 2009). Various strategies are revealed in the literature that can reduce the amount of water consumed through a building's life cycle (Akadiri *et al.*, 2012). For instance, it is reducing wastewater by using water-efficient plumbing equipment, including waterless urinals, ultra-low flow toilets and urinals, low-flow and censored sinks, low-flow showerheads and water-efficient dishwashers and washing machines (Ilha *et al.*, 2009). It also includes the dual plumbing design, which recovers non-potable water from rain or other sources and uses it for site irrigation (Ilha *et al.*, 2009).

2.2.15 Improved use of construction resources. A paradigm shift from the linear economy to the circular economy model is unavoidable to conserve resources and encourage their efficient use considering the physical limit of resources (Hossain *et al.*, 2020). Hossain *et al.* (2020) encourage a circular economy in the construction industry to facilitate the shift to sustainable building practices. Similarly, frequent evaluations and audits of costs, regular site meetings, cost analysis and market testing are necessary to prevent resource overuse that could compromise profitability and efficacy (Fapohunda and Chileshe, 2014).

2.2.16 Protection of biodiversity and ecology. Achieving the SDGs in general and SDG 15 in particular depends heavily on contributing a sustainable built environment to biodiversity conservation (Opoku, 2019; Fei *et al.*, 2021). All significant stakeholders in the built environment must be involved in raising awareness of the effects of biodiversity loss because of construction activities on human health and well-being. Reducing the built environment's impact on biodiversity should be integral to policies and strategies towards a sustainable built environment (Opoku, 2019).

2.2.17 Decrease in the use of toxic materials. One of the tenets of sustainable construction is to steer clear of harmful building materials (Wang and Adeli, 2014). Conventional building materials mostly contain toxic chemicals and toxins that can lower the air quality inside a building (Utilities One, 2023a). The release of volatile organic compounds from paints and varnishes, the toxicity of impregnating agents, materials that release toxic fumes in the event of a fire, asbestos-based materials, radioactive materials and lead plumbing are a few examples of toxins in building construction (Pacheco-Torgal and Jalali, 2011).

2.2.18 Minimisation of the use of non-renewable goods. Lawrence (2015) posits that using non-renewable resources such as steel, cement sourced from limestone or sand and other aggregates for building envelops should be minimised and replaced with bio-based materials that consume less embodied and operational energy.

2.2.19 Green procurement. Incorporating environmental factors into procurement/purchasing policies, plans and actions is green procurement (Liu *et al.*, 2020). Contractors and environmental standards should be stipulated in the contract (Srinivas, 2014). The main benefit of using green procurement in construction is the enhancement of the building and construction process's financial and environmental performance (Wong *et al.*, 2016).

2.2.20 Diminished operational and utility costs in buildings. This is one of the significant economic benefits of SBC (Simpeh and Smallwood, 2018). During the operating phase, SBC seeks to reduce waste generation, water use and energy use (Simpeh and Smallwood, 2018; Utilities One, 2023b). Ongoing operating expenses can be significantly decreased by implementing smart building management systems, which include occupancy sensors, automated controls and efficient water fixtures (Utilities One, 2023b).

2.2.21 Usage of smart appliances. Using smart appliances in houses/smart houses allows for efficient use/consumption of energy from automated systems to remote control of house conditions through the internet (Ko *et al.*, 2012). Besides, using smart appliances adds to the efficient use of energy and innovation, end-user satisfaction and comfort (Willar *et al.*, 2020).

2.2.22 Impact consideration on social background. The social impact of a construction project should be prioritised. Social sustainability is generally understood as improving people's well-being and quality of life (Mulholland *et al.*, 2019). Therefore, attributes such as safety and health, impact assessment on livelihood and culture, employment, stakeholder involvement, satisfaction, human rights and project team formation with a sustainability focus should be considered (Rostamnezhad and Thaheem, 2022).

2.2.23 Compliance with regulations on sustainable practices. The gap between green building and legislation requirements in South Africa is non-compliance with policies (Windapo and Goulding, 2015). Implementation of green practices (*per se*) has been "behind" legislation enacted to regulate the design and construction of green buildings (Windapo and Goulding, 2015; Emere *et al.*, 2023). Major regulations regarding SBC in South Africa include the Green Building Council of South Africa standards (GBCSA), the Department of Public Works green building policy and the National Environmental Management Act 107 of 1998 (Windapo and Goulding, 2015; Aboginije *et al.*, 2020).

2.2.24 Compliance with sustainability assessment measures. Currently, South Africa is the only nation in Africa with a green building council that has both fully embraced a sustainable building evaluation methodology and is a fully certified member of the World Green Building Council (GBCSA, 2017a). GBCSA adopted Green Star SA in 2009, like the Green Star assessment tool launched in 2002 by the Green Building Council of Australia (Hoffman *et al.*, 2020). Based on nine separate areas – each with various credits – the Green Star evaluation addresses sustainability and environmental challenges in building design, construction and usage (GBCSA, 2017b). Consequently, compliance with the assessment measures will ensure effective SBC.

3. Research methodology

The study aimed to evaluate SBC features for project delivery in South Africa. It used a deductive methodology predicated on a positivist philosophical framework and used quantitative data obtained through a questionnaire survey from experts in the built environment. The questionnaire survey was chosen because it facilitates data collection from many respondents and makes the research quantifiable and objective (Tan, 2011). The questionnaire was divided into sections A and B. Section A comprised demographic data like educational qualification, professional background, project role and industrial experience. Section B contained the SBC features. Respondents were asked to indicate the extent to which the features are essential for SBC project delivery in South Africa. A five-point Likert scale was used, which ranged from 1 (No extent) to 5 (Very high extent).

Professionals in the built environment who are knowledgeable and qualified to provide information to address the research topic were given the questionnaire. A total of 281 completed questionnaires were received, which were suitable for the analysis and surpassed the 150 respondents' threshold for factor analysis (Pallant, 2020). Convenience sampling was used instead of random sampling, which relies only on chance. Although a major disadvantage of convenience sampling is that it lacks clear generalisability (Obilor, 2023), it was found suitable to use in the context of this study. According to Etikan *et al.* (2016), an advantage of convenience sampling is that it is useful when randomisation is impossible, such as when the population is enormous. Hence, this sampling technique was chosen to represent the population of construction practitioners in the Gauteng province, which is approximately 333,000 (Statista, 2023), not to mention South Africa at large. In addition, the nature of the research necessitates experienced and knowledgeable respondents to contribute meaningfully. Hence, randomisation may not be suitable in achieving this goal. Besides, the convenient sampling technique is cost-effective, less time-consuming, efficient and simple to implement (Golzar *et al.*, 2022). Therefore, it was chosen considering the limited time frame to complete the study, the availability of respondents and the willingness to participate (Etikan *et al.*, 2016). Furthermore, the data elicited were based on respondents' perceptions, and the researcher planned to produce hypotheses being tested in detail in upcoming studies, which makes the convenience sampling technique suitable (Golzar *et al.*, 2022). These considerations (including the study's sample size, which enhanced the statistical power of this sampling technique) ensured that the sample represented the population. As recommended by Golzar *et al.* (2022), the authors also dispersed the questionnaires at various times and locations to obtain a suitable cross-section of the target population.

The Statistical Package for Social Sciences (SPSS) version 29 software produced the study results. Descriptive statistics with frequency, mean and standard deviation were used as outputs where applicable, and factors were ranked. Similarly, exploratory factor analysis (EFA) was used to collect data or explore the correlations between variables. PCA was used to reduce many correlated variables and resize the variables into a set of components (Pallant, 2020). This threshold was chosen to reduce the large data set of SBC features, thereby increasing interpretation while minimising the loss of information (Jolliffe and Cadima, 2016). Varimax method rotation and eigenvalue above one were used to extract the principal factors of SBC implementation.

Moreover, the reliability and internal consistency of the collected data were assessed based on Cronbach's alpha threshold of 0.70. The average value for the variables was 0.978, indicating excellent reliability and internal consistency of the collected data (Pallant, 2020). Similarly, the principal factors were separately assessed with Cronbach's alpha test, and the results exceeded the threshold. This contributed to the discriminatory validity of the study.

4. Findings

4.1 Demographical data

Results showed that respondents with Honours/Btech degrees came first at 44.8%, followed by those with master's degrees (24.2), bachelor's degrees (14.6), national diplomas (10.7) and doctorates (5.7%). Similarly, most of the respondents were from the background of construction management (21.4%), followed by engineering (20.6%), quantity surveying (19.6%), project management (17.1%), architecture (14.6%) and town/urban and regional planning (6.0). The fact that the sample accommodated the various backgrounds within the South African built environment helped authenticate the collected data. Regarding industrial experience, respondents with 6–10 years were predominant (19.6%), followed by 1–5 years (18.1%), 11–15 years (15.7%), 16–20 years (14.6%), 21–25 years (11.4%), 26–30 years (8.1%) and more than 30 years were the lowest ranked group. Likewise, many respondents performed the role of project managers (33.1%), followed by construction managers (17.1%), quantity surveyors (16.4%), project engineers (14.9%), principal agents (8.9%) and town planners (5.7%). Generally, the demographic data results showed that participants had enough knowledge and experience and were in an excellent position to respond to the questionnaire.

4.2 Assessing sustainable building construction features

Table 1 presents the critical SBC features for project delivery in South Africa. The respondents were asked to rate the extent to which the deliverables are essential in achieving SBC a five-point Likert scale ranging from 1 (no extent) to 5 (very high extent). The mean score (MS) and standard deviation (SD) were used as outputs to rank the measuring variables. Table 1 shows that all the variables recorded MS value $\geq 4.07 \leq 4.41$. Nonetheless, some variables were more notable than others. The first and second ranked were *sustainable and efficient designs* (MS = 4.41; SD = 0.726) and *sustainable structural materials* (MS = 4.39; SD = 0.719), respectively. The third was energy consumption minimisation (MS = 4.33; SD = 0.838), consideration of supplementary energy systems (MS = 4.33; SD = 0.820) and usage of renewable resources (MS = 4.33; SD = 0.802). However, the penultimate ranked feature was impact consideration on social background (MS = 4.12; SD = 0.910), while the least ranked was usage of biodegradable materials (MS = 4.07; SD = 0.985). Nevertheless, the MS values showed a good indication of the significance of all the variables. Furthermore, the internal consistency and reliability of the measuring variables were excellent, with Cronbach's alpha value of 0.978 above the threshold of 0.70 (Pallant, 2020).

Variable	MS	SD	Rank
Sustainable and efficient designs	4.41	0.726	*1st*
Sustainable structural materials	4.39	0.719	*2nd*
Energy consumption minimisation	4.33	0.838	*3rd*
Consideration of supplementary energy systems	4.33	0.820	*3rd*
Usage of renewable resources	4.33	0.802	*3rd*
Compliance with sustainability assessment measures	4.32	0.804	*6th*
Promotion of waste material recyclability	4.32	0.818	*6th*
Compliance with regulations on sustainable practices	4.32	0.772	*6th*
Green procurement	4.32	0.812	*6th*
Consideration of the project's effect on air, soil, water, etc.	4.31	0.819	*10th*
Minimisation of the use of non-renewable goods	4.30	0.795	*11th*
Water usage minimisation	4.30	0.825	*11th*
Decrease in generating waste	4.29	0.828	*13th*
Improved use of construction resources	4.28	0.795	*14th*
Usage of waste in making construction materials	4.25	0.847	*15th*
Protection of biodiversity and ecology	4.25	0.837	*15th*
Usage of materials with low carbon footprint	4.25	0.833	*15th*
Minimisation of pollution and greenhouse gas emission	4.25	0.874	*15th*
Usage of smart appliances	4.24	0.852	*19th*
Sustainability indicators in project briefs	4.24	0.786	*19th*
Diminished operational and utility costs in building	4.23	0.828	*21st*
Decrease in the use of toxic materials	4.22	0.834	*22nd*
Impact consideration on social background	4.12	0.910	*23rd*
Usage of biodegradable materials	4.07	0.985	*24th*
Kaiser–Meyer–Olkin measure sampling adequacy = 0.959			
Bartlett's test of sphericity significance = 0.000			
Cronbach's alpha		*0.978*	

Source: Author's own work

Table 1. Critical sustainable building construction implementation features

4.3 Principal component analysis for sustainable building construction features

This process commenced with EFA. In all, 24 SBC implementation measuring variables were examined with EFA. The Kaiser–Meyer–Olkin sample adequacy test and Bartlett's test of sphericity were done, as shown in Table 1. Kaiser–Meyer–Olkin score was 0.959, exceeding the minimal 0.6 required to continue factor analysis (Pallant, 2020). Also, Bartlett's test of sphericity result (0.001) supported factorability. Likewise, the extraction and rotation of the variables were done with PCA and the varimax rotation method, respectively.

Three principal component factors achieved values above one and were extracted with a cumulative percentage variance of 76.440, surpassing the recommended minimum threshold of 50% (Field, 2009). The principal component 1 accounted for 66.596% of the variance explained, while components 2 and 3 accounted for 5.453% and 4.391%, respectively.

Table 2 presents the results of the rotated component matrix with the factor loadings of the SBC implementation measuring variables categorised according to the principal components. The varimax rotated component matrix was used to achieve a simple, robust structure and results that were more straightforward to identify and interpret (Tengan, 2018). With values above 0.5, the variables loading in each extracted principal component were significant. Similarly, the extracted principal components had multiple variables, suggesting reasonable results (Field, 2009). The Cronbach's alpha test was used to ascertain the reliability/suitability of the items in each principal component, excluding variables with cross-loadings, as shown in Table 2.

		Component	
Variable	1	2	3
Improved use of construction resources	*0.788*		
Compliance with regulations on sustainable practices	*0.781*		
Diminished operational and utility costs in building	*0.772*		
Compliance with sustainability assessment measures	*0.772*		
Water usage minimisation	*0.755*		
Consideration of the project's effect on air, soil, water, etc.	*0.745*		
Impact consideration on social background	*0.724*		
Minimisation of pollution and greenhouse gas emission	*0.708*		
Energy consumption minimisation	*0.698*		
Green procurement	*0.686*		
Consideration of supplementary energy systems (solar etc.)	0.674	0.505	
Usage of renewable resources	0.658	0.514	
Usage of smart appliances	*0.656*		
Protection of biodiversity and ecology	0.582	0.512	
Decrease in the use of toxic materials	*0.570*		
Promotion of waste material recyclability		*0.818*	
Decrease in generating waste		*0.787*	
Usage of waste in making construction materials		*0.783*	
Usage of materials with low carbon footprint	0.531	0.682	
Minimisation of the use of non-renewable goods		*0.663*	
Usage of biodegradable materials		*0.623*	
Sustainable and efficient designs			*0.836*
Sustainable structural materials			*0.819*
Sustainability indicators in project briefs			*0.748*
Cronbach's alpha	0.966	0.931	0.913

Source: Author's own work

Table 2. Rotated component matrix for sustainable building construction implementation features

4.3.1 Naming of components. The three principal components extracted were named considering the interrelationships and loadings of the variables/items between them. Component 1 was named *Sustainable Resource Use and Compliance*; Component 2 was called *Sustainable Waste Minimisation and Recycling*; and Component 3 was named *Sustainable Designs and Materials*.

4.3.1.1 Component 1 – sustainable resource use and compliance. This comprised 12 variables with their loadings, namely, Improved use of construction resources (0.788), Compliance with regulations on sustainable practices (0.781), Diminished operational and utility costs in building (0.772), Compliance with sustainability assessment measures (0.772), Water usage minimisation (0.755), Consideration of the project's effect on air, soil, water, etc. (0.745), Impact consideration on social background (0.724), Minimisation of pollution and GHG emission (0.708), Energy consumption minimisation (0.698), Green procurement (0.686), Usage of Smart appliances (0.656) and Decrease in the use of toxic materials (0.570).

4.3.1.2 Component 2 – sustainable waste minimisation and recycling. This comprised five variables with their loadings, namely, Promotion of waste material recyclability (0.818), Decrease in generating waste (0.787), Usage of waste in making construction materials (0.783), Minimisation of the use of non-renewable goods (0.663) and Usage of biodegradable materials (0.623).

4.3.1.3 Component 3 – sustainable designs and materials. This comprised three variables with their loadings, namely, Sustainable and efficient designs (0.836), Sustainable structural materials (0.819) and Sustainability indicators in project briefs (0.748).

5. Discussions

The results presented in Table 1 provide valuable insights into the prioritised features for SBC implementation in South Africa, particularly concerning project delivery. Among the numerous factors evaluated, the top five SBC implementation features that received the highest rankings were sustainable and efficient designs, sustainable structural materials, energy consumption minimisation, consideration of supplementary energy systems and using renewable resources. On the other hand, the factors that received the lowest rankings were decreased use of toxic materials, impact consideration on social background and the use of biodegradable materials. Notably, all these identified factors had mean values exceeding 4.0, indicating their statistical significance at the established three-point threshold, per Kothari and Garg (2014).

The prominence of *sustainable and efficient designs* provides evidence of its criticality for implementing SBC in South Africa and agrees with the study's hypothesis. It echoes the findings of Wang and Adeli (2014), who emphasise the importance of holistic approaches to building construction that encompass the entire life cycle of a building. Sustainable and efficient design approaches seek to mitigate the adverse environmental impacts of construction activities, aligning well with SBC's sustainability goals (Wang and Adeli, 2014). Abruzzini and Abrishami (2022) suggest that integrating BIM and advanced digital technologies can support the decision-making process towards efficient designs.

The respondents' emphasis on sustainable structural materials corresponds with the study's proposition and provides evidence of its importance for implementing SBC in South Africa. This result aligns with the insights provided by Hussain and Kamal (2015), who highlighted the significance of using materials that minimise environmental impacts and pose minimal risks to human health. Such materials as timber and alternative lumber, composite bricks, cellular lightweight concrete blocks and so on (Wang and Adeli, 2014; Kumar *et al.*, 2015).

The focus on *minimisation of energy consumption aligns with the study's hypothesis* and reveals its vitality. Therefore, emphasis should be placed on reducing the embodied and operational energy of the buildings in South Africa. This necessitates designing lightweight structures and using low-embodied energy materials (Karimpour *et al.*, 2014; Adebowale and Agumba, 2023). Also, most buildings should be retrofitted rather than demolished (Adebowale and Agumba, 2023).

The respondents' emphasis on *consideration of supplementary energy systems* and *use renewable resources* also agrees with the study's hypothesis and provides evidence of their criticality. This necessitates using solar energy (thermal and photovoltaic) and other alternative energy supplies that are environmentally friendly, efficient and healthy for society (Rabaia *et al.*, 2021). Switching to renewable energy sources can lead to zero-energy buildings (Hussin *et al.*, 2013; Karimpour *et al.*, 2014). This underscores the importance of adopting renewable energy sources and materials in achieving sustainability goals within the construction industry.

5.1 Component 1 – sustainable resource use and compliance

The PCA results shed light on the principal elements in SBC implementation, particularly emphasising the importance of "Sustainable Resource Utilisation and Compliance" as the first principal component. Within this cluster, a range of features was identified as essential for SBC implementation. These features encompass Improved use of construction resources, Compliance with regulations on sustainable practices, Diminished operational and utility costs in building, Compliance with sustainability assessment measures, Water usage minimisation, Consideration of the project's effect on air, soil, water and surroundings, Impact consideration on social background, Minimisation of pollution and GHG emissions, Energy consumption minimisation, Green procurement, Usage of smart appliances and Decrease in the use of toxic materials. The finding regarding the *improved use of construction materials* aligns with the proposition of the study. This is also consistent with Hussin *et al.* (2013), who stressed the importance of efficiently using construction materials to minimise the demand for non-renewable resources, thereby reducing the environmental impact of construction. This revelation also suggests the need to shift from the linear economy to the circular economy model to conserve resources and encourage their efficient use, as well as curb the challenge of resource consumption without regard for the physical limits of resources (Hossain *et al.*, 2020). Similarly, the importance of *compliance with regulations on sustainable practices* and *sustainability assessment measures* as critical features of SBC implementation concur with the study's hypothesis. The respondents' opinions validate the need for these features among construction practitioners and stakeholders in SACI. This revelation concurs with Windapo and Goulding (2015), who found that the gap between green building and legislation requirements in South Africa is non-compliance with policies.

This study's finding concerning water usage minimisation agrees with the notion that it is crucial to SBC. Unfortunately, water conservation tactics and technologies are the most disregarded components of a whole-building design plan (Ilha *et al.*, 2009). This finding suggests inter-alia the reduction of wastewater by using water-efficient plumbing equipment (Ilha *et al.*, 2009). *Consideration of the project's effect on air, soil and water* and *Impact consideration on social background* speak volumes by their importance in this study. There is a need to keep the environmental impact assessment at the forefront of construction projects. This will enable the mitigation of pollution in the air and water and the dangers of erosion and soil loss (Rahman and Esa, 2014; Cheriyan and Choi, 2020). Similarly, emphasis should be placed on improving people's well-being and quality of life (Mulholland *et al.*, 2019). Therefore, to make a grave contribution to society, attributes such as safety and health, impact assessment on livelihood and culture, employment, stakeholder involvement, satisfaction, human rights and formation of the project team with a sustainability focus should be considered (Rostamnezhad and Thaheem, 2022).

The findings regarding *diminished operational and utility costs in building* and *using smart appliances* align with the study's hypothesis and suggest their criticality to SBC. Smart technologies can be used to reduce energy consumption and improve efficiency in buildings, including using automated systems and remote control via the internet (Ko *et al.*, 2012; Utilities One, 2023a). Similarly, the findings regarding *green procurement* and a *decrease in the use of toxic materials* align with the study's hypothesis. Construction procurement and purchasing policies, plans and actions should incorporate environmental factors (Liu *et al.*, 2020) to implement SBC effectively. Yudelson (2010) assert that green procurement and a decrease in the use of toxic materials for buildings can significantly reduce energy use, often achieving reductions of around 30%–50%.

5.2 Component 2 – sustainable waste minimisation and recycling

The second component, "Sustainable Waste Minimisation and Recycling", highlights the importance of managing waste and recycling materials in the context of SBC implementation. This component consists of five key variables: Promotion of waste material recyclability, Decrease in generating waste, Usage of waste in making construction materials, Minimisation of the use of non-renewable goods and Usage of biodegradable materials.

The emphasis on *promoting waste material recyclability, decreasing waste generation* and *using waste in the production of construction materials* aligns with the proposition of the study, indicating their importance. The findings concur with the insights provided by Simpeh and Smallwood (2018), who underscore the essential benefits of these practices within SBC, emphasising the need to minimise waste and maximise its reusability and recycling in construction projects. Waste should be reduced at the source or before ultimate disposal (Chadar and Chadar, 2017). Adopting lean techniques and industrialised building systems can facilitate waste management (Hussin *et al.*, 2013). Also, cementitious materials made of agro-waste can be used as suitable alternatives to Portland cement in South Africa. Moreover, the findings on *minimising non-renewable good*s and *using biodegradable materials* align with Hussin *et al.* (2013) and Simpeh and Smallwood (2018), who underscore the importance of reducing the reliance on non-renewable resources and adopting biodegradable materials that have a minimal environmental impact.

5.3 Component 3 – sustainable designs and materials

The third component identified through PCA, named "Sustainable Designs and Materials", comprised three variables: sustainable and efficient designs, sustainable structural materials and sustainability indicators in project briefs. This component sheds light on the crucial aspects of design and materials within the context of SBC, which aligns with the study's hypothesis. The emphasis on sustainable and efficient designs within this component aligns with the findings of Wang and Adeli (2014), who emphasised the critical role of these designs in SBC. Sustainable and efficient designs entail approaches that encompass the entire life cycle of a building to reduce adverse environmental impacts associated with design and construction activities (Efthymiou *et al.*, 2010). Such designs are integral to achieving SBC's sustainability goals by promoting environmentally responsible building practices.

Similarly, the recognition of sustainable structural materials as a vital feature within this component resonates with the perspectives of various scholars, including Wang and Adeli (2014) and Hussain and Kamal (2015). Priority should be given to materials that pose minimal human health risks while contributing to minimal environmental impact and resource conservation. In addition, *sustainability indicators in project briefs* emphasise the importance of early identification of the project's primary sustainability goals and objectives (Wang and Adeli, 2014). Objectives such as lowering carbon emissions, conserving natural resources, advancing social equity or strengthening the local economy should be decided early (Tupenaite *et al.*, 2017; Intuitix, 2023). This ensures that SBC's environmental, social and economic objectives are effectively incorporated and achieved throughout the project's lifecycle. Moreover, deciding the project's key performance metrics and key indicators early enables the gathering of information that can be examined and compared to the results of related projects or industry standards for improvement (Wang and Adeli, 2014; Intuitix, 2023).

6. Conclusions, implications and recommendations

SBC is an innovative approach that is expected to transform the construction industry activities in South Africa. Several features of its implementation have been identified. Using a questionnaire survey, respondents ranked the features according to their criticality. The features were categorised into three clusters or principal components: *Sustainable Resource Use and Compliance*, *Sustainable Waste Minimisation and Recycling* and *Sustainable Designs and Materials*. The respondents' perspectives on the features regarding the implementation of SBC in South Africa are elucidated by these clusters.

The current study contributed to theory, methodology, policy and practice. Theoretically, studies have yet to explore the principal features of SBC implementation in SACI. Consequently, the current research fills this gap. Similarly, this is one of the recent studies in South Africa that provides insights into the features for effective implementation of SBC. Methodologically, this study used PCA techniques to reveal the principal features of SBC implementation in South Africa. Therefore, the findings added to knowledge by confirming three fundamental factors for the SBC implementation for project delivery in South Africa. They include *Sustainable Resource Use and Compliance*, *Sustainable Waste Minimisation and Recycling* and *Sustainable Designs and Materials*. The consciousness of these features by the construction stakeholders and built environment organisations will help curb unsustainable practices in the construction industry. Therefore, the study recommends adequately considering and prioritising the revealed principal features to implement SBC project delivery effectively. Findings from this study will enable decision-makers within construction organisations to direct improvement initiatives appropriately. It will mitigate the reluctance to shift from the conventional methods and poor knowledge sharing among the public/clients on the essence of SBC.

The findings on sustainable and efficient designs and waste minimisation suggest that modern building techniques applicable to these features, such as BIM, IBS, value engineering/management and lean techniques, should be embraced and prioritised in South Africa. The study, therefore, recommends effective enforcement and mobilisation of resources to support technological changes. Also, social acceptance of cutting-edge and innovative technologies can be achieved by deploying awareness programs by professional bodies in the built environment. Similarly, information technological specialists can collaborate with the built environment professional bodies to curb the technological barriers identified from the literature regarding cost. This can give clients and users the desired value for money in implementing SBC.

To curb the prevalent non-compliance challenge identified from the literature concerning South African built environment practitioners, the government and policymakers in the SA construction industry should make regulations/legislation regarding SBC compulsory and defaulters penalised. The GBCSA and Department of Public Works green building policies should be taken seriously. This will mitigate unsustainable practices in the built environment. The government should also be a driving force in implementing sustainable practices which will facilitate the actualisation of SDGs. Providing financial incentives to organisations prioritising SBC is also advised (Agyekum *et al.*, 2021; Agyekum *et al.*, 2022).

In addition, energy efficiency programs and systems and renewable energy sources like solar should be implemented and prioritised to reduce the overreliance on conventional electricity in South Africa. Moreover, sustainable materials should be prioritised in SACI. The embrace of sustainable materials with increased quality performance can lessen the frequency and intensity of maintenance and repair tasks, improving long-term productivity and increasing longevity and durability (Adebowale and Agumba, 2023).

With the insights from the value and findings of this study, the SA construction industry can contribute immensely towards achieving SDGs by aligning its activities with sustainability initiatives. Furthermore, the general results can serve as a support tool for identifying the most significant implementation features to enhance the decision of built environment professionals and stakeholders to adopt SBC.

The study has some limitations. It focused on exploring the principal features of SBC implementation. Future studies may use structural equation modelling to confirm the impact of the identified principal factors on project success. Similarly, the study was predominantly conducted in the Gauteng province because of time constraints and difficulty reaching experts from other South African provinces. Therefore, the findings of this study may not be generalised to the South African built environment. For a comprehensive view of built environment professionals' perception of SBC and its implementation features, more research can be done using data from other provinces in South Africa.

References

Aboginije, A., Aigbavboa, C., Thwala, W. and Samuel, S. (2020), "Determining the impact of construction and demolition waste reduction practices on green building projects in Gauteng province, South Africa", Proceedings of International Engineering and Operations Management, Dubai, UAE, pp. 10-12.

Abruzzini, A. and Abrishami, S. (2022), "Integration of BIM and advanced digital technologies to the end of life decision-making process: a paradigm of future opportunities", *Journal of Engineering, Design and Technology*, Vol. 20 No. 2, pp. 388-413, doi: 10.1108/jedt-12-2020-0524.

Adebowale, O.J. and Agumba, J.N. (2023), "Sustainable building materials utilisation in the construction sector and the implications on labour productivity", *Journal of Engineering, Design and Technology*, doi: 10.1108/jedt-04-2023-0164.

Aghimien, D.O., Aigbavboa, C.O. and Thwala, W.D. (2019), "Microscoping the challenges of sustainable construction in developing countries", *Journal of Engineering, Design and Technology*, Vol. 17 No. 6, pp. 1110-1128, doi: 10.1108/jedt-01-2019-0002.

Agyekum, K., Goodier, C. and Oppon, J.A. (2021), "Key drivers for green building project financing in Ghana. Engineering", *Engineering, Construction and Architectural Management*, Vol. 29 No. 8, pp. 3023-3050, doi: 10.1108/ecam-02-2021-0131.

Agyekum, K., Opoku, A., Oppon, A.J. and Opoku, D.G.J. (2022), "Obstacles to green building project financing: an empirical study in Ghana", *International Journal of Construction Management*, Vol. 22 No. 15, pp. 2922-2930, doi: 10.1080/15623599.2020.1832182.

Aigbavboa, C., Ohiomah, I. and Zwane, T. (2017), "Sustainable construction practices: 'a lazy view' of construction professionals in the South African construction industry", *Energy Procedia*, Vol. 105, pp. 3003-3010, doi: 10.1016/j.egypro.2017.03.743.

Akadiri, P.O., Chinyio, E.A. and Olomolaiye, P.O. (2012), "Design of a sustainable building: a conceptual framework for implementing sustainability in the building sector", *Buildings*, Vol. 2 No. 2, pp. 126-152, doi: 10.3390/buildings2020126.

Ametepey, O., Aigbavboa, C. and Ansah, K. (2015), "Barriers to successful implementation of sustainable construction in the Ghanaian construction industry", *Procedia Manufacturing*, Vol. 3, pp. 1682-1689, doi: 10.1016/j.promfg.2015.07.988.

Austin Energy (2013), "Energy efficient programs", Green building resources [online], available at: www.austinenergy.com/Energy%20Efficiency/Programs/Green%20Building/Resources/Fact%20Sheets/deckLumberAlts.pdf (accessed 10 October 2022).

Bowen, P., Edwards, P. and Cattell, K. (2014), "Corruption in the South African construction industry: a thematic analysis of verbatim comments from survey participants", *Construction Management and Economics*, Vol. 30 No. 10, pp. 789-806, doi: 10.1080/01446193.2012.711909.

Bruno, F. (2011), "On-site experimental testing of a novel dew point evaporative cooler", *Energy and Buildings*, Vol. 43 No. 12, pp. 3475-3483, doi: 10.1016/j.enbuild.2011.09.013.

Chadar, S.N. and Chadar, K. (2017), "Solid waste pollution: a hazard to environment", *Recent Advances in Petrochemical Science*, Vol. 2 No. 3, pp. 41-43, doi: 10.19080/rapsci.2017.02.555586.

Cheriyan, D. and Choi, J.H. (2020), "A review of research on particulate matter pollution in the construction industry", *Journal of Cleaner Production*, Vol. 254, p. 120077, doi: 10.1016/j.jclepro.2020.120077.

De Amorim, W.S., Valduga, I.B., Ribeiro, J.M.P., Williamson, V.G., Krauser, G.E., Magtoto, M.K. and de Andrade, J.B.S.O. (2018), "The nexus between water, energy, and food in the context of the global risks: an analysis of the interactions between food, water, and energy security", *Environmental Impact Assessment Review*, Vol. 72, pp. 1-11, doi: 10.1016/j.eiar.2018.05.002.

Dodge Data and Analytics (DDA) (2018), "World green building trends", *Smart Market Report*, McGraw-Hill International Edition, New York, NY.

Efthymiou, E., Cöcen, Ö.N. and Ermolli, S.R. (2010), "Sustainable aluminium systems", *Sustainability*, Vol. 2 No. 9, pp. 3100-3109, doi: 10.3390/su2093100.

Emere, C., Aigbavboa, C. and Thwala, D. (2023), "A principal component analysis of regulatory environment features for sustainable building construction in South Africa", *Journal of Construction Project Management and Innovation*, Vol. 13 No. 2, pp. 17-32, doi: 10.36615/jcpmi.v13i2.2745.

Etikan, I., Musa, S.A. and Alkassim, R.S. (2016), "Comparison of convenience sampling and purposive sampling", *American Journal of Theoretical and Applied Statistics*, Vol. 5 No. 1, pp. 1-4, doi: 10.11648/j.ajtas.20160501.11.

Fapohunda, J.A. and Chileshe, N. (2014), "Essential factors towards optimal utilisation of construction resources", *Journal of Engineering, Design and Technology*, Vol. 12 No. 4, doi: 10.1108/jedt-02-2013-0016.

Fei, W., Opoku, A., Agyekum, K., Oppon, J.A., Ahmed, V., Chen, C. and Lok, K.L. (2021), "The critical role of the construction industry in achieving the sustainable development goals (SDGs): delivering projects for the common good", *Sustainability*, Vol. 13 No. 16, p. 9112, doi: 10.3390/su13169112.

Field, A. (2009), *Discovering Statistics Using SPSS*, 3rd edition Sage Publications, London.

GBCSA (2017a), "How We certify", available at: www.gbcsa.org.za/certify/ (accessed 30 March 2023).

GBCSA (2017b), "Green star certification", available at: www.gbcsa.org.za/certify/green-star-sa/ (accessed 30 March 2023).

GBCSA (2019), "Integrated annual report 2019", available at: www.gbcsa.org.za/2019-integratedannual-report-released/ (accessed 20 April 2021).

Golzar, J., Noor, S. and Tajik, O. (2022), "Convenience sampling", *IJELS*, Vol. 1 No. 2.

Green directory (2021), "Carbon reduction in construction – the time to act is now", 3rd November, 2021, available at: www.sa-green-info.co.za/portal/article/3008/carbon-reduction-in-construction-the-time-to-act-is-now (accessed 3 February 2024).

Gurung, N. (2020), "BIM for infrastructure in developing countries", Unpublished Bachelor's Dissertation, University of Applied Sciences, Metropolia.

Häkkinen, T., Rekola, M., Ala-Juusela, M. and Ruuska, A. (2016), "Role of municipal steering in sustainable building and refurbishment", *Energy Procedia*, Vol. 96, pp. 650-661, doi: 10.1016/j.egypro.2016.09.123.

Hoffman, D., Huang, L.Y., Van Rensburg, J. and Yorke-Hart, A. (2020), "Trends in application of green star SA credits in South African green building", *Acta Structilia*, Vol. 27 No. 2, pp. 1-29, doi: 10.18820/24150487/as27i2.1.

Hossain, M.U., Ng, S.T., Antwi-Afari, P. and Amor, B. (2020), "Circular economy and the construction industry: existing trends, challenges and prospective framework for sustainable construction", *Renewable and Sustainable Energy Reviews*, Vol. 130, p. 109948, doi: 10.1016/j.rser.2020.109948.

Hussain, A. and Kamal, M.A. (2015), "Energy efficient sustainable building materials: an overview", *Key Engineering Materials*, Trans Tech Publications Ltd, Vol. 650, pp. 38-50, doi: 10.4028/www.scientific.net/kem.650.38.

Hussin, J.M., Rahman, I.A. and Memon, A.H. (2013), "The way forward in sustainable construction: issues and challenges", *International Journal of Advances in Applied Sciences*, Vol. 2 No. 1, pp. 15-24, doi: 10.11591/ijaas.v2i1.1321.

Ilha, M.S.D.O., Oliveira, L.H.D. and Gonçalves, O.M. (2009), "Environmental assessment of residential buildings with an emphasis on water conservation", *Building Services Engineering Research and Technology*, Vol. 30 No. 1, pp. 15-26, doi: 10.1177/0143624408098274.

Intuitix (2023), "How to measure the sustainability of a project", available at: www.intuitix.co/how-to-measure-sustainability-of-a-project/ (accessed 13 February 2024).

Jackson, C. (2023), "Reducing waste and recycling materials in commercial construction projects", Construction21. 16 August, 2023, available at: www.construction21.org/articles/h/reducing-waste-and-recycling-materials-in-commercial-construction-projects.html (accessed 5 February 2024).

Jolliffe, I.T. and Cadima, J. (2016), "Principal component analysis: a review and recent developments", *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, Vol. 374 No. 2065, p. 20150202, doi: 10.1098/rsta.2015.0202.

Karimpour, M., Belusko, M., Xing, K. and Bruno, F. (2014), "Minimising the life cycle energy of buildings: review and analysis", *Building and Environment*, Vol. 73, pp. 106-114, doi: 10.1016/j.buildenv.2013.11.019.

Ko, H., Marreiros, G., Morais, H., Vale, Z. and Ramos, C. (2012), "Intelligent supervisory control system for home devices using a cyber physical approach", *Integrated Computer-Aided Engineering*, Vol. 19 No. 1, pp. 67-79, doi: 10.3233/ica-2012-0388.

Kothari, C. and Garg, G. (2014), *Research Methodology*, New Age International Publishers, New Delhi.

Krizmane, M., Slihte, S. and Borodinecs, A. (2016), "Key criteria across existing sustainable building rating tools", *Energy Procedia*, Vol. 96, pp. 94-99, doi: 10.1016/j.egypro.2016.09.107.

Kumar, A., Chani, P.S. and Deoliya, R. (2015), "Low embodied energy sustainable building materials and technologies", *Key Engineering Materials*, Trans Tech Publications Ltd, Vol. 650, pp. 13-20, doi: 10.4028/www.scientific.net/kem.650.13.

Kwofie, T.E., Aigbavboa, C.O. and Thwala, W.D. (2020), "Clusters of key barriers to life cycle assessment adoption in the South African construction industry: perspectives of stakeholders", *Journal of Engineering, Design and Technology*, Vol. 19 No. 4, pp. 888-903, doi: 10.1108/jedt-06-2020-0223.

Lawrence, M. (2015), "Reducing the environmental impact of construction by using renewable materials", *Journal of Renewable Materials*, Vol. 3 No. 3, pp. 163-174, doi: 10.7569/jrm.2015.634105.

Liu, J., Liu, Y. and Yang, L. (2020), "Uncovering the influence mechanism between top management support and green procurement: the effect of green training", *Journal of Cleaner Production*, Vol. 251, p. 119674, doi: 10.1016/j.jclepro.2019.119674.

Marsh, R.J., Brent, A.C. and De Kock, I.H. (2021), "Understanding the barriers and drivers of sustainable construction adoption and implementation in South Africa: a quantitative study using the theoretical domains framework and COM-B model", *Journal of the South African Institution of Civil Engineering*, Vol. 63 No. 4, pp. 11-23, doi: 10.17159/2309-8775/2021/v63n4a2.

Mashwama, N., Thwala, D. and Aigbavboa, C. (2020), "Obstacles of sustainable construction project management in South Africa construction industry", Sustainable Ecological Engineering Design: Selected Proceedings from the International Conference of Sustainable Ecological Engineering Design for Society (SEEDS) 2019, Springer International Publishing, pp. 305-314.

Masia, T., Kajimo-Shakantu, K. and Opawole, A. (2020), "A case study on the implementation of green building construction in Gauteng province, South Africa", *Management of Environmental Quality: An International Journal*, Vol. 31 No. 3, pp. 602-623, doi: 10.1108/meq-04-2019-0085.

Mulholland, C., Ejohwomu, O.A. and Chan, P.W. (2019), "Spatial-temporal dynamics of social value: lessons learnt from two UK nuclear decommissioning case studies", *Journal of Cleaner Production*, Vol. 237, p. 117677, doi: 10.1016/j.jclepro.2019.117677.

Murtagh, N., Scott, L. and Fan, J. (2020), "Sustainable and resilient construction: current status and future challenges", *Journal of Cleaner Production*, Vol. 268, p. 122264, doi: 10.1016/j.jclepro.2020.122264.

Obilor, E.I. (2023), "Convenience and purposive sampling techniques: Are they the same", *International Journal of Innovative Social and Science Education Research*, Vol. 11 No. 1, pp. 1-7.

Ofori, G. (2019), "Challenges of construction industries in developing countries: lessons from various countries", *In Construction in Developing Countries*, Routledge, pp. 15-32.

Oke, A.E., Aigbavboa, C.O. and Semenya, K. (2017), "Energy savings and sustainable construction: examining the advantages of nanotechnology", *Energy Procedia*, Vol. 142, pp. 3839-3843, doi: 10.1016/j.egypro.2017.12.285.

Olanipekun, A.O., Xia, B.P. and Nguyen, H.T. (2017), "Motivation and owner commitment for improving the delivery performance of green building projects: a research framework", *Procedia Engineering*, Vol. 180, pp. 71-78, doi: 10.1016/j.proeng.2017.04.166.

Omopariola, E.D., Olanrewaju, O.I., Albert, I., Oke, A.E. and Ibiyemi, S.B. (2022), "Sustainable construction in the Nigerian construction industry: unsustainable practices, barriers and strategies", *Journal of Engineering, Design and Technology*, doi: 10.1108/jedt-11-2021-0639.

Opoku, A. (2019), "Biodiversity and the built environment: implications for the sustainable development goals (SDGs)", *Resources, Conservation and Recycling*, Vol. 141, pp. 1-7, doi: 10.1016/j.resconrec.2018.10.011.

Owoha, F., Simpeh, E.K., Fapohunda, J.A., Ahadzie, D.K. and Mensah, H. (2022), "Categorising green building features in developing countries: the case of South Africa", *Journal of Engineering, Design and Technology*, Vol. 20 No. 6, pp. 627-1647, doi: 10.1108/jedt-01-2021-0012.

Pacheco-Torgal, F. and Jalali, S. (2011), "Toxicity of building materials: a key issue in sustainable construction", *International Journal of Sustainable Engineering*, Vol. 4 No. 3, pp. 281-287, doi: 10.1080/19397038.2011.569583.

Pallant, J. (2020), *SPSS Survival Manual: A Step-by-Step Guide to Data Analysis Using IBM SPSS*, McGraw-hill Education (UK).

Rabaia, M.K.H., Abdelkareem, M.A., Sayed, E.T., Elsaid, K., Chae, K.J., Wilberforce, T. and Olabi, A.G. (2021), "Environmental impacts of solar energy systems: a review", *Science of the Total Environment*, Vol. 754, p. 141989, doi: 10.1016/j.scitotenv.2020.141989.

Rahman, N.N.N.A. and Esa, N. (2014), "Managing construction development risks to the environment", *Sustainable Living with Environmental Risks*, pp. 193-202, doi: 10.1007/978-4-431-54804-1_16.

Rautray, P., Roy, A., Mathew, D.J. and Eisenbart, B. (2019), "Bio-brick-development of sustainable and cost-effective building material", *Proceedings of the Design Society: International Conference on Engineering Design*, Vol. 1 No. 1, pp. 3171-3180, doi: 10.1017/dsi.2019.324.

Rostamnezhad, M. and Thaheem, M.J. (2022), "Social sustainability in construction projects—a systematic review of assessment indicators and taxonomy", *Sustainability*, Vol. 14 No. 9, p. 5279, doi: 10.3390/su14095279.

Saad, M. (2016), "Impediments to implementation of green buildings in South Africa", Proceedings of 9th CIDB Postgraduate Conference, Emerging trends in construction organisational practices and project management knowledge area, *Cape Town, South Africa*.

Simpeh, E.K. and Smallwood, J.J. (2018), "Analysis of the benefits of green building in South Africa", *Journal of Construction Project Management and Innovation*, Vol. 8 No. 2, pp. 1829-1851, doi: 10.1080/15623599.2020.1863172.

Simpeh, E.K. and Smallwood, J.J. (2020), "An integrated model for predicting the probability of adoption of green building in South Africa", *Journal of Engineering, Design and Technology*, Vol. 18 No. 6, pp. 1927-1950, doi: 10.1108/jedt-09-2019-0244.

Simpeh, E.K., Smallwood, J.J., Ahadzie, D.K. and Mensah, H. (2023), "Analytical taxonomy of challenges to the implementation of green building projects in South Africa", *International Journal of Construction Management*, Vol. 23 No. 2, pp. 286-296, doi: 10.1080/15623599.2020.1863172.

Sinha, R. (2009), "Green building: a step towards sustainable architecture", *IUP Journal of Infrastructure*, Vol. 7 No. 2, p. 91.

Srinivas, H. (2014), "Sustainability concepts: green procurement", available at: www.gdrc.org/sustdev/concepts/14-gproc.html (accessed 6 February 2022).

Statista (2023), "Number of people employed in construction in South Africa 2022, by region", available at: www.statista.com/statistics/1129833/number-of-people-employed-in-construction-in-south-africa-by-region/ (accessed 18 May 2023).

Tabassi, A.A., Roufechaei, K.M., Ramli, M., Bakar, A.H.A., Ismail, R. and Pakir, A.H.K. (2016), "Leadership competencies of sustainable construction project managers", *Journal of Cleaner Production*, Vol. 124, pp. 339-349, doi: 10.1016/j.jclepro.2016.02.076.

Taki, K., Gahlot, R. and Kumar, M. (2020), "Utilisation of fly ash amended sewage sludge as brick for sustainable building material with special emphasis on dimensional effect", *Journal of Cleaner Production*, Vol. 275, pp. 1-12, doi: 10.1016/j.jclepro.2020.123942.

Tengan (2018), "Integrated monitoring and evaluation model", University of Johannesburg, Unpublished Doctoral Thesis.

Tupenaite, L., Lill, I., Geipele, I. and Naimaviciene, J. (2017), "Ranking of sustainability indicators for assessment of the new housing development projects: case of the Baltic States", *Resources*, Vol. 6 No. 4, p. 55, doi: 10.3390/resources6040055.

Ugwu, C.O., Ozoegwu, C.G., Ozor, P.A., Agwu, N. and Mbohwa, C. (2021), "Waste reduction and utilization strategies to improve municipal solid waste management on Nigerian campuses", *Fuel Communications*, Vol. 9, p. 100025, doi: 10.1016/j.jfueco.2021.100025.

Utilities One (2023a), "Analyzing life cycle costs in sustainable construction Decision-Making. Construction in the energy sector", 24 October 2023, available at: www.utilitiesone.com/analyzing-life-cycle-costs-in-sustainable-construction-decision-making (accessed 13 February 2023).

Utilities One (2023b), "Green building materials reducing carbon emissions in the construction industry. Construction in the energy sector", 27 October 2023, available at: www.utilitiesone.com/green-building-materials-reducing-carbon-emissions-in-the-construction-industry (accessed 14 February 2024).

Wang, N. and Adeli, H. (2014), "Sustainable building design", *Journal of Civil Engineering and Management*, Vol. 20 No. 1, pp. 1-10, doi: 10.3846/13923730.2013.871330.

Willar, D., Waney, E.V.Y., Pangemanan, D.D.G. and Mait, R.E.G. (2020), "Sustainable construction practices in the execution of infrastructure projects: the extent of implementation", *Smart and Sustainable Built Environment*, Vol. 10 No. 1, pp. 106-124, doi: 10.1108/sasbe-07-2019-0086.

Windapo, A.O. and Goulding, J.S. (2015), "Understanding the gap between green building practice and legislation requirements in South Africa", *Smart and Sustainable Built Environment*, Vol. 4 No. 1, pp. 67-96, doi: 10.1108/sasbe-01-2014-0002.

Windapo, O.A. and Cattell, K. (2013), "The South African construction industry: perceptions of key challenges facing its performance, development and growth", *Journal of Construction in Developing Countries*, Penerbit Universiti Sains Malaysia, Vol. 18 No. 2, pp. 65-79.

Wong, K.D. and Fan, Q. (2013), "Building information modelling (BIM) for sustainable building design", *Facilities*, Vol. 31 Nos 3/4, pp. 138-157, doi: 10.1108/02632771311299412.

Wong, J.K.W., San-Chan, J.K. and Wadu, M.J. (2016), "Facilitating effective green procurement in construction projects: an empirical study of the enablers", *Journal of Cleaner Production*, Vol. 135, pp. 859-871, doi: 10.1016/j.jclepro.2016.07.001.

Yang, J., Huang, J., Su, Y., He, X., Tan, H., Yang, W. and Strnadel, B. (2019), "Eco-friendly treatment of low-calcium coal fly ash for high pozzolanic reactivity: a step towards waste utilisation in sustainable building material", *Journal of Cleaner Production*, Vol. 238, p. 117962, doi: 10.1016/j.jclepro.2019.117962.

Yudelson, J. (2010), "The business case for green buildings", *Sustainable Investment and Places–Best Practices in Europe (88-91)*, Union Investment Real Estate AG Hamburg.

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