Global NEST Journal, Vol 28, No 2, 07649

A VIKOR Approach to Embodied Energy Minimisation Techniques Towards Sustainable Construction

Abdulrahman Haruna[1,2], Mishal H. Aljarbou[3]* and Musa Adamu[4]*

[1]Department of Building Technology, Abubakar Tafawa Balewa University, Bauchi State, Nigeria

[2]Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia

[3]Department of Civil and Environmental Engineering, College of Engineering, Majmaah University, Al-Majmaah, 11952, Saudi Arabia.

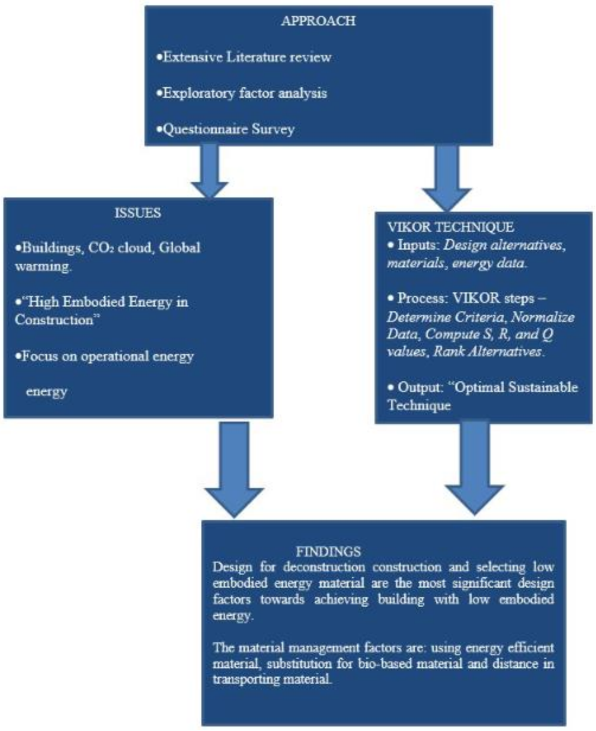
[4]Engineering Management Department, College of Engineering, Prince Sultan University, 11586 Riyadh, Saudi Arabia

Received: 14/05/2025, Accepted: 10/02/2026, Available online: 25/02/2026

*to whom all correspondence should be addressed: e-mail: m.aljarbou@mu.edu.sa, madamu@psu.edu.sa

https://doi.org/10.30955/gnj.07649

Graphical abstract



Abstracts

The principle of the embodied energy (EE) has drawn more recognition from various professionals within the construction industry. This is in line with the sustainable development goal (SDG), towards minimisation of environmental impacts and global warming effect caused by construction activities. However, in support of sustainable construction objectives and the reduction of embodied energy (EE) impacts, this study examines EE minimisation techniques in the Nigerian construction industry. This paradigm is important in light of the continuous efforts towards a drastic shift by professionals for less embodied energy structures. This prompts the identification of numerous EE minimisation techniques from literature from four categories consisting of design, material management, manufacturing and policy makers considerations. Subsequently, a mixed method approach consisting of 105 questionnaire survey and three (3) expert opinion survey was conducted to gather insight from the Nigerian construction processionals. A multi criteria decision technique using the provided initial weights, the VIKOR method was implemented to determine the priority ranking of the alternatives. The findings indicate that design for deconstruction and selecting low embodied energy material are the most significant design factors towards achieving building with low embodied energy. The material management factors are: using energy efficient material, substitution for bio-based material and distance in transporting material. The study contributes to sustainable construction by providing a structured framework for prioritizing EE reduction strategies in developing country contexts.

Keywords: Embodied Energy, Sustainability, Nigerian Construction Industry, VIKOR Approach

1. Introduction

Presently, Ecological involvement is moderately little in the construction processes. It is necessary for the construction industry to shift from its usual systems of operation due to the needs to secure the natural environmental by preventing ecological deterioration (Abidin 2009). There are currently a lot of efforts being made to encourage environmentally friendly construction practices. The focus of the building sector is now shifting away from creating an adverse deleterious environment into having a greener sustainable habitat. Sustainable improvement is now the new norm in the built environment (Pearce 2006). Similarly, Du Plessis (2005) examined several definitions of environmentally friendly building development. Notwithstanding, achieving sustainability in the building business is critical. In Nigeria,

Abdulrahman Haruna, Mishal H. Aljarbou and Musa Adamu (2026), A VIKOR Approach to Embodied Energy Minimisation Techniques Towards Sustainable Construction, *Global NEST Journal*, **28**(2), 07649.

non-sustainable power sources are fundamentally the energy used in the generation of the needed construction materials (Mari 2007). Energy utilised in building operation can promptly be realistic, whereas, the EE contain in the building is hard to measure. In spite of the Nigerian government recommendation to contractors on industrialised building system (IBS), the construction practice in Nigeria is as yet base on the conventional cast in situ (Ajayi, Faremi *et al.*). The most weight put on the common habitat originates from the built environment, which accounts for approximately 42% of definite energy utilisation, with ozone depleting substance outflow of around 35% and waste conveying about 32% (Moldan, Janoušková *et al.* 2012). The demand for building materials in Africa's construction industry is greater than what local producers can supply. Countries that produce cement confront a number of obstacles, mainly in terms of material availability due to demand shifts and a shortage of investment. The manufacturing of cement is the biggest driver of greenhouse gas emissions. While, concrete and steel are the most influential elements in the impact of climate change. The average concrete mix contains 12-14% cement; however, transportation, aggregate production, and manufacturing all contribute to the EE.

This paper, is aimed at assessing the embodied energy (EE) minimisation techniques by professionals in the Nigerian construction industry. This is as a result to the needs for a shift towards more sustainable construction in the Nigerian building sector. A hybrid approach consisting of questionnaire and semi structure interview was utilised in order to assess the EE minimisation techniques employed by construction professionals. Considering the lack of research on EE minimization in Nigeria's construction industry, this study contributes to knowledge by enriching the literatures thereby filling the existing research gap in the study area.

2. Literature review

2.1. Sustainability in Nigerian Construction Industry

Sustainable construction aims to create buildings and infrastructure that balance the natural and built environments. Promoting human dignity and economic equality, improve quality of life and customer satisfaction, provide flexibility for future user changes, and promote desirable natural and social environments is sustainability (Omopariola, Olanrewaju *et al.* 2022). Numerous pilot projects have been the outcome of the Nigerian government's active promotion of sustainability efforts in the construction industry. According to Sev (2009), buildings consume the most energy and are the primary source of both direct and indirect carbon emissions, negatively impacting the environment. The Nigerian government has committed to adopt an indicator of voluntary reduction of emission intensity as a way to compliment the sustainable development goal (SDG). The construction sector contributes to the country's socio-economic development, but also uses non-renewable resources and pollutes the environment significantly. The construction industry contributes to the environmental disaster by depleting resources, consuming energy, polluting the air, and creating waste throughout raw material acquisition, building, and facility use (Windapo, Omopariola *et al.* 2021). Nigeria's building industry, including the government, increasingly relies on foreign contractors. Therefore, the constraints in home-grown construction capability in Nigeria have generated an undesirable dependence on imported inputs such as construction supplies, machinery, and experts (Omopariola, Albert *et al.* 2019). In the majority of cases, foreign contractors specify building materials in accordance with their own country's norms. This results in a high use of foreign building materials and a low use of locally sourced building materials. The procedure has a negative influence on the sustainability of the building materials supply chain, resulting in increased transportation emissions. Many stakeholders in construction enterprises lack appropriate information on sustainable construction (Abolore 2012). Therefore, the effects of the construction stage arise from energy use, primarily involving petroleum, gas, diesel and power during the establishment of construction materials, items and administrations up to extend of project consummation.

2.2. Embodied Energy (EE) in the Built Environment

A major contributor to climate change is the accumulation of greenhouse gases (GHGs) in the atmosphere, which is mostly caused by the burning of fossil fuels. To stabilize global concentrations by 2100, GHG emissions must be reduced by at least 50% (Menzies, Turan *et al.* 2007). EE is the energy consumed throughout building material manufacturing, construction, demolition, and disposal (Dixit, Fernández-Solís *et al.* 2010). Numerous studies have been conducted on operational energy of building, i.e., energy used in heating and cooling of buildings. There is a long-term neglect on EE in the construction industry. When assessing embodied energy levels for building materials, it's important to consider the energy used in transporting materials from production to the construction site, as well as the potential energy savings from recycling (Sattary and Thorpe 2012). Concrete, blocks, and timber are examples of building materials with lower embodied energy levels that are frequently utilized in enormous amounts. Other building materials with higher embodied energy levels, for example, stainless steel, are normally used in much littler sum (Sattary and Thorpe 2012). According to Sattar Sattary (2012), construction strategies essentially decide the magnitude of embodied energy of the structures from low or high due to the material usage. Several factors are considered at design stage in minimising embodied energy (Yeo and Gabbai 2011, Foraboschi, Mercanzin *et al.* 2014, Park, Lee *et al.* 2014, Häkkinen, Kuittinen *et al.* 2015, Miller, Doh *et al.* 2015). This includes the application of construction automation and techniques such as building information modeling (BIM), bioclimatic design and the re-use and recycling of building materials. Conceptual design considers structure scope, orientation, and appearance to construct a structure that will generate the best: warming, cooling, and lighting loads from the start. Embodied energy estimation is usually tedious due to the required number of data involved. **Figure 1** shows the detail of element required for its estimation.

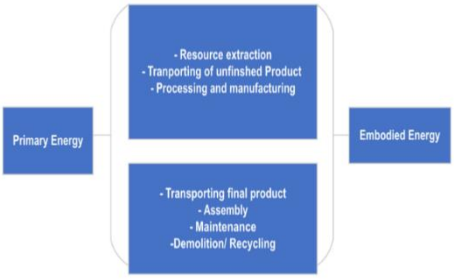


Figure 1. Embodied energy estimation

3. Methodology

This study employs a mixed-methods approach which was employed to examine the previously mentioned considerations consisting of design, material management, manufacturers and policy makers regarding embodied energy minimisation techniques in Nigerian construction industry as shown in **Figure 2**. This approach involves collecting, analysing, and combining both qualitative and quantitative data, which includes conducting interviews and administering expert opinion surveys (Creswell 2014). The Exploratory Factor Analysis (EFA) analysis using pilot survey was used to examine the comprehensiveness and clarity of the factors in conjunction with the research of these factors and their categories. A structured questionnaire developed was used to gather data. The evaluation comprised 52 items divided into four embodied energy minimisation categories: design, material management, manufacturers and policy makers consideration. A 5-point Likert scale, spanning from strongly disagree to strongly agree, was used to record responses. Participants completed it anonymously and it was given online. To determine the relationship between the EE minimisation techniques and validate the EFA results, the Pearson correlation analysis was used. Additionally, the relative importance index (RII) study was performed to look at the many elements and groups that are essential for successful implementation of EE minimisation in the Nigerian construction industry. A multi criteria decision technique using the VIKOR method was used to determine the priority ranking of the alternatives.

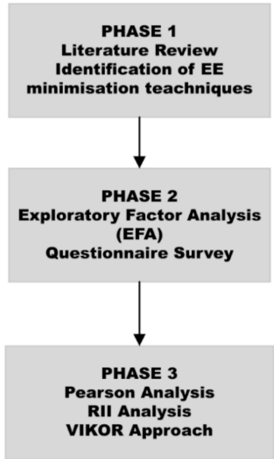


Figure 2. Research Design.

3.1. Embodied Energy (EE) Minimisation Techniques

The identified factors of the EE minimisation techniques were extracted from numerous studies as can be seen in **Table 1 and 2**. The factors have been categorised into four groups namely: Design, material management, manufacturers and policy makers considerations.

Table 1. Design and Material management considerations to EE minimisation.

Code	Design Considerations	References
D01	Select low embodied energy material	(Danatzko, Sezen *et al.* 2013, Lupíšek, Nehasilová *et al.* 2016, Morini, Ribeiro *et al.* 2019)
D02	Specify standard sizes	(Orr, Drewniok *et al.* 2019)
D03	Specify low carbon concrete mixes	(Bostanci, Limbachiya *et al.* 2018, Hawkins, Orr *et al.* 2020)
D04	Limit carbon-Intensive efficiency	(Victoria and Perera 2018, Kumari, Kulatunga *et al.* 2020)
D05	Maximize structural efficiency	(Pacheco, Ordóñez *et al.* 2012, Basbagill, Flager *et al.* 2013)
D06	Minimize waste	(Holtzhausen 2007)
D07	Use fewer finish materials	(Bribián, Capilla *et al.* 2011, Cabeza, Barreneche *et al.* 2013)
D08	Design for deconstruction	(Kanters 2018)
D09	Optimize design	(Choi, Oh *et al.* 2016, Park, Choi *et al.* 2016)
D10	Design for durability and longevity	(Ampofo-Anti 2010, Tingley and Davison 2011) (Cabeza, Barreneche *et al.* 2013)
D11	Use local materials	(Wiik, Fufa *et al.* 2018)
D12	Use of recyclable material	(Holtzhausen 2007, Danatzko, Sezen *et al.* 2013)
D13	Re-use of Building part and elements	(Lupíšek, Vaculíková *et al.* 2015, Malmqvist, Nehasilova *et al.* 2018)
D14	Reducing the amount of cement	(Myers, Fullera *et al.* 2012)
D15	Optimization of structural system	(Yeo and Potra 2015)
D16	Low maintenance design	(Holtzhausen 2007)
D17	Optimization of layout plan	(Shadram, Johansson *et al.* 2016, Azari and Abbasabadi 2018)
D18	Use of innovative material	(Chen, Burnett *et al.* 2001)
D19	Use material produce using renewable energy	(Reddy and Jagadish 2003)
D20	Increase use of prefabricated element	(Abey and Anand 2019)
D21	Using lightweight material	(Lupíšek, Nehasilová *et al.* 2016, Pan, Iturralde *et al.* 2020)

D22	Efficient building envelop design	(Hamida, Alsudairi *et al.* 2022)
Material Management Consideration		
M01	Use of innovative materials with lower environmental impacts	(Reddy and Jagadish 2003)
M02	Substitution for bio-based materials	(Galimshina, Moustapha *et al.* 2022)
M03	Material manufacture through low density industrial process	(Reddy and Jagadish 2003)
M04	Using Energy efficient material	(Hammond and Jones 2008, Mandley 2014)
M05	Material that comes from Renewable source	(Morini, Ribeiro *et al.* 2019)
M06	Ease of manufacturing	(Duflou, Sutherland *et al.* 2012, Mawson and Hughes 2019)
M07	Amount of raw materials involved	(Kara and Ibbotson 2011)
M08	Distance covered in transporting material	(Ding 2018)
M09	Deleterious nature of the material	(Ashby 2012)
M10	Recycling of materials	(Saghafi and Teshnizi 2011)

Table 2. Manufacturers and policy makers consideration to EE minimization.

Code	Manufacturers Consideration	References
MF01	Using sustainable material	(Tingley and Davison 2011, Dixit, Fernández-Solís *et al.* 2012)
MF02	Use sustainable energy source	(Ampofo-Anti 2010)
MF03	Establish target for performance improvement	(Yeo and Gabbai 2011)
MF04	Better supply chain management	(Seow 2011)
MF05	Improving the recycling of product	(Häkkinen, Kuittinen *et al.* 2015, Dixit 2017)
MF06	Use LCA to improve manufacturing	(Dixit, Fernández-Solís *et al.* 2012)
MF07	New- Innovation in product	(Duflou, Sutherland *et al.* 2012)
MF08	Offer take back guarantees	(Cabeza, Barreneche *et al.* 2013)
MF09	Decentralize production	(Duflou, Sutherland *et al.* 2012)
MF10	Maximize the use of local skill	(Akadiri, Chinyio *et al.* 2012)
MF11	Minimize transportation	(Dixit, Fernández-Solís *et al.* 2012, Akbarnezhad and Xiao 2017)
MF12	Eliminating waste in fabrication	(Watson and Taminger 2018)
MF13	Inclusion of waste in building material	(Thormark 2002)
Policy Makers consideration		
P01	Consider embodied energy in national building regulation	(Goggins, Keane *et al.* 2010, Dixit, Fernández-Solís *et al.* 2012)
P02	Mandating the declaration of environmental impact of product	(Cooper and Gutowski 2017, Resalati, Kendrick *et al.* 2020)
P03	Promoting the use of low-impacts material during design	(Zaini, Ibrahim *et al.* 2015)
P04	Develop national LCA Database	(Dixit, Fernández-Solís *et al.* 2012)
P05	Certification systems of embodied impacts	(Crawford and Stephan 2013)
P06	Provision of freely data and tools	(Cabeza, Rincón *et al.* 2014, Röck, Saade *et al.* 2020)
P07	Consideration of embodied energy in Residential Building	(Dixit, Fernández-Solís *et al.* 2012)

3.2. Pilot Survey

EFA brought the pilot questionnaire to the appropriate number of participants (105 construction professionals), a pilot survey was conducted to examine the results in the Nigerian construction industry (Tabachnick, Fidell *et al.* 2013). The Cronbach alpha test was used to gauge the reliability of the research instrument. This test enables the accuracy of the questionnaire and the completeness of every component taken into consideration to be evaluated. The surveys used in the study had high reliability levels, with alpha values ranging from 0.76 to 0.85 (Moser and Kalton 2017).

3.3. Main Survey

Due to the newness of EE minimisation studies in the Nigerian construction industry, a stratified sample of the particular categories has been considered (Bressanelli, Perona *et al.* 2019). In stratification, the construction stakeholders' diverse demographics are considered. Questionnaire as suggested by Fellows and Liu (2021), was utilised to conduct the survey in order to evaluate the EE minimisation techniques utilised from various context which include design, material selection, manufacturing and policy consideration.

3.4. Pearson Correlation Analysis

Examining the relationships in the survey data is necessary to achieve the study's aim. A descriptive statistic, such as the Pearson correlation coefficient, summarises the features of a dataset. The intensity and direction of the linear relationship between two quantitative variables are specifically described (Hellebrand 2023). The following equation is used to determine the correlation between two variables X and Y, whose estimates range between -1 and 1.

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2}} \quad (1)$$

where, r is the Pearson correlation coefficient and $\bar{X}$ and $\bar{Y}$ are the means of the two samples, respectively. The range of r's estimated values is between -1 and 1. The degree of correlation increases with increasing absolute value. The degree of correlation increases as the coefficient of correlation approaches 1 or -1. In contrast, the correlation is lower the closer the coefficient of correlation is to 0.

3.5. Ranking Analysis

Construction management researchers frequently utilise the relative importance index (RII) to analyse structured questionnaire responses that are measured ordinally (Sakhare and Chougule 2019). This can be obtained using equation (2).

$$RII = \frac{\sum w}{AXN} = \frac{5_{n5} + 4_{n4} + 3_{n3} + 2_{n2} + 1_{n1}}{5XN} \quad (2)$$

where, w is the weight given to each factor, A is the highest weight, N is the total number of respondents.

3.6. Expert Opinion survey

The study utilised the expert survey to gather primary data on embodied energy minimisation techniques that are more suitable from the existing top ranked factors initially assess through questionnaire survey. Experts' perspectives were solicited to identify the most critical factors for minimising EE in sustainable construction.

3.7. VIKOR Approach

Serafim Opricovic first introduced VIKOR, which stands for Vise Kriterijumska Optimizajica I Kompromisno Resenje in 1998 (El-Santawy 2012). VIKOR is an MCDM strategy that selects the most effective choice from the closest perfect alternative. The ranking steps are then determined by comparing the discrepancy to the optimal solution. The VIKOR technique uses uniform normalisation to reach the ideal solution. VIKOR can be computed by the following phases:

Phase 1: Identifying the best y_j^+ and worst value y_j^- of all criterion operation.

j = 1, 2, …, n. If the jth function is valuable, thus

$$y_j^+ = m_{ax} y_{ij}, \qquad y_j^- = m_{in} y_{ij} \quad (3)$$

Phase 2: Applying equation 4 to normalise the choice matrix.

$$r_{ij} = \frac{\left(y_j^+ - y_{ij}\right)}{\left(y_j^+ - y_j^-\right)} \quad (4)$$

Phase 3: Using equations 5 and 6, calculate the Utility measure (Si) and Regret measure (Ri) values. To calculate Si and Ri, we need to know the criteria weighting values. The criteria weight *(wj)* is intended to express relative relevance.

$$S_i = \sum_{i=1}^{n} \frac{\left(y_j^+ - y_{ij}\right)}{\left(y_j^+ - y_j^-\right)} \quad (5)$$

$$r_{ij} = \max{}_j = \left[w_j \frac{\left(y_j^+ - y_{ij}\right)}{\left(y_j^+ - y_j^-\right)} \right] \quad (6)$$

where, *wj* are the weights of the criterion, indicating their impact.

Phase 4: Using equation 7, compute the VIKOR index value.

$$Q_i = v\left[\frac{S_i - S^+}{S^- - S^+}\right] + (1 - v)\left[\frac{R_i - R^+}{R^- - R^+}\right] \quad (7)$$

Assume that v = 0.5 is introduced as the weight of the strategy of "the majority of criteria" (or "the maximum group utility").

Where, $S^+=\min S_i$, $S^-=\max S_i$ and $R^+=\min R_i$, $R^-=\max R_i$

Phase 5: Graded values for the Utility Measure (Si), Regret Measure (Ri), and VIKOR Index (Qi) are available. As Si, Ri, and Qi are ordered in ascending order, the smallest value acts as the most significant EE minimisation technique.

4. Results

The following section seeks to give the findings from the evaluation of the tools utilised, based on the methods described. As a result, the findings of the study are examined, and conclusions are drawn based on the outcome.

4.1. Pearson Correlation Analysis

Using SPSS software, the Pearson relationship between the EE minimisation techniques were examined. The outcomes are indicated by the descriptive and correlation results in **Table 3**. Design consideration with a mean and standard deviation values of 3.854 and 0.825 respectively, it is then followed by manufacturers consideration having a mean value of 3.682 and standard deviation of 0.908. Material management consideration has a mean value of 3.545 and standard deviation of 0.926, lastly policy makers consideration has a mean value of 3.365 and a standard deviation of 0.916. The Pearson correlation indicates the strength of a relationship between two variables as well as its direction (positive or negative). The findings indicate that there is a positive correlation between the variables as the Pearson correlation alternates from negative to positive (Pallant and Manual 2011). The results also show a P value of < 0.01 indicating statistically significant relationship.

4.2 EE Minimisation in Construction Industry

EE minimisation in the construction industry is considered to be very limited among stakeholders in the built environment. To determine the relative importance of EE minimisation factors, the survey data obtained was imported into SPSS and the RIIs is subsequently evaluated as shown in **Table 4**. Results show that design for deconstruction and selecting low EE material are the most significant design factors towards achieving building with low embodied energy. This can be seen from the RIIs values of the factors obtained which are 0.87 and 0.84 respectively.

Table 3. Pearson correlation Analysis for EE minimisation Techniques.

EE Minimisation Constructs	Design	Manufacturers	Material Management	Policy Makers
Design	1	0.412	0.385	0.276
		0.000	0.001	0.001
Manufacturers		1	0.324	0.160
Material Management			1	0.002
Mean	3.854	3.682	3.545	3.365
SD	0.825	0.908	0.926	0.916
P < 0.01				

Table 4. EE Minimisation RII and Significance Level.

EE Design Consideration Factors				
Items	**Codes**	**RII**	**Ranking**	**Significance level**
Selecting low embodied energy material	D01	0.84	2	H
Specify standard sizes	D02	0.57	22	M
Specify low carbon concrete mixes	D03	0.81	4	H
Limit carbon-Intensive efficiency	D04	0.73	12	H-M
Maximize structural efficiency	D05	0.63	20	H-M
Minimize waste	D06	0.78	7	H-M
Use fewer finish materials	D07	0.68	17	H-M
Design for deconstruction	D08	0.87	1	H
Optimize design	D09	0.77	8	H-M
Design for durability and longevity	D10	0.67	18	H-M
Use local materials	D11	0.75	10	H-M
Use of recyclable material	D12	0.76	9	H-M
Re-use of Building part and elements	D13	0.71	13	H-M
Reducing the amount of cement	D14	0.81	3	H
Optimization of structural system	D15	0.61	21	H-M
Low maintenance design	D16	0.70	14	H-M
Optimization of layout plan	D17	0.69	16	H-M
Use of innovative material	D18	0.79	5	H-M
Use material produce using renewable energy	D19	0.78	6	H-M
Increase use of prefabricated element	D20	0.69	15	H-M
Using lightweight material	D21	0.75	11	H-M
Efficient building envelop design	D22	0.64	19	H-M

Table 5. EE Minimisation RII and Significance Level.

EE Material Management Consideration Factors				
Items	**Codes**	**RII**	**Ranking**	**Significance level**
Use of innovative materials with lower environmental impacts	M01	0.77	5	H-M
Substitution for bio-based materials	M02	0.89	2	H
Material manufacture through low density industrial process	M03	0.74	6	H-M
Using energy efficient material	M04	0.92	1	H
Material that comes from Renewable source	M05	0.74	7	H-M
Ease of manufacturing	M06	0.65	10	H-M
Amount of raw materials involved	M07	0.67	9	H-M
Distance covered in transporting material	M08	0.78	3	H-M
Deleterious nature of the material	M09	0.70	8	H-M
Recycling of materials	M10	0.78	4	H-M

Material management factors that are most significant towards EE sustainable construction are using energy efficient material, substitution for bio-based material and distance covered in transporting material with RIIs values of 0.92, 0.89 and 0.78 respectively. This can be seen in **Table 5** having high (H) significance level.

For manufacturers considerations, using sustainable material during manufacturing and the application of new- innovative products as shown in **Table 6**, are the most significant factors to minimise EE in construction having RIIs values of 0.88 and 0.86 respectively. Among the factors considered by manufacturers, decentralising production was rated the least important. This is supported by the studies conducted by (Kara and Ibbotson 2011, Myers, Fullera *et al.* 2012).

Table 6. EE Minimisation RII and Significance Level.

EE Manufacturers Consideration Factors				
Items	**Codes**	**RII**	**Ranking**	**Significance level**
Using sustainable material	MF01	0.88	1	H
Use sustainable energy source	MF02	0.86	3	M
Establish target for performance improvement	MF03	0.58	12	H
Better supply chain management	MF04	0.69	8	H-M
Improving the recycling of product	MF05	0.73	7	H-M
Use LCA to improve manufacturing	MF06	0.77	6	H-M
New- Innovation in product	MF07	0.86	2	H-M
Offer take back guarantees	MF08	0.61	11	H
Decentralize production	MF09	0.52	13	H-M
Maximize the use of local skill	MF10	0.81	4	H-M
Minimize transportation	MF11	0.77	5	H-M
Eliminating waste in fabrication	MF12	0.64	9	H-M
Inclusion of waste in building material	MF13	0.64	10	H-M

Table 7. EE Minimisation RII and Significance Level.

EE Policy Makers consideration Factors				
Items	**Codes**	**RII**	**Ranking**	**Significance level**
Considering embodied energy in national building regulation	P01	0.86	1	H
Mandating the declaration of environmental impact of product	P02	0.84	2	H
Promoting the use of low-impacts material during design	P03	0.76	5	H-M
Develop national LCA Database	P04	0.84	3	H
Certification systems of embodied impacts	P05	0.79	4	H-M
Provision of freely data and tools	P06	0.69	7	H-M
Consideration of embodied energy in Residential Building	P07	0.71	6	H-M

Table 8. Criteria and Weight for EE Minimisation Techniques.

Criteria	Description of EE Minimisation Techniques	Weight
C_1	Design Considerations	25%
C_2	Material Management Considerations	25%
C_3	Manufacturers Consideration	25%
C_4	Policy Makers Consideration	25%

Table 9. Weighting Alternative Values.

Description	Weight
Very Significant (VS)	5
Significant (S)	4
Neutral (N)	3
Insignificant (I)	2
Very Insignificant (VI)	1

Table 10. EE minimisation techniques expert Survey.

Participants	Design	Material Management	Manufacturers	Policy Makers
Expert 1	5	5	4	4
Expert 2	5	4	5	4
Expert 3	4	3	4	5

Table 7 on the other hand, shows that considering embodied energy in national building regulation and mandating the declaration of environmental impact of product by policy makers are the most crucial factors to be considered towards EE minimisation in the Nigerian construction industry. This finding has supported the assertions made by (Acquaye, Duffy *et al.* 2011).

4.2. Expert opinion Survey

The study used an expert survey to gather three participants comments on the MCDM-based VIKOR technique. The experts were picked from the group that participated at the initial interview based on their expertise in EE minimisation. All three experts are engineers working with private companies with more than ten years working experience.

4.3. VIKOR Approach

The performance index for the provided criteria is used to identify ways for minimising embodied energy in the Nigerian construction industry. Weights are assigned to each criterion according to the requirements of the set standards. The performance index was calculated utilising three (3) professionals in this research. Factors with high performance index values are prioritised, with a lower VIKOR Index value. **Table 8** contains the required criteria and weight, whereas **Table 9** contains the weighting alternate values. In this paper, equal weight of 25% is used for all elements under consideration.

4.3.1. Linguistic Variable

Vinodh, Sarangan *et al.* (2014), suggest that it is difficult to effectively quantify and depict decision-makers' judgement, instinct, and excitement in plan selection. As a result, employing numerical numbers to represent these language variables would improve precision. This study classifies linguistic qualities into five tiers: Very Significant (VS), Significant (S), Neutral (N), Insignificant (I), and Very Insignificant (VI) as can be seen in **Table 9**.

Normalised matrix is computed from equation 1 as shown in **Table 11**. The normalised results indicate that design, material management and manufacturers consideration with normalized values of 0.00 are the most significant in EE minimisation towards achieving sustainability.

The result then utilises equations 3 and 4 to get the utility measure (Si) and regret measure (Ri) as shown in **Table 12**. The presentation of the Si and the Ri is shown in **Figure 3**.

Table 11. Normalised Matrix.

Participants	Design	Material Management	Manufacturers	Policy Makers
Expert 1	0.00	0.00	1.00	1.00
Expert 2	0.00	0.50	0.00	1.00
Expert 3	1.00	1.00	1.00	0.00

Table 12. Utility Measure (Si) and Regret Measure (Ri).

Participants	Utility Measure (Si)	Regret Measure (Ri)
Expert 1	0.50	0.25
Expert 2	0.38	0.25
Expert 3	0.75	0.25
	S^{+}=0.38	R^{+}=0.25
ν=0.50		R^{-}=0.25

Table 13. VIKOR Index value and Ranking.

Participants	Qi	Rank
Expert 1	0.16	2
Expert 2	0.00	1
Expert 3	0.50	3

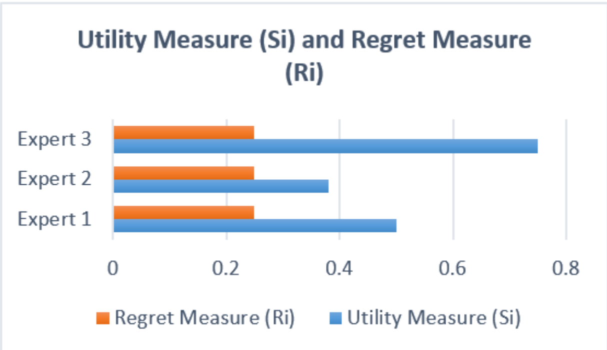


Figure 3. Utility and regret measure.

Figure 4. EE minimization Index value.

The VIKOR (Qi) index value is then calculated using equation (5). **Table 13** shows the VIKOR index computation findings for the most significant embodied energy minimisation approaches.

From the VIKOR index results obtained as shown in **Table 13**, the significant embodied energy minimisation techniques are design and material management as indicates by expert 2. These techniques include: design for deconstruction, selecting low EE material and reducing the amount of cement. Also, using sustainable material, new- innovation in product and using sustainable energy source in the Nigerian construction industry are ranked high having the least VIKOR index value of 0.00 which was ranked first. Expert 1 was ranked second with a VIKOR index value of 0.166, which indicates that the factors considered by the respondent to be significant technique in minimising EE in the Nigerian construction industry are: design and material management factors. These include using energy efficient material, substitution for bio-based materials and distance covered in transporting material. This is also in agreement with expert 2 design consideration. With a VIKOR index value of 0.50, The respondent indicates policy makers consideration such as: Consider embodied energy in national building regulation, Mandate the declaration of environmental impact of product and Develop national LCA Database as the best achievable strategies towards EE minimisation in the built environment. Results are consistent with the research carried out by (Haruna, Shafiq *et al.* 2020). **Figure 4** shows the representation of the respondent opinion on the EE minimisation techniques that should be employed towards sustainable construction in the Nigerian construction industry.

5. Conclusion

This research pinpoint about a new method that uses a set of criteria to give a full assessment of the MCDM VIKOR approach for embodied energy minimisation in the Nigerian construction industry. By reviewing literatures on the subject matter, and also by collecting data from a questionnaire survey and conducting semi structured expert opinion survey, the research has provided important insights into the EE minimisation techniques that needs to be implemented in Nigerian construction industry. Despite the EE minimisation is increasingly adopted in the construction industries of developed countries in the western world, its implementation remains rare in developing nations. There is a limited literature on EE in the Nigerian built environment. This necessitates a complete systematic literature assessment of the EE minimisation strategies towards sustainable construction. There is a need for all stakeholders in the Nigerian construction industry to accept the EE minimisation as an important tool in their project delivery system. However, EE minimisation is gaining acceptance, with both developed and developing countries debating its potential environmental impacts (Guerra and Leite 2021). The EE minimisation techniques were extracted for this study from design, material management, manufacturers and policy makers considerations that are consistent with Yoon, Kim *et al.* (2014), findings. Despite the increased emphasis on sustainable construction, the EE implementation still faces a number of obstacles in the built environment. Among which are; Inadequate awareness and lack of understanding, lack of interest by stakeholders involved, and resistance to change. On the other hand, the design techniques towards EE minimisation are found to be design for deconstruction, selecting low embodied energy material and reducing the amount of cement. The Nigerian construction industry will strive higher and achieved sustainability when EE is managed and its minimisation adequately supported and implemented by the construction stakeholders.

The study has limitations despite its contributions, such as its dependence on particular criteria and the availability of data that may differ depending on the region and type of project. In order to increase the model's robustness, future research could employ hybrid decision-making techniques and add life-cycle cost analysis, carbon emissions, or social sustainability indicators.

Overall, the study supports the wider use of the VIKOR technique in encouraging sustainable construction and environmentally friendly building practices and validates its value as a tool for developing embodied energy minimization measures.

Limitation and Future Studies

This study's focus on the Nigerian construction industry restricts its generalizability, and its reliance on expert assessment may introduce subjectivity. A small number of criteria and options were also considered in the analysis. Future studies should use hybrid decision-making techniques, include more sustainability indicators, and test the framework using case studies from various construction categories and geographical areas.

Disclosure of Statement

The authors declare no conflict of interest.

Acknowledgment

The authors would like to thank Prince Sultan University for their viable support.

References

Abey, S. T. and K. Anand (2019). "Embodied energy comparison of prefabricated and conventional building construction." *Journal of The Institution of Engineers (India)*: Series A **100**: 777-790.

Abidin, N. Z. (2009). "Sustainable construction in Malaysia–Developers' awareness." World Academy of Science, *Engineering and Technology* **53**: 807-814.

Abolore, A. A. (2012). "Comparative study of environmental sustainability in building construction in Nigeria and Malaysia." *Journal of Emerging Trends in Economics and Management Sciences* **3**(6): 951-961.

Acquaye, A., A. Duffy and B. Basu (2011). "Embodied emissions abatement—A policy assessment using stochastic analysis." *Energy Policy* **39**(1): 429-441.

Ajayi, O. O., O. J. Faremi, K. Ibilola, I. B. J. Zakariyyah, F. A. Anifowoshe and O. M. Alimi "Challenges and enhanced measures for implementation of industrialized building system in Lagos Metropolis."

Akadiri, P. O., E. A. Chinyio and P. O. Olomolaiye (2012). "Design of a sustainable building: A conceptual framework for implementing sustainability in the building sector." *Buildings* **2**(2): 126-152.

Akbarnezhad, A. and J. Xiao (2017). "Estimation and minimization of embodied carbon of buildings: A review." *Buildings* **7**(1): 5.

Ampofo-Anti, N. (2010). Material selection and embodied energy, Alive2green Publishers.

Ashby, M. F. (2012). *Materials and the environment: eco-informed material choice*, Elsevier.

Azari, R. and N. Abbasabadi (2018). "Embodied energy of buildings: A review of data, methods, challenges, and research trends." *Energy and Buildings* **168**: 225-235.

Basbagill, J., F. Flager, M. Lepech and M. Fischer (2013). "Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts." *Building and Environment* **60**: 81-92.

Bostanci, S. C., M. Limbachiya and H. Kew (2018). "Use of recycled aggregates for low carbon and cost effective concrete construction." *Journal of Cleaner Production* **189**: 176-196.

Bressanelli, G., M. Perona and N. Saccani (2019). "Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study." *International Journal of Production Research* **57**(23): 7395-7422.

Bribián, I. Z., A. V. Capilla and A. A. Usón (2011). "Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential." *Building and environment* **46**(5): 1133-1140.

Cabeza, L. F., C. Barreneche, L. Miró, J. M. Morera, E. Bartolí and A. I. Fernández (2013). "Low carbon and low embodied energy materials in buildings: A review." *Renewable and Sustainable Energy Reviews* **23**: 536-542.

Cabeza, L. F., L. Rincón, V. Vilariño, G. Pérez and A. Castell (2014). "Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review." *Renewable and sustainable energy reviews* **29**: 394-416.

Chen, T., J. Burnett and C. K. Chau (2001). "Analysis of embodied energy use in the residential building of Hong Kong." *Energy* **26**(4): 323-340.

Choi, S. W., B. K. Oh, J. S. Park and H. S. Park (2016). "Sustainable design model to reduce environmental impact of building construction with composite structures." *Journal of cleaner production* **137**: 823-832.

Cooper, D. R. and T. G. Gutowski (2017). "The environmental impacts of reuse: a review." *Journal of Industrial Ecology* **21**(1): 38-56.

Crawford, R. H. and A. Stephan (2013). "The significance of embodied energy in certified passive houses." *International Journal of Architectural and Environmental Engineering* **7**(6): 427-433.

Creswell, J. W. (2014). *A concise introduction to mixed methods research*, SAGE publications.

Danatzko, J. M., H. Sezen and Q. Chen (2013). "Sustainable design and energy consumption analysis for structural components." *Journal of Green Building* **8**(1): 120-135.

Ding, G. (2018). "Embodied carbon in construction, maintenance and demolition in buildings." *Embodied Carbon in Buildings: Measurement, Management, and Mitigation*: 217-245.

Dixit, M. K. (2017). "Life cycle embodied energy analysis of residential buildings: A review of literature to investigate embodied energy parameters." *Renewable and Sustainable Energy Reviews* **79**: 390-413.

Dixit, M. K., J. L. Fernández-Solís, S. Lavy and C. H. Culp (2010). "Identification of parameters for embodied energy measurement: A literature review." *Energy and buildings* **42**(8): 1238-1247.

Dixit, M. K., J. L. Fernández-Solís, S. Lavy and C. H. Culp (2012). "Need for an embodied energy measurement protocol for buildings: A review paper." *Renewable and sustainable energy reviews* **16**(6): 3730-3743.

Du Plessis, C. (2005). "Action for sustainability: preparing an African plan for sustainable building and construction." *Building Research & Information* **33**(5): 405-415.

Duflou, J. R., J. W. Sutherland, D. Dornfeld, C. Herrmann, J. Jeswiet, S. Kara, M. Hauschild and K. Kellens (2012). "Towards energy and resource efficient manufacturing: A processes and systems approach." *CIRP annals* **61**(2): 587-609.

El-Santawy, M. F. (2012). "A VIKOR Method for Solving Personnel Training." *Int. J. Comput. Sci* **1**(2): 9-12.

Fellows, R. F. and A. M. Liu (2021). *Research methods for construction*, John Wiley & Sons.

Foraboschi, P., M. Mercanzin and D. Trabucco (2014). "Sustainable structural design of tall buildings based on embodied energy." *Energy and Buildings* **68**: 254-269.

Galimshina, A., M. Moustapha, A. Hollberg, P. Padey, S. Lasvaux, B. Sudret and G. Habert (2022). "Bio-based materials as a robust solution for building renovation: A case study." *Applied Energy* **316**: 119102.

Goggins, J., T. Keane and A. Kelly (2010). "The assessment of embodied energy in typical reinforced concrete building structures in Ireland." *Energy and Buildings* **42**(5): 735-744.

Guerra, B. C. and F. Leite (2021). "Circular economy in the construction industry: An overview of United States stakeholders' awareness, major challenges, and enablers." *Resources, conservation and recycling* **170**: 105617.

Häkkinen, T., M. Kuittinen, A. Ruuska and N. Jung (2015). "Reducing embodied carbon during the design process of buildings." *Journal of Building Engineering* **4**: 1-13.

Hamida, A., A. Alsudairi, K. Alshaibani and O. Alshamrani (2022). "Parametric study of the impact of building envelope systems on embodied and operational carbon of residential buildings." *International Journal of Building Pathology and Adaptation* **40**(5): 753-774.

Hammond, G. P. and C. I. Jones (2008). "Embodied energy and carbon in construction materials." *Proceedings of the Institution of Civil Engineers-Energy* **161**(2): 87-98.

Haruna, A., N. Shafiq, M. O. Ali, M. Mohammed and S. Haruna (2020). "Design and construction technique for low embodied energy building: An analytical network process approach." *Journal of Engineering and Technological Sciences* **52**(2): 166-180.

Hawkins, W., J. Orr, T. Ibell and P. Shepherd (2020). "A design methodology to reduce the embodied carbon of concrete buildings using thin-shell floors." *Engineering Structures* **207**: 110195.

Hellebrand, J. (2023). "Anthropometrical, physiological, strength and other determinants of rowing performance-review of correlation-predictive analyses."

Holtzhausen, H. (2007). "Embodied energy and its impact on architectural decisions." *WIT Transactions on Ecology and the Environment* **102**.

Kanters, J. (2018). "Design for deconstruction in the design process: State of the art." *Buildings* **8**(11): 150.

Kara, S. and S. Ibbotson (2011). "Embodied energy of manufacturing supply chains." *CIRP Journal of Manufacturing Science and Technology* **4**(3): 317-323.

Kumari, L., U. Kulatunga, N. Madusanka and N. Jayasena (2020). *Embodied carbon reduction strategies for buildings*. ICSBE 2018: Proceedings of the 9th International Conference on Sustainable Built Environment, Springer.

Lupíšek, A., M. Nehasilová, Š. Mančík, J. Železná, J. Růžička, C. Fiala, J. Tywoniak and P. Hájek (2016). *Design strategies for buildings with low embodied energy*. Proceedings of the institution of civil engineers-engineering sustainability, Thomas Telford Ltd.

Lupíšek, A., M. Vaculíková, Š. ManĽík, J. Hodková and J. RůžiĽka (2015). "Design strategies for low embodied carbon and low embodied energy buildings: principles and examples." *Energy Procedia* **83**: 147-156.

Malmqvist, T., M. Nehasilova, A. Moncaster, H. Birgisdottir, F. N. Rasmussen, A. H. Wiberg and J. Potting (2018). "Design and construction strategies for reducing embodied impacts from buildings–Case study analysis." *Energy and Buildings* **166**: 35-47.

Mandley, S. (2014). *Identifying Potential Resource and Embodied Energy Savings within the UK Building Sector-Through Implementation of Reduction measures–*.

Mari, T. S. (2007). *Embodied Energy of Building Materials: A Comparative Analysis of Terraced Houses in Malaysia*. Proc. 41st Annual Conference of the Architectural Science Association (ANZAScA), Deakin University, Australia.

Mawson, V. J. and B. R. Hughes (2019). "The development of modelling tools to improve energy efficiency in manufacturing processes and systems." *Journal of Manufacturing Systems* **51**: 95-105.

Menzies, G. F., S. Turan and P. F. Banfill (2007). "Life-cycle assessment and embodied energy: a review." *Proceedings of the Institution of Civil Engineers-Construction Materials* **160**(4): 135-143.

Miller, D., J.-H. Doh, K. Panuwatwanich and N. van Oers (2015). "The contribution of structural design to green building rating systems: An industry perspective and comparison of life cycle energy considerations." *Sustainable Cities and Society* **16**: 39-48.

Moldan, B., S. Janoušková and T. Hák (2012). "How to understand and measure environmental sustainability: Indicators and targets." *Ecological Indicators* **17**: 4-13.

Morini, A. A., M. J. Ribeiro and D. Hotza (2019). "Early-stage materials selection based on embodied energy and carbon footprint." *Materials & Design* **178**: 107861.

Moser, C. A. and G. Kalton (2017). *Survey methods in social investigation*, Routledge.

Myers, F., R. Fullera and R. Crawford (2012). *The potential to reduce the embodied energy in construction through the use of renewable materials*. Proceedings of the ASA2012: The 46th Annual Conference of the Architectural Science Association (Formerly ANZAScA)—Building on Knowledge: Theory and Practice, Gold Coast, Australia.

Omopariola, E. D., I. Albert and A. Windapo (2019). *Appropriate drivers for sustainable construction practices on construction sites in Nigeria*. Proceedings of the 10th West Africa Built Environment Research (WABER) Conference.

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

Orr, J., M. P. Drewniok, I. Walker, T. Ibell, A. Copping and S. Emmitt (2019). "Minimising energy in construction: Practitioners' views on material efficiency." *Resources, Conservation and Recycling* **140**: 125-136.

Pacheco, R., J. Ordóñez and G. Martínez (2012). "Energy efficient design of building: A review." *Renewable and Sustainable Energy Reviews* **16**(6): 3559-3573.

Pallant, J. and S. S. Manual (2011). "A step by step guide to data analysisusing spss 4th edition." *Australia: Allen & Unwin*.

Pan, W., K. Iturralde, T. Bock, R. G. Martinez, O. M. Juez and P. Finocchiaro (2020). "A conceptual design of an integrated façade system to reduce embodied energy in residential buildings." *Sustainability* **12**(14): 5730.

Park, H. S., H. Lee, Y. Kim, T. Hong and S. W. Choi (2014). "Evaluation of the influence of design factors on the CO2 emissions and costs of reinforced concrete columns." *Energy and Buildings* **82**: 378-384.

Park, S. W., S. W. Choi, Y. Kim, B. K. Oh and H. S. Park (2016). "Optimal Retrofit Design of Reinforced Concrete Frame with Infill Wall Using Fiber Reinforced Plastic Materials." *International Journal of Civil and Environmental Engineering* **10**(5): 572-576.

Pearce, D. (2006). "Is the construction sector sustainable?: definitions and reflections." *Building Research & Information* **34**(3): 201-207.

Reddy, B. V. and K. Jagadish (2003). "Embodied energy of common and alternative building materials and technologies." *Energy and buildings* **35**(2): 129-137.

Resalati, S., C. C. Kendrick and C. Hill (2020). "Embodied energy data implications for optimal specification of building envelopes." *Building Research & Information* **48**(4): 429-445.

Röck, M., M. R. M. Saade, M. Balouktsi, F. N. Rasmussen, H. Birgisdottir, R. Frischknecht, G. Habert, T. Lützkendorf and A. Passer (2020). "Embodied GHG emissions of buildings–The hidden challenge for effective climate change mitigation." *Applied Energy* **258**: 114107.

Saghafi, M. D. and Z. S. H. Teshnizi (2011). "Recycling value of building materials in building assessment systems." *Energy and Buildings* **43**(11): 3181-3188.

Sakhare, M. and M. Chougule (2019). "Construction Equipment Monitoring: By Using Relative Important Indices (Rii) Analysis."

Sattar Sattary, D. (2012). *Optimizing embodied energy of building construction through bioclimatic principles*. IN SMITH, SD (Ed. Procs 28th Annual ARCOM Conference. Edinburgh, Association of Researchers in Construction Management.

Sattary, S. and D. Thorpe (2012). *Optimizing embodied energy of building construction through bioclimatic principles*. Procs 28th Annual ARCOM Conference, Association of Researchers in Construction Management Edinburgh, UK.

Sattary, S. and D. Thorpe (2012). *Optimizing embodied energy of building construction through bioclimatic principles*. proceedings of 28th Annual ARCOM Conference, Edinburgh, Association of Researchers in Construction management.

Seow, Y. (2011). *A framework for modelling embodied product energy to support energy efficient manufacturing*, Loughborough University.

Sev, A. (2009). "How can the construction industry contribute to sustainable development? A conceptual framework." *Sustainable Development* **17**(3): 161-173.

Shadram, F., T. D. Johansson, W. Lu, J. Schade and T. Olofsson (2016). "An integrated BIM-based framework for minimizing embodied energy during building design." *Energy and Buildings* **128**: 592-604.

Tabachnick, B. G., L. S. Fidell and J. B. Ullman (2013). *Using multivariate statistics*, pearson Boston, MA.

Thormark, C. (2002). "A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential." *Building and environment* **37**(4): 429-435.

Tingley, D. D. and B. Davison (2011). "Design for deconstruction and material reuse." *Proceedings of the institution of civil engineers-energy* **164**(4): 195-204.

Victoria, M. F. and S. Perera (2018). "Managing embodied carbon in buildings: a Pareto approach." *Built Environment Project and Asset Management* **8**(5): 504-514.

Vinodh, S., S. Sarangan and S. C. Vinoth (2014). "Application of fuzzy compromise solution method for fit concept selection." *Applied Mathematical Modelling* **38**(3): 1052-1063.

Watson, J. and K. Taminger (2018). "A decision-support model for selecting additive manufacturing versus subtractive manufacturing based on energy consumption." *Journal of Cleaner Production* **176**: 1316-1322.

Wiik, M. K., S. M. Fufa and I. Andresen (2018). "Design strategies for low embodied carbon in building materials." *Embodied Carbon in Buildings: Measurement, Management, and Mitigation*: 323-339.

Windapo, A., E. D. Omopariola, O. Olugboyega and A. Moghayedi (2021). "Use and performance of conventional and sustainable building technologies in low-income housing." *Sustainable Cities and Society* **65**: 102606.

Yeo, D. and R. D. Gabbai (2011). "Sustainable design of reinforced concrete structures through embodied energy optimization." *Energy and buildings* **43**(8): 2028-2033.

Yeo, D. and F. A. Potra (2015). "Sustainable design of reinforced concrete structures through CO_2 emission optimization." *Journal of structural engineering* **141**(3): B4014002.

Yoon, Y.-C., K.-H. Kim, D. Yeo and S.-H. Lee (2014). "Sustainable Design Method of Reinforced Concrete Beam Using Embodied Energy Optimization Technique." *KSCE Journal of Civil and Environmental Engineering Research* **34**(4): 1053-1063.

Zaini, N., S. H. Ibrahim, A. Baharun and M. Nawi (2015). "A review on embodied energy through industrialised building system implementation in construction industries." *Sains Humanika* **6**(1).