Oguntona, O.A., Ngobeni, F., Akinradewo, O., Ogunbayo, B. and Aigbavboa, C., 2023. Barriers to emerging smart solutions adoption for energy efficiency in the construction industry. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 269-280. DOI: https://doi.org/10.31705/WCS.2023.23. Available from: https://ciobwcs.com/papers/

BARRIERS TO EMERGING SMART SOLUTIONS ADOPTION FOR ENERGY EFFICIENCY IN THE CONSTRUCTION INDUSTRY

Olusegun Aanuoluwapo Oguntona[1], Fikile Ngobeni[2], Opeoluwa Akinradewo[3], Babatunde Ogunbayo[4] and Clinton Aigbavboa[5]

ABSTRACT

Globally, the construction industry (CI) has been blamed to be directly responsible for climate change and its consequential adverse impacts. As a sector known to be energy-intensive and energy-dependent, it is logically right for energy efficiency reforms and strategies to begin in the CI. While energy challenges are largely constituting a hindrance to the accelerated growth and socio-economic development of Africa, the continent continually commits to unsustainable means in meeting its energy demands. Therefore, the adoption of energy efficiency solutions is pivotal for the continent to meet its sustainability agenda. Hence, this study is aimed at identifying the various barriers hindering the adoption of Emerging Smart Solutions (ESS) for energy efficiency in the South African construction industry (SACI). The quantitative research method was utilised in this research study. A questionnaire survey was administered to registered and active construction professionals in the SACI for data collection. Both descriptive and exploratory factor analysis were used to analyse the retrieved data. Findings from the study revealed 17 barriers with high initial cost, lack of financial incentives, and theft and security concerns as the top three barriers hindering the adoption of ESS for energy efficiency in the SACI. The study concluded that a multi-stakeholder approach is embraced to mitigate these barriers so that the potential benefits of ESS can be maximised in the sector. It is recommended that government intervention and support be increased to pave the way for the proliferation of ESS and other energy-efficient strategies.

Keywords: *Africa; Built Environment; Climate Change; Innovative Solutions; Sustainability.*

---

[1] Senior Lecturer, Department of Built Environment, Walter Sisulu University, South Africa, architectoguntona12@gmail.com ooguntona@wsu.ac.za

[2] Student, cidb Centre of Excellence, University of Johannesburg, South Africa, fikileinebong@gmail.com

[3] Researcher, cidb Centre of Excellence, University of Johannesburg, South Africa, opeakinradewo@gmail.com

[4] Postdoctoral fellow, cidb Centre of Excellence, University of Johannesburg, South Africa, tundeogunbayo7@gmail.com

[5] Professor, cidb Centre of Excellence, University of Johannesburg, South Africa, caigbavboa@uj.ac.za

1. INTRODUCTION

Several negative impacts have been attributed to the processes and activities of the construction industry (CI). A few of these adverse environmental impacts are carbon dioxide (CO_2) emissions, waste generation, and excessive energy consumption among others (Ahmad et al., 2019; Ahmed Ali et al., 2020; Purchase et al., 2022; Wu et al., 2019). However, the severity of the effect and impacts of energy issues on the human and natural environment seems to outweigh others. As indicated by Tawalbeh et al. (2021), the world's total primary electricity generation in 2017 was majorly through environmentally hazardous means of coal (38.3%) and oil (3.3%). To curb emissions because of the various climate targets established globally, the need for energy efficiency is highly imperative (McAndrew et al., 2021). Energy efficiency is, therefore, a cogent consideration for the implementation of sustainable practices in the CI. As evident in notable green building assessment tools such as the Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Comprehensive Assessment System for Built Environment Efficiency (CASBEE), energy efficiency is a core category that a building or infrastructure project must be compliant before it is regarded as sustainable (Kim et al., 2013; Sev, 2011; Sharma, 2018). It is however important that energy efficiency is promoted and well-considered if the CI is to achieve its global sustainability agenda.

Energy efficiency plays an important role by enforcing sustainable consumption, and reducing strain on the energy grid, thereby ensuring an accessible, cheaper, and reliable energy supply (Russell-Bennett et al., 2019). Energy efficiency entails the consumption of less energy to perform the same or higher tasks. The subject of energy efficiency aims to reduce CO_2 emissions, reduce energy consumption, and encourage the responsible and eco-friendly generation and use of energy. In Europe for example, two decrees namely the Energy Efficiency Directive (EDD) and Energy Performance of Buildings Directive (EPBD) were developed by the European Union to achieve energy efficiency within the region (Camarasa et al., 2019). The requirements of these directives are geared towards ensuring all new public and other categories of buildings are nearly zero-energy buildings (nZEB) before the set dates. This concept plays a crucial role in promoting sustainable (social, economic, and environmental) development, improving energy security, and minimising different kinds of emissions in the built environment. Hence, innovative technological options are becoming popular and proliferated to minimise the energy demands of the construction sector. With building automation as one of the key tenets of energy efficiency in the CI, the integration and interoperability of emerging smart solutions (ESSs) are imperative to addressing the energy crisis in the sector. This will ensure energy demands and costs are reduced thereby conserving the continuous depletion of energy resources (Shafie et al., 2021).

Novel technologies, applications, and products integrated with automated controls and sensors to optimise and ensure an effective energy management system are referred to as ESS. These technologies and solutions can be in the form of an embedded part of a product (such as a smart light bulb), a purely digital service (for regulating, monitoring, and analysing energy consumption), or a combination of both among others (Paukstadt, 2019). As further stated by Paukstadt (2019), ESS appears promising for achieving efficiency in energy management due to the proliferation of digitalisation in the sector. ESSs for energy efficiency leverage advanced Information and Communications Technology (ICT) to provide, plan, and manage energy resources for improving, advancing, and achieving the environmental goals of sustainability (Bibri, 2020). Though not exhaustive, ESS for energy efficiency includes smart grid technologies (that utilise real-time data to improve the efficiency and reliability of the electrical grid); artificial intelligence (AI), and machine learning algorithms (that can analyse energy consumption data, identify patterns, and provide opportunities); internet of things (IoT) devices (that allow for remote control and monitoring of appliances at home); building energy management systems (that uses automation, data analysis, and sensors to optimise energy use); energy storage systems (that allow for the storage of excess energy generated renewable sources); electric vehicle charging infrastructure (that uses smart technology to optimise charging and reduce demand on the grid); smart streetlights (that use automated dimming and sensors to control lighting levels based on demand); and power-saving smart home devices such as smart plugs and thermostats.

Despite the need for ESSs, various hindrances prevent the adoption of such solutions in the larger architecture, engineering, and construction industry. As identified in the literature reviewed, there are several hindrances to the adoption of ESSs for energy efficiency. These include a lack of supporting infrastructure, lack of political will, paucity of resources, lack of awareness, cultural barriers, high initial cost, lack of financing and capital, regulatory barriers, resistance to change among stakeholders, paucity of technologies, lack of incentives for adoption and implementation, lack of skilled labour, the complexity of technologies, limited access, lack of assessment tools for the technologies, and lack of technical capability among others (Alam et al., 2019; Brown, 2001; Goodier & Chmutina, 2014; Juszczyk et al., 2022; Oguntona et al., 2019; Palm, 2009; Ratner et al., 2022; Teng et al., 2021; Thollander & Palm, 2012). It is, therefore, crucial to tackle these barriers in a bid to promote sustainability in the CI. Hence, this paper is aimed at identifying the barriers hindering the adoption of ESSs for achieving energy efficiency in the South African construction industry (SACI). This paper is part of a concluded research study that evaluated the adoption of ESSs for energy efficiency in the SACI. The next section presents the research methodological framework adopted in the study, followed by the findings and discussion and lastly the conclusion and recommendations.

2. RESEARCH METHODOLOGY

The study employed the quantitative research method to identify the hindrances to the adoption of emerging smart solutions (ESSs) for energy efficiency in the South African construction industry (SACI). The combination of a literature review (secondary data source) and a questionnaire survey (primary data source) was utilised to present the informative corroboration of construction professionals' perceptions of the key barriers to the adoption of ESSs in the SACI. To achieve the objective of this study, a questionnaire survey was developed and administered to registered and active construction professionals in the Mpumalanga Province of South Africa, which is the study area. These professionals are construction project managers, construction managers, mechanical engineers, electrical engineers, town planners, architects, quantity surveyors, and civil engineers. From the literature review, a total of seventeen (17) barriers to ESSs adoption for energy efficiency were identified and extracted for use.

Since it was envisaged that the total population will not be able to participate in the survey, a random sampling method was adopted. The first part of the questionnaire survey contained questions that pertain to the background information of the respondents. The second section contained questions aimed at identifying the significant barriers to the adoption of ESSs for energy efficiency based on the respondents' agreement level. The questions in section two of the questionnaire were formulated on a five-point Likert scale (agreement scale). The respondents are required to specify their level of disagreement or agreement with the highlighted barriers in the questionnaire. The completed questionnaire survey was returned and cleaned to ensure they are complete and useful for analysis purposes. The collated data were analysed using both the descriptive and exploratory factor analysis (EFA) methods. The software utilised for data analysis is the Statistical Package for Social Sciences (SPSS). To ascertain the respondent's level of agreement with the identified barriers, the means item scores, standard deviation, and ranking of the seventeen (17) variables were tabulated and presented.

3. RESULTS AND DISCUSSION

This study achieved a Cronbach alpha value of 0.829 for the reliability of the data collection instrument. This value is an indication that the results received are largely accurate and the data collection instrument is trustworthy (Hayes & Coutts, 2020; Schrepp, 2020). Considering the demographics of the respondents, 64.2% are males while 35.8% are females. Civil engineers represent 24.5% of the respondents, mechanical engineers are 20.8%, quantity surveyors are 18.9%, electrical engineers are 15.1%, construction managers are 7.5%, town planners are 5.7%, and architects and construction project managers are 3.8%. Respondents that work for contracting firms are 67.9%, 18.9% work for the government, and 13.2% work for consulting firms.

3.1 DESCRIPTIVE ANALYSIS OF THE BARRIERS TO THE ADOPTION OF EMERGING SMART SOLUTIONS FOR ENERGY EFFICIENCY

As shown in table 1, the mean value and standard deviation ranking of each of the identified barriers were tabulated to reveal the consensus reached by the respondents. All the barriers revealed a mean value higher than 2.50. According to Field (2005), a factor is deemed significant to a study if it has a mean value of 2.50 or more. Based on the findings from the descriptive analysis of the study as presented in table 1, 'high initial cost' ranked first with a mean value of 4.21 and a standard deviation (SD) value of 0.863. Ranked second are 'lack of financial incentives' with a mean value of 4.09 and SD of 0.883 and 'theft and security concerns' also with a mean value of 4.09 and SD of 0.714. Ranked fourth is 'restricting financing options' with a mean value of 4.06 and SD of 0.633 and 'absence of innovation' was ranked fifth with a mean value of 3.94 and SD of 0.842. However, the trio of 'installation complexity' (mean value of 3.55 and SD of 1.030), 'absence of data about existing redesign measures' (mean value of 3.42 and SD of 0.776), and 'obstructions to energy efficiency' (mean value of 3.36 and SD of 0.857) were regarded as the least of the barriers to the adoption of ESSs for energy efficiency in the SACI. A country like South Africa which is known to be one of the most economically developed on the African continent is presently facing energy challenges. There are incessant load-shedding and outages across the country which has subsequently started to cripple all sectors of the economy while the small, medium, and micro enterprises (SMMEs) are badly hit. While the coal-generated energy in South Africa is detrimental to the environment and now unreliable, the recent proclamations by the government on the need to adopt renewable energy sources showed that the government agrees with the urgent need to adopt energy-efficient means and technologies in tackling the lingering energy crisis. The state-owned electricity utility company (ESKOM) faces several challenges such as cash crunch, cable theft, sabotage, corruption, looting, and vandalism while lack of financial incentives and relief for adopting alternative and renewable energy means are widely known to be hindering the adoption of innovative technologies for energy efficiency in the country. The results are in tandem with the realities of the major issues preventing the adoption of ESSs for energy efficiency and are general knowledge.

Table 1: Barriers to the adoption of emerging smart solutions for energy efficiency

Barriers	Mean	Standard Deviation	Rank
High initial cost	4.21	0.863	1
Lack of financial incentives	4.09	0.883	2
Theft and security concerns	4.09	0.714	2
Restricting financing options	4.06	0.633	4
Absence of innovation	3.94	0.842	5
Poor maintenance culture	3.89	0.847	6
Inability to demonstrate investment returns for potential clients	3.72	0.907	7
Disregard for energy efficiency alternatives	3.68	0.827	8
Limited experts	3.68	0.956	8
Lack of knowledge	3.66	0.979	10
Lack of framework and regulations	3.65	0.988	11
Vandalism	3.62	1.042	12
Absence of project consolidation	3.62	1.078	12
Lack of consumer awareness	3.62	1.060	12
Installation complexity	3.55	1.030	15
Absence of data about existing redesign measures	3.42	0.776	16
Obstructions to energy efficiency	3.36	0.857	17

3.2 EXPLORATORY FACTOR ANALYSIS OF THE BARRIERS TO THE ADOPTION OF EMERGING SMART SOLUTIONS FOR ENERGY EFFICIENCY

The data retrieved was further subjected to exploratory factor analysis and the result is presented below. Table 2 shows the results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity for barriers to the adoption of ESS for energy efficiency. The KMO value of 0.618 indicates that the sample size is adequate for conducting factor analysis, as it is above the recommended threshold of 0.5. This means that the data is suitable for further analysis using factor analysis techniques. The Bartlett's Test of Sphericity result shows an approximate Chi-square value of 341.323, with 136 degrees of freedom and a significance level of 0.000. This indicates that the correlation matrix is significantly different from an identity matrix, and therefore, the variables are suitable for factor analysis.

Table 2: KMO and Batlett's test result barriers to the adoption of ESS for energy efficiency

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.618
Bartlett's Test of Sphericity	Approx. Chi-Square	341.323
	df	136
	Sig.	0.000

Table 3 presents the total variance explained by each component, as well as the initial eigenvalues and extraction sums of squared loadings for each component. The table also shows the percentage of variance explained by each component and the cumulative percentage of variance explained by all components up to that point. The results show that the first component explains 28.542% of the total variance, the second component explains 11.578% of the total variance, and so on. The first five components together explain 65.471% of the total variance. It is important to note that when components are correlated, sums of squared loadings cannot be added to obtain a total variance. The table also shows the rotation sums of squared loadings for each component, which consider correlations between components. These values are provided for reference only and cannot be added to obtain a total variance.

Table 3: Total variance explained for barriers to the adoption of ESS for energy efficiency

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**[a]
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**
1	4.852	28.542	28.542	4.852	28.542	28.542	3.465
2	1.968	11.578	40.120	1.968	11.578	40.120	2.484
3	1.633	9.603	49.723	1.633	9.603	49.723	2.511
4	1.479	8.703	58.426	1.479	8.703	58.426	2.614
5	1.198	7.045	65.471	1.198	7.045	65.471	2.017
6	0.976	5.739	71.210				
7	0.875	5.150	76.359				
8	0.750	4.414	80.773				
9	0.676	3.975	84.748				
10	0.606	3.563	88.311				
11	0.519	3.055	91.366				
12	0.385	2.266	93.631				
13	0.321	1.885	95.517				
14	0.302	1.779	97.296				
15	0.185	1.091	98.386				
16	0.167	0.984	99.370				
17	0.107	0.630	100.000				

Extraction Method: Principal Component Analysis.

a. When components are correlated. sums of squared loadings cannot be added to obtain a total variance.

The scree plot in figure 1 shows the eigenvalues plotted against the number of factors/components extracted for the barriers to the adoption of ESS for energy efficiency. The scree plot helps to determine the number of factors/components to retain in the analysis. In this plot, the first few components have relatively high eigenvalues, indicating that they explain a large proportion of the variance in the data. As we move to the right on the plot, the eigenvalues decrease, and the factors explain less and less of the variance. Based on the screen plot, it appears that the first five components should be retained, as they have eigenvalues greater than 1.0, and they explain a cumulative percentage of the variance of about 58.4%. Beyond the fourth component, the eigenvalues decrease more slowly, suggesting that the additional components explain relatively little additional variance in the data.

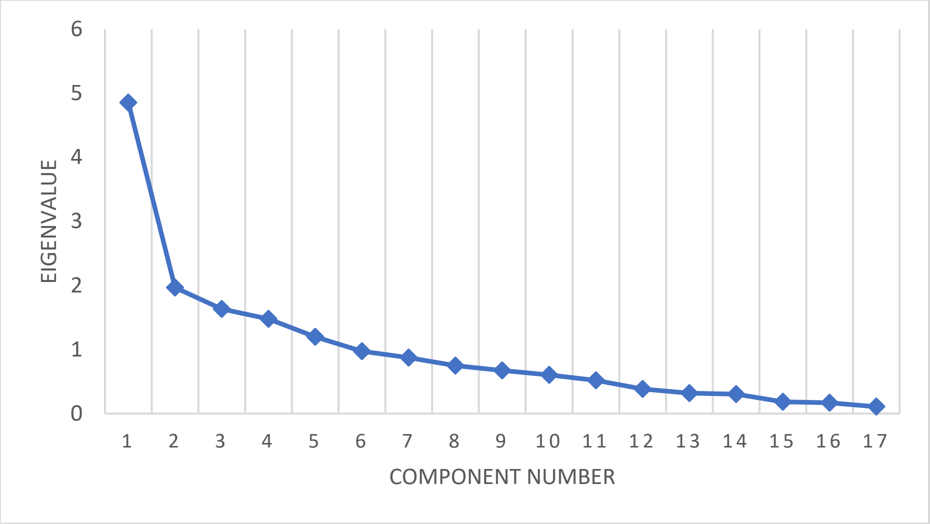

Figure 1: Scree plot for barriers to the adoption of ESS for energy efficiency

Table 4 presents the pattern matrix for barriers to the adoption of ESS for energy efficiency, generated through principal component analysis with oblique rotation. The pattern matrix shows the relationship between the original variables (barriers) and the extracted components. The values in the table represent the factor loadings, which indicate the strength and direction of the relationship between each variable and each component. There are five components extracted in this analysis, and the variables with the highest loadings in each component are as follows:

Component 1: This component is characterised by concerns related to theft and security, as well as vandalism. The variables with the highest loadings in this component are theft and security concerns (loading = 0.809) and vandalism (loading = 0.787). The high loading value for theft and security concerns implies that stakeholders are apprehensive about the security of ESS installations, particularly regarding the safety of energy storage equipment and the potential loss of stored energy due to theft or unauthorised access (Johnson et al., 2020). This perception may arise from the high value and importance of energy systems in general and the consequences of system failure or interruption. Additionally, ESS installations can be targets for theft or vandalism due to their high-value components and remote locations (Azzuni & Breyer, 2018). The high loading value for vandalism implies that stakeholders perceive ESS installations as being at risk of intentional damage, either for malicious purposes or because of accidents. This perception could result from inadequate security measures, insufficient surveillance, or a lack of knowledge about the potential threats to ESS installations (Chua, 2021). The concern about vandalism highlights the need for proper security measures and appropriate location selection for ESS installations.

Component 2: This component is characterised by financial barriers to adoption, including the lack of financial incentives, high initial costs, limited financing options, and the absence of experts. The variables with the highest loadings in this component are lack of financial incentives (loading = -0.878) and high initial cost (loading = -0.675). Limited financing options may make it difficult for potential adopters to secure funding for ESS adoption, while the absence of experts may increase the cost of ESS adoption due to the need for specialised skills and knowledge (Ghobakhloo et al., 2011). These financial barriers to adoption can be significant obstacles for individuals or organisations that may be interested in adopting ESS for energy efficiency. However, there are potential solutions to address these financial barriers, such as government incentives, grants, or subsidies to offset the high initial cost of ESS, or financing options with lower interest rates to facilitate the adoption of ESS (Dowelani et al., 2022). Increasing awareness and access to expert advice on financing and installing ESS may also help overcome some of the financial barriers to adoption (Matsepe & Van der Lingen, 2022).

Component 3: This component is characterised by barriers related to consumer awareness, including the lack of consumer awareness and disregard for energy efficiency alternatives. The variable with the highest loading in this component is lack of consumer awareness (loading = 0.885). A lack of knowledge and understanding about the benefits of energy efficiency measures can impede adoption. Disregarding energy efficiency alternatives may also stem from a lack of awareness or understanding of their benefits (Pelenur & Cruickshank, 2014). This component suggests that efforts to increase consumer awareness and education about energy efficiency measures and their benefits could be a key strategy in overcoming adoption barriers.

Component 4: This component is characterised by barriers related to project consolidation, such as the absence of project consolidation, lack of framework and regulations, and inability to demonstrate investment returns for potential clients. The variable with the highest loading in this component is the absence of project consolidation (loading = 0.804). The absence of project consolidation may stem from the lack of a clear strategy or approach to coordinating various aspects of the project, such as identifying stakeholders, defining roles and responsibilities, and establishing performance metrics (Jeffery, 2009). The lack of framework and regulations may refer to the absence of clear policies, standards, or guidelines that govern the design, implementation, and monitoring of energy efficiency projects. This can make it difficult for project developers and investors to navigate the regulatory landscape and obtain the necessary permits and approvals. The inability to demonstrate investment returns for potential clients can also hinder project consolidation by making it challenging to secure funding and attract stakeholders (Boaz et al., 2018).

Component 5: This component is characterised by barriers related to knowledge and information, including installation complexity, obstructions to energy efficiency, absence of data about existing redesign measures, and lack of knowledge. The variable with the highest loading in this component is the absence of data about existing redesign measures (loading = 0.461). The absence of data about existing redesign measures suggests that there is a lack of information about the impact and effectiveness of ESS in previous projects, making it difficult for potential adopters to make informed decisions (Johnson et al., 2020). The lack of knowledge may refer to a general lack of understanding of ESS technologies and their potential benefits. Obstructions to energy efficiency may refer to existing structural and systemic barriers to the adoption of energy efficiency measures (Boaz et al., 2018). For example, existing building codes and regulations may not support the integration of ESS, or there may be a lack of available expertise to design and implement ESS effectively. Finally, installation complexity may refer to the challenges associated with installing and integrating ESS into existing buildings and energy systems, which may require specialised expertise and equipment (Chua, 2021).

Overall, the pattern matrix shows that the barriers to the adoption of ESS for energy efficiency can be grouped into five distinct components based on their interrelatedness.

This information can be used to develop targeted interventions aimed at addressing the specific barriers that are most relevant to the adoption of ESS for energy efficiency.

Table 4: Pattern matrix for barriers to the adoption of ESS for energy efficiency

	Component				
	1	**2**	**3**	**4**	**5**
Theft and security concerns	0.809				
Vandalism	0.787				
Absence of innovation	0.586				
Poor maintenance culture	0.569				
Lack of financial incentives		-0.878			
High initial cost		-0.675			
Limited experts		-0.530			
Restricting in financing options		-0.449			
Lack of consumer awareness			0.885		
Absence of project consolidation			0.804		
Lack of framework and regulations			0.682	0.311	
Inability to demonstrate investment returns for potential clients				0.752	
Installation complexity				0.680	
Obstructions to energy efficiency				0.654	
Absence of data about existing redesign measures				0.461	
Lack of knowledge					0.669
Disregard for energy efficiency alternatives					0.641

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalisation.
a. Rotation converged in 14 iterations.

4. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the analysis of the barriers to the adoption of ESS for energy efficiency has identified several key factors that limit its widespread use. These barriers include concerns related to theft and security, financial constraints, lack of consumer awareness, barriers to project consolidation, and knowledge and information gaps. The study highlights the need for policy interventions to address these barriers, including the development of frameworks and regulations to promote ESS adoption, the provision of financial incentives, and increasing consumer awareness through education campaigns.

Based on these findings, it is recommended that policymakers, energy companies, and other stakeholders work together to develop comprehensive strategies to address the barriers identified in this study. These strategies should include targeted interventions to address financial barriers, such as the provision of subsidies or tax incentives, as well as efforts to raise consumer awareness and promote knowledge sharing. Additionally, governments and regulators should work to establish clear frameworks and regulations to promote the adoption of ESS technologies, and efforts should be made to increase investment in research and development to drive innovation in this field. By taking these steps, it is possible to overcome the barriers to the adoption of ESS for energy efficiency and pave the way for a more sustainable energy future. Further research can be carried out on the investigation of the specific financial incentives that can be offered to overcome the financial barriers to the adoption of ESS, especially in the construction industry.

5. ACKNOWLEDGEMENTS

The authors wish to thank the reviewers of the World Construction Symposium for their valuable comments. The authors acknowledge the support from the Department of Built Environment, Faculty of Engineering and Technology, and the Directorate of Research Development and Innovation, Walter Sisulu University, South Africa, and the CIDB Centre of Excellence situated at the University of Johannesburg, South Africa.

6. REFERENCES

Ahmad, M., Zhao, Z. Y., & Li, H. (2019). Revealing stylized empirical interactions among construction sector, urbanization, energy consumption, economic growth and CO2 emissions in China. *Science of the Total Environment*, *657*, pp.1085-1098. https://doi.org/10.1016/j.scitotenv.2018.12.112.

Ahmed Ali, K., Ahmad, M. I., & Yusup, Y. (2020). Issues, impacts, and mitigations of carbon dioxide emissions in the building sector. *Sustainability, 12*(18), 7427. https://doi.org/10.3390/su12187427.

Alam, M., Zou, P. X., Stewart, R. A., Bertone, E., Sahin, O., Buntine, C., & Marshall, C. (2019). Government championed strategies to overcome the barriers to public building energy efficiency retrofit projects. *Sustainable Cities and Society, 44*, pp.56-69. https://doi.org/10.1016/j.scs.2018.09.022.

Azzuni, A., & Breyer, C. (2018). Energy security and energy storage technologies. *Energy Procedia*, *155*, pp.237-258. https://doi.org/10.1016/j.egypro.2018.11.053

Bibri, S. E. (2020), The eco-city and its core environmental dimension of sustainability: Green energy technologies and their integration with data-driven smart solutions. *Energy Informatics, 3*(1), pp.1-26. https://doi.org/10.1186/s42162-020-00107-7

Boaz, A., Hanney, S., Borst, R., O'Shea, A., & Kok, M. (2018). How to engage stakeholders in research: design principles to support improvement. *Health Research Policy and Systems, 16*(1), pp.1-9. https://doi.org/10.1186/s12961-018-0337-6

Brown, M. A. (2001). Market failures and barriers as a basis for clean energy policies. *Energy Policy, 29*(14), pp.1197-1207. https://doi.org/10.1016/S0301-4215(01)00067-2

Camarasa, C., Nägeli, C., Ostermeyer, Y., Klippel, M., & Botzler, S. (2019). Diffusion of energy efficiency technologies in European residential buildings: A bibliometric analysis. *Energy and Buildings*, 202, 109339. https://doi.org/10.1016/j.enbuild.2019.109339

Chua, E. (2021). *Management of safety hazards in residential buildings with multiple electrical energy storage systems* [Master's thesis]. University of Twente.

Dowelani, M., Okoro, C., & Olaleye, A. (2022). Factors influencing blockchain adoption in the South African clearing and settlement industry. *South African Journal of Economic and Management Sciences*, *25*(1), pp.1-11. https://doi.org/10.4102/sajems.v25i1.4460.

Field, A. (2005). *Discovering Statistics Using SPSS*, (2nd ed.). Sage Publications Ltd. Retrieved from https://uk.sagepub.com/en-gb/eur/discovering-statistics-using-ibm-spss-statistics/book257672

Ghobakhloo, M., Sabouri, M. S., Hong, T. S., & Zulkifli, N. (2011). Information technology adoption in small and medium-sized enterprises; an appraisal of two decades literature. *Interdisciplinary Journal of Research in Business*, *1*(7), pp.53-80. Retrieved from https://journaldatabase.info/articles/information_technology_adoption_small.html

Goodier, C. I., & Chmutina, K. (2014). Non-technical barriers for decentralised energy and energy efficient buildings. *International Journal of Energy Sector Management*, *8*(4), pp.544-561. https://doi.org/10.1108/IJESM-03-2014-0001

Hayes, A. F., & Coutts, J. J. (2020). Use omega rather than Cronbach's alpha for estimating reliability. But…. *Communication Methods and Measures*, *14*(1), pp.1-24. https://doi.org/10.1080/19312458.2020.1718629

Jeffery, N. (2009). *Stakeholder engagement: A road map to meaningful engagement*. Doughty Centre - Cranfield School of Management. Retrieved from http://hdl.handle.net/1826/3801

Johnson, J., Hoaglund, J. R., Trevizan, R. D., & Nguyen, T. A. (2021). *Physical security and cybersecurity of energy storage systems*. Sandia National Laboratories. Retrieved from https://www.sandia.gov/app/uploads/sites/163/2021/09/ESHB_Ch18_Physical-Security_Johnson.pdf

Juszczyk, O., Juszczyk, J., Juszczyk, S., & Takala, J. (2022). Barriers for renewable energy technologies diffusion: Empirical evidence from Finland and Poland. *Energies, 15*(2), 527. https://doi.org/10.3390/en15020527

Kim, M. J., Oh, M. W., & Kim, J. T. (2013). A method for evaluating the performance of green buildings with a focus on user experience. *Energy and Buildings*, 66, pp.203-210. https://doi.org/10.1016/j.enbuild.2013.07.049

Matsepe, N. T., & Van der Lingen, E. (2022). Determinants of emerging technologies adoption in the South African financial sector. *South African Journal of Business Management*, *53*(1), 2493. https://doi.org/10.4102/sajbm.v53i1.2493

McAndrew, R., Mulcahy, R., Gordon, R., & Russell-Bennett, R. (2021). Household energy efficiency interventions: A systematic literature review. *Energy Policy*, 150, 112136. https://doi.org/10.1016/j.enpol.2021.112136

Oguntona, O. A., Maseko, B. M., Aigbavboa, C. O., & Thwala, W. D. (2019). Barriers to retrofitting buildings for energy efficiency in South Africa. In *IOP Conference Series: Materials Science and Engineering* (640, pp. 12-15), IOP Publishing. doi:10.1088/1757-899X/640/1/012015.

Palm, J. (2009). Placing barriers to industrial energy efficiency in a social context: a discussion of lifestyle categorisation. *Energy Efficiency, 2*(3), pp.263-270. https://doi.org/10.1007/s12053-009-9042-1

Paukstadt, U. (2019). A survey of smart energy services for private households, In *14th International Conference on Wirtschaftsinformatik* (pp. 1448-1462). European Research Center for Information Systems (ERCIS). Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1292&context=wi2019

Pelenur, M. J., & Cruickshank, H. J. (2014). Motivations to adopting energy efficiency measures in the home. In *Proceedings of the Institution of Civil Engineers-Energy* (167, pp.103-116). ICE Publishing. https://doi/10.1680/ener.14.00013

Purchase, C. K., Al Zulayq, D. M., O’Brien, B. T., Kowalewski, M. J., Berenjian, A., Tarighaleslami, A. H., & Seifan, M. (2022). Circular economy of construction and demolition waste: A literature review on lessons, challenges, and benefits. *Materials*, *15*(1), 76. https://doi.org/10.3390/ma15010076

Ratner, S., Berezin, A., Gomonov, K., Serletis, A., & Sergi, B. S. (2022). What is stopping energy efficiency in Russia? exploring the confluence of knowledge, negligence, and other social barriers in the Krasnodar Region. *Energy Research & Social Science*, 85, 102412. https://doi.org/10.1016/j.erss.2021.102412

Russell-Bennett, R., McAndrew, R., Gordon, R., Mulcahy, R. and Letheren, K. (2019). Effectiveness of household energy efficiency interventions in advanced economies – what works and what doesn’t. *Final Report*. Brisbane: Queensland University of Technology. Retrieved from https://energyconsumersaustralia.com.au/wp-content/uploads/Effectiveness-of-Household-Energy-Efficiency-Interventions-in-Advanced-Economies.pdf

Schrepp, M. (2020). On the usage of Cronbach's alpha to measure reliability of UX scales. *Journal of Usability Studies*, *15*(4), pp.247-258. Retrieved from https://uxpajournal.org/wp-content/uploads/sites/7/pdf/JUS_Schrepp_Aug2020.pdf

Sev, A. (2011). A comparative analysis of building environmental assessment tools and suggestions for regional adaptations. *Civil Engineering and Environmental Systems, 28*(3), pp.231-245. https://doi.org/10.1080/10286608.2011.588327

Shafie, S. M., Nu’man, A. H., & Yusuf, N. N. A. N. (2021). Strategy in energy efficiency management: University campus. *International Journal of Energy Economics and Policy, 11*(5), pp.310-313. https://doi.org/10.32479/ijeep.11265

Sharma, M. (2018). Development of a ‘green building sustainability model’ for green buildings in India. *Journal of Cleaner Production,* 190, pp.538-551. https://doi.org/10.1016/j.jclepro.2018.04.154

Tawalbeh, M., Al-Othman, A., Kafiah, F., Abdelsalam, E., Almomani, F., & Alkasrawi, M. (2021). Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook. *Science of The Total Environment*, 759, 143528. https://doi.org/10.1016/j.scitotenv.2020.143528

Teng, S. Y., Touš, M., Leong, W. D., How, B. S., Lam, H. L., & Máša, V. (2021). Recent advances on industrial data-driven energy savings: Digital twins and infrastructures. *Renewable and Sustainable Energy Reviews*, 135, 110208. https://doi.org/10.1016/j.rser.2020.110208

Thollander, P., & Palm, J. (2012). *Improving energy efficiency in industrial energy systems: An interdisciplinary perspective on barriers, energy audits, energy management, policies, and programs*. (1st Ed.). Springer Science & Business Media.

Wu, P., Song, Y., Zhu, J., & Chang, R. (2019). Analyzing the influence factors of the carbon emissions from China's building and construction industry from 2000 to 2015. *Journal of Cleaner Production*, 221, pp.552-566. https://doi.org/10.1016/j.jclepro.2019.02.200