Global Trend in Retrofitting using Smart Technology: A Scientometric Review

[1]Cyril EJIDIKE, [1]Modupe MEWOMO*, Timothy O. OLAWUMI

[1]Department of Construction Management and Quantity Surveying, Durban University of Technology, 4001, South Africa
22175606@dut4life.ac.za, Modupem@dut.ac.za
[2]School of Engineering and Built Environment, Edinburgh Napier University, United Kingdom. **ORCiD:** 0000-0003-3380-4702. T.Olawumi@napier.ac.uk

Abstract. Retrofitting an existing structure enhances its energy efficiency, aesthetic appearance, and thermal comfort while also reducing the building's energy costs. Buildings account for 40% of global energy consumption, which is also responsible for CO_2 emissions than any other economic sector. The achievement of high energy performance, thermal comfort, and cost optimization for new buildings has become more realistic with the rise in the use the innovative technology in building construction. However, studies have increased the contribution of smart technology in retrofitting a building, but the extent of the work remains unmapped. Hence, the domain knowledge must be documented, especially regarding the global perspective of smart technology in retrofitting the building. Therefore, this study critically reviews existing literature on smart technology use in retrofitting using a scientometric analysis approach. VosViewer software was employed to analyze the retrieved research corpus. Findings revealed momentum in retrofitting studies in 2017. The smart technology most used in retrofitting is smart meters, heat pumps and photovoltaics. The scope of the study is limited, with the majority of studies focusing on trade-offs between energy costs and thermal comfort. Also, the Energy and Buildings journal is the most cited and published research outlet in building retrofitting with technologies. The United States was identified as the most productive nation in the subject matter, while South Africa is the most productive country in sub–Saharan Africa.

Keywords: Retrofitting, Network trends, Scientometric, Smart Technology

1 Introduction

Cities are predicted to house 70% of the world's population by 2050 [1] and are projected to account for nearly three-quarters of global (direct) final energy use [2]. It entails significant environmental and social sustainability challenges in the built environment [3]. The building sector accounts for 40% of global annual energy consumption, increasing yearly, making the sector a primary energy consumer [4]. Meanwhile, the sector is also responsible for 39% of greenhouse gas emissions than any other economic sector [5]. In Africa, the building sector accounts for 61% of final energy use and 32% of greenhouse gas emissions CO_2 [6], which contribute significantly to global concerns such as global warming, environmental degradation, and ozone layer depletion [7]. The goal to achieve sustainability in the built environment depends on the ability of countries to reduce the level of fossil-based energy consumption [8]. The advent of innovative and efficient smart technology has facilitated high energy performance, thermal comfort, and cost optimization for new buildings [9].

Moreover, although some new building developments meet the requirement of near-zero energy building, the energy consumption and CO_2 emission in the building sectors will still be high as most of the global building stock are existing buildings [9]. Hence, it is essential to emphasized the retrofitting of the building towards minimizing the energy consumption (heating, cooling, and lighting) and cost of operation to achieve sustainability in the built environment [10]. According to Asadi et al. [11], developing a list of appropriate retrofit measures for specific projects remains a significant technical and methodological research gap; despite an emerging range of retrofit technologies. Therefore, this study explores these smart technology approaches used in building retrofitting and design.

2 Building Retrofitting

The retrofitting of existing buildings allows for significant energy and non-energy performance improvement with mature and off-the-shelf technologies [9]. According to Saleem [12], retrofitting can be described as adding new components (hardware and software) to an existing building to improve its performance. Also, retrofitting involves eliminating, installing, rearranging, or replacing one or more components of a building [4]. The U.S. Department of Energy defines building retrofit or renovation as a chance for existing structures to improve their energy performance across their lifecycle [13]. Meanwhile, the application of smart technologies is a set of functionalities supplied by hardware and software components that work together to create seamless connectivity within a building, such as smart devices and smart systems [14].

Several studies have applied smart technologies for building retrofitting. For instance, Zhai et al. [15] regard deep-energy retrofitting of commercial buildings as a key pathway toward low-carbon cities. Zhai et al. used an integrated energy-efficient measure portfolio that links the lighting occupancy and heating control sensor to achieve optimal light distribution in a building. Glad [16] used a thermostat, smart meter, and billing to control occupant energy consumption and water-filled radiators to control water usage. The smart meter collects data at constant intervals, providing occupant usage data, while single-handle taps and low-flush toilets helped save water consumption. Skea [17] advocated using biomass boilers, heat pumps, solar thermal energy, and smart metering as an alternative to reducing energy consumption from non-renewable sources. Also, Asadi et al. [18] presented a multiobjective optimization model to assess technology choice in a building retrofit project quantitatively. Such as insulation materials for walls, roofs, and solar collectors. Desogus et al. [19] employed resistive temperature detector sensors to measure the surface temperature of the ceiling and wall.

Meanwhile, Zhu et al. [20] applied ground water-source heat pump system technology for hotel building retrofit to save the water source consumption and electricity used in heating and cooling in a clean and new way, which improved the building performance of the hotel. Bhati et al. [22] investigated the use of smart meters to detect behavioural patterns and proactively turn off the lighting and appliances, thereby conserving energy in smart homes. Bonamente et al. [23] highlighted the benefits of innovative renewable energy technology such as photovoltaic and energy-efficient lighting systems to reduce buildings' operational carbon emissions.

Hence, the current study aims to thoroughly review one-decade research breakthroughs in building retrofitting technology applications with bibliometric analysis techniques. This study's objectives include (1) identifying the most influential journals and countries in the field and (2) identifying the research focus on building retrofitting and salient research themes. The study findings would increase the knowledge base on building retrofitting by providing a broad overview of the trend and structure. To the best of the authors' knowledge, this is the first study that uses a scientometric technique to analyze extant literature related to building retrofitting using smart technology.

The study was limited to the scope of building retrofitting technology despite the noteworthy findings. Furthermore, the study mainly examined research publications published between 2011 and 2021. Also, it omitted the advancement of optimization applications for retrofitting decision-making. This type of analysis is critical for discovering new trends in the subject that can be researched further in the future. As a result, the current paper is distinct from [24].

3 Methodology

The choice of a database is critical when conducting scientific reviews as it directly impacts the quality of the outcome [25]. The primary bibliometric data sources include the Web of Science (WoS), SpringerLink, Google Scholar, ProQuest, ScienceDirect, Scopus, PubMed, Dimensions Microsoft Academic. WoS and Scopus are the most widely utilized databases in science mapping. Since 1900, WoS has indexed more than 21,000 peer-reviewed journals, resulting in about 1.9 billion cited references from over 171 million entries [26]. Therefore, this study selected WoS as the primary database for retrieving published research articles because of its scientific soundness and comprehensiveness [26].

3.1 Data collection

The study used journal articles as the article type since it has been peer-reviewed for quality and reliability. Search terms such as "building retrofit", OR "smart technology", OR "retrofitting building" were used to identify relevant literature within the Web of Science Core Collection from the year 2011 to 2021, making it a one-decade research output discovery.

Scientometric is defined as applying quantitative research methodologies to the evolution of science as an information process [27]. He et al. [28] pointed out that the goal of scientometric research is to examine the intellectual landscape of a knowledge domain, the issues that scholars have been striving to answer, and the methods they have devised to attain their objectives. Olawumi and Chan [29] further affirmed that scientometric analysis is one of the most widely used approaches for evaluating and examining the research development and performance of academics, faculties, colleges, countries, and journals in a given subject matter. The scientometric analysis provides a more comprehensive yet concise capturing and mapping of a scientific knowledge domain by finding structural trends and delineating critical research horizons. Other scientific methodologies, such as the bibliometric technique, are also helpful [37]. Although Amirkhani et al. [26] emphasized that scientometrics and bibliometrics are similar, they both deal with quantitative analysis of publications or other types of communication that deal with scientific output and value.

In construction research, these methodologies are widely accepted and encouraged, as they assist the researcher in comprehending the current research trend [32]. In scientometrics, the number of times publications cite each other is used to determine their relatedness. Also, researchers use this method to determine the field core trends [31]. Meanwhile, co-occurrence analysis is used to evaluate the association between research sources, keywords, and the like in publication data.

3.2 Visualisation of data

This study used VOSviewer to perform the analysis of the bibliometric data retrieved. Figure 1 shows the overall research approach for the study.

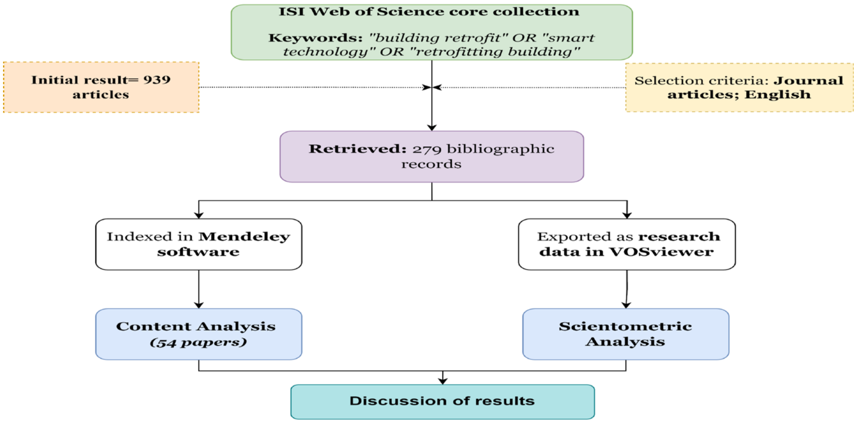

Fig. 1. ***Overview of research approach***

4 Results And Discussion

4.1 Trends of publications

The first research article using smart technology in building retrofit was conducted by Moreno-Munoz et al. [32]; the study focuses on integrating smart technology into building to improve energy efficiency. The article has 11 citations. Figure 2 shows the publication distribution of the articles on retrofitting technology applications between 2011 and 2021. The result indicates that retrofitting started gaining interest between 2012 and 2013, with eight publications each. The year 2020 has the highest number of publications with 58 articles. The results show that interest in retrofitting technology applications has increased. The trends of publications are expected to grow due to increasing demand for the reduced environmental impact of the energy used in the building, coupled with the introduction of optimization model methodologies in retrofitting for financial decision making of stakeholders to achieve sustainable development in the built environment.

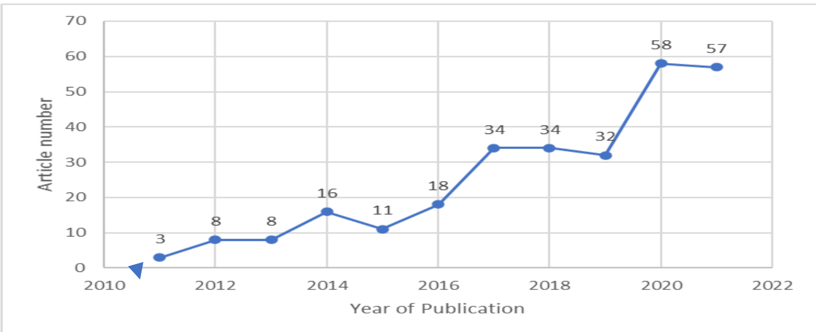

Fig. 2: Distribution of research publications from 2011 to 2021

4.2 The co-occurrence of keywords analysis

The keywords analysis is a vital bibliographic analysis that identifies the major research areas within the discipline [33]. The networks created using keyword analysis provide a holistic view of a research field by revealing tangled relationships within a domain's research topics/subtopics. The formula is based on the frequency of co-occurring keywords in publications and the strength of their correlations Omrany et al. [33]. The VOSviewer software was utilized to explore the co-occurring keywords network. In the co-occurrence analysis, all keywords were considered, including those used by authors and those indexed by publishing journals. [34]. The minimum number of occurrences of a keyword was set at 10. The analysis results with a minimum threshold of 35 keywords are shown in Figure 3. The size of the nodes represents the number of periods keywords have been used in the literature. The thickness of connecting links shows the density of connections, and the closeness of notes indicates solid interconnections between them.

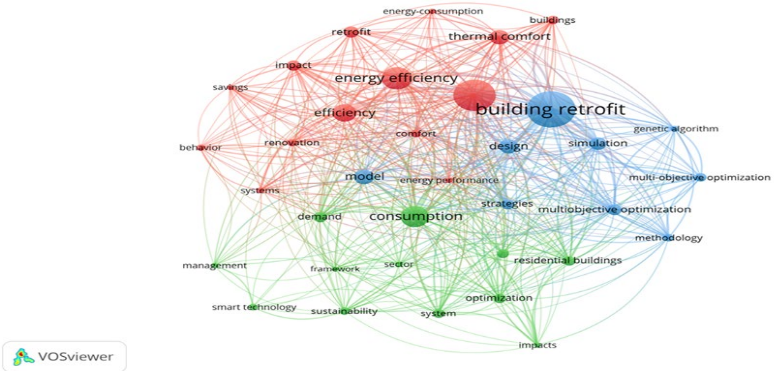

Fig. 3. ***Co-occurrences keywords.***

Fig.4. shows the top 20 keywords with the highest co-occurrence values and their link strength, showing that they have gotten greater attention and are closely linked to other keywords. The keywords such as 'performance,' 'consumption,' 'energy efficiency,' 'multiobjective optimization', 'efficiency,' 'building retrofit,' and 'thermal comfort' indicate those with higher occurrences and total link strength, which shows that they have received more attention and are highly linked terms. Smart technology that occurred on the string search list was included. Hence, a higher value is expected. Despite this expected result, these keywords are kept in the analysis because excluding them may omit essential keywords linked to them.

It can be observed that these keywords and others, such as the design and model, are located near the borders of the clusters, indicating that they are cross-cutting keywords with a solid linkage to different clusters. These and other keywords, such as "consumption" and "building retrofit," are found at the cluster's borders, indicating cross-cutting terms with solid ties to multiple clusters and subjects. As a result, to improve the sustainability potentials of existing buildings, efforts must be directed toward improving energy efficiency and reducing CO2 emission and water consumption, which are the primary aim of retrofitting [44]. The higher value of the terms "energy efficiency" and "performance" implies that much attention has been paid to developing the energy performance of buildings. The study's findings are consistent with previous studies, which show that close attention has been paid to improving existing buildings' performance and energy efficiency through retrofitting [46,47]. The term "smart technology and multiobjective optimization" shows hardware and software applications, indicating the importance of technology in achieving sustainability in the built environment[48, 49].

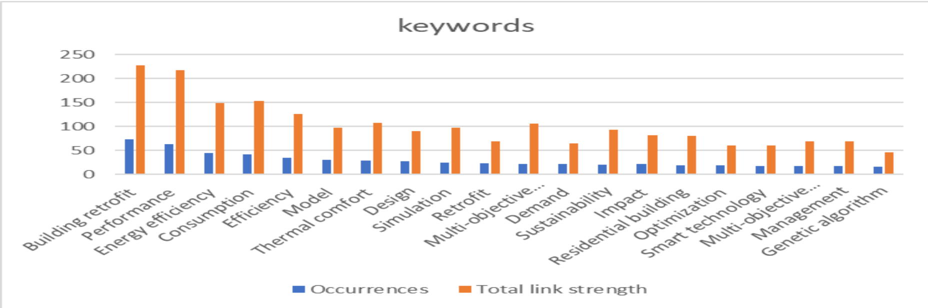

Fig. 4 Twenty keywords with the highest occurrence

4.3 Trending research topics.

The cluster provides insight into the current trends through the co-occurrence analysis in popular retrofitting research topics. Developing such an understanding lays the foundation for future technology and expansion in the sector. The list below indicates three significant clusters. Red is the largest cluster that includes 14 keywords. It is primarily due to increased building energy efficiency. The top five co-occurrence keywords are as follows: performance (217), energy efficiency (154), efficiency (126), thermal comfort (108), and impact (82) (see Table 2 for the complete list of keywords clusters). Red clusters indicate the focus in the built environment on mitigating the effects of energy consumption in the building construction sectors, which dominates existing buildings. The keywords are closely related to retrofitting of buildings. The importance of energy-related policies cannot be underscored in buildings, transitioning our facility towards net-zero building and achieving sustainability [29,33]. The second cluster (green colour) has 12 keywords related to management, framework, and policy in the building sector. The clear focus is on developing a retrofitting polices roadmap to achieve energy efficiency and CO_2 emissions reduction for a sustainable built environment [50,51]. The third cluster (blue) consists of 9 keywords. It mainly focuses on methodologies and computer-aided tools to support decision-making in building retrofitting, such as the model, multiobjective optimization, genetic algorithm, and design technology application. The simulation mathematical building performance optimization formulas allow for adequate decision-making support to the bast retrofitting measure to adopt in a particular project while considering the thermal comfort cost of retrofitting, CO_2 emission reduction, and energy efficiency measure [4, 9,].

Red cluster (Behavior, Building, Comfort, Efficiency, Energy efficiency, Energy consumption, Impact, Performance, Renovation, Retrofit, Saving, and Thermal comfort). Green cluster (Consumption, Demand, Energy, Framework, Impact, Management, Optimization, Residential building, Simulation, Sectors, Smart building technology, Sustainability, and System). Blue cluster (Building retrofit, Design, Genetic algorithm, Methodology, Model, Multiobjective optimization, Multiobjective optimization, Strategies, Genetic algorithm, and Methodology)

4.4 Citation analysis of journals and countries.

Three methods are primarily used to correlate citation between sources: bibliographic coupling, direct citation, and co-citation analysis [26]. The co-citation method quantifies the strength of association between two papers cited by the same documents [49 38]. The direct citation approach investigates relationships between two publications in which one cites the other. The process of bibliographic coupling is used to find relationships between publications that cite the same publications. According to Klavans and Boyack [46], co-citation and bibliographic coupling correlations are indirect correlations and provide less reliable data on the connectedness of articles than direct citation correlations.

Furthermore, for direct citation correlation, Amirkhani et al. [26] claimed that the best and quickest way for identifying emerging research fields domains is to compare co-citation and bibliographic coupling correlations. Direct citation analysis, however, has its limits. Some articles, for example, may lack direct citation correlations with other items and, as a result, cannot be assigned to a source [26]. Therefore, the direct citation was utilized to identify the most dominant journal by setting the minimum number of source documents to 1 and the minimum number of citations of a source to 50. The results in Figure 4 show that Energy and Building (2245), Building and Environment (649), Sustainability Cities and Society (342), and Sustainability (236) are the dominant journal sources of research citation.

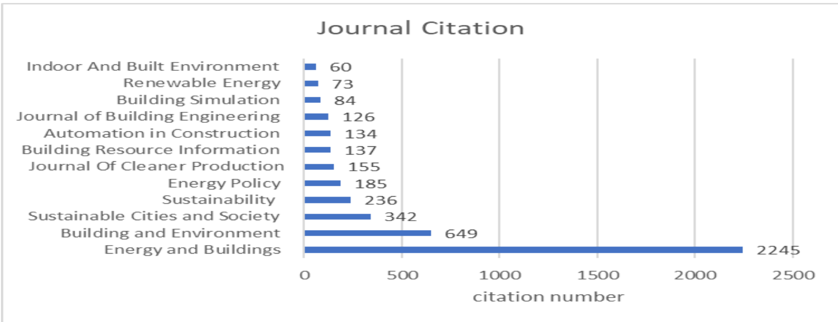

Fig. 4. ***Citations by journal***

Author citation. The scientometric analysis of the most contributing authors in building retrofitting with the application of technologies revealed that Antunes, Carlos Henggeler (725), Asadi Ehsan (676), Da silva Manuel Gamerio (676), and Xia Xiaohua (112) are the most contributing authors with the minimum of 5 documents and minimum of 50 citations. Additionally, this information helps identify research groups and assist research partnerships and policymaking.

Table 2. Authors citations

Author	Institution	Country	Citation
Antunes, Henggeler	University of Coimbra	Portugal	725
Asadi Ehsan	RMIT University	Australia.	676
DaSilva Gamerio	University of Coimbra,	Portugal	676
Xia Xiaohua	University of Pretoria	South Africa	112
Augenbore Godfried	Georgia Institute of Technology	United States	98
Ascione, Fabrizio	University of Naples Federico II	Italy	93
Bianco Nicola	University of Naples Federico II	Italy	85
Deb Chirag	Institute of Technology in Architecture	Switzerland	79
Freire Fausto	University of Coimbra,	Portugal	74
Caputo Paola	The University of Palermo	Italy	71
Schlueter Arno	Institute of Technology in Architecture (ITA),	Switzerland	54

Citations by countries. The countries with the greatest contributions to the growth of the retrofitting topic were identified by bibliographic coupling. The term "bibliographic coupling" refers to studying the relationships between two publications that cite the same document. [26]. The result in figure 5 illustrations the analysis carried out for a minimum of 100 citations per country. The findings indicate that the United States (1241), Portugal (965), and Italy (842) are the most cited countries. However, most of the citations are from developed countries.

Furthermore, it can be observed that the studies from African countries are not well cited, except for South Africa, which had 133 citations in the field of building retrofitting. South Africa has been a frontline in sub-Saharan Africa in reducing energy consumption and CO_2 emission [47]. The citation can be attributed to reducing energy consumption and CO_2 emission**.**

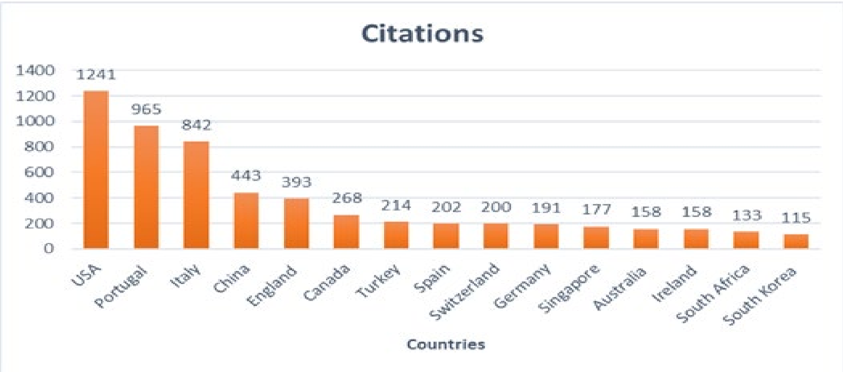

Fig.5. ***Countries citation***

5 Conclusions

The need to create a climate-friendly built environment has called for a collective effort from countries worldwide to reduce greenhouse gas emissions in their environment. Human-induced activities and climate change have led to several challenges in recent years, and carbon emissions are the leading environmental concerns caused by fossil fuel consumption. The built asset itself consumes vast global energy. It contributes to the degradation of the environment, air pollution, high construction waste, and ineffective consumption of water and electricity in the built environment, which causes a poor environment for human inhabitants.

In addressing this challenge, attention should be directed to the new buildings and the retrofitting of existing building stock because they are the primary consumer of the vast energy usage in the built environment. In the subject of retrofitting research, the study via the illustrated research networks provides useful insights to researchers, practitioners, and governmental organizations. The study's findings revealed that retrofitting with technology started gaining interest in 2011 with a few publications. It has garnered increasing interest from relevant stakeholders over the years. The study showed that interest in retrofitting is importantly directed to the alternative ways to offset the rising energy cost primarily caused by heating, water, cooling, and lighting in a building. However, there are limited studies on digital or smart technologies that address ineffective electricity and water consumption and the maintenance of existing buildings.

A major focus of these research articles is the need to find alternative ways to reduce the cost of heating (energy) and maintain the building performance rather than demolishing old buildings as a more viable option. Also, it revealed that these studies focused on the trade-offs between thermal comfort and energy usage reduction strategies. Furthermore, most citations are from a few journals of which 'Energy and Buildings' and 'Building and Environment' stand out as key research outlets. Also, the most productive country is the USA, with the highest citation. In Africa, South Africa had the highest citation. The most contributing authors in building retrofitting with the application of technologies were also revealed.

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