Bibliometric analysis, scientometrics and metasynthesis of Internet of Things (IoT) in smart buildings

Article

Accepted Version

Bibliometric Analysis, Scientometrics and Metasynthesis of Internet of Things (IoT) In Smart Buildings

Abstract

Purpose: The Internet of Things has made the shift to the digital era possible, even though the Architecture, Engineering, and Construction (AEC) sector has not embraced nor integrated it within the core functions compared to other sectors. The need to enhance sustainable construction with the adoption of Internet of Things in this sector cannot be overemphasized. However, the real-world applications of Internet of Things in smart buildings remain relatively unexplored in the AEC sector due to several issues related to deployment and energy-saving potentials. Given these challenges, this paper proposes to identify the present state of development and research in Internet of Things and smart buildings, and identify Internet of Things clusters and applications in smart buildings.

Design/methodology/approach: Bibliometric analyses of papers from 2010 to 2023 using the Scopus database and scientometric evaluations using the VosViewer software were undertaken. The proper search keyword was identified by using the phrases " Internet of Things" and "Smart Building". A total of 1158 documents in all, written by 3540 different writers, representing 2285 different institutions from 97 different countries were looked at. A metasynthesis was conducted and a system of Internet of Things applications in a smart building is illustrated.

Findings: The development of IoT and Smart Buildings is done in two phases: initiation (2010-2012) and development (2013-2023). The IoT clusters comprised internet of things, energy efficiency, intelligent buildings, smart buildings, and automation; while the most commonly used applications were analysed and established. The study also determined the productive journals, documents, authors, and countries.

Research limitations/implications: Documents published in the Scopus database from 2010 to 2023 were considered for the bibliometric analysis. Journal articles, conference papers, reviews, books, and book chapters written in English language represent the inclusion criteria, while articles in press, conference reviews, letters, editorials, undefined sources, and all medical and health publications were excluded.

Practical implications: The results of this study will be used by construction stakeholders and policymakers to identify key themes and applications in IoT-enabled smart buildings and to guide future research in the policymaking process of asset management.

Originality/value: The study utilised bibliometric analysis, scientometrics and metasynthesis to investigate internet of things applications in smart buildings. The study identified internet of things clusters and applications for smart building design and construction.

Keywords: Artificial intelligence, bibliometrics, internet of things, network sensors, smart buildings.

1 Introduction

The Internet of Things is a network of interconnected devices and sensors that can communicate and exchange data with each other. According to Elijah *et al.* (2018), the Internet of Things is "a system of interconnected computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without needing human-to-human or human-to-computer interaction". By enabling high-quality services, delivering efficient features, and assisting in the pursuit of sustainable development goals, the Internet of Things may have a substantial impact on a few industries, including the construction, operation, and management of buildings (Jia *et al.*, 2019).

In the context of smart buildings, Internet of Things technology can be used to improve building automation, energy efficiency, and overall occupant comfort (Saputra and Ramadhan, 2023) and safety. The idea of "smart buildings" emerged from the increasing integration of cutting-edge technology into buildings and their systems, enabling remote operation and management of the whole life cycle of the structures for comfort, convenience, and cost and energy efficiency (Jia *et al.*, 2019). This can be achieved using smart devices such as sensors, network protocols, wireless communications, cloud computing (Afonso *et al*., 2023), actuators, and control systems that can monitor and control various building systems such as lighting, heating, ventilation, and security (Ansari *et al*., 2017). However, problematic smart building innovation in the context of Internet of Things is widespread and ineffective (Verma *et al.*, 2019). This is because the AEC industry has not adopted digital transformation with the same fervour as other industries (Lokshina *et al.*, 2019). Nonetheless, the construction, operation, and administration of buildings are among the sectors where Internet of Things would have a big impact by enabling high-class services, delivering effective functionality, and advancing sustainable development goals (Jia *et al.*, 2019).

Exploring Internet of Things applications in smart and intelligent buildings may yield promising avenues for methodological and technological enhancements and further research areas. Given the continuous evolution of research in the realm of smart buildings and the integration of the latest advancements in information technology, identifying clusters and themes within a smart building remains a significant determinant in uncovering viable research directions. Over time, the building envelope has undergone a transformation from being a simple shelter to a more sophisticated and intelligent structure that incorporates emerging technologies (Li *et al.*, 2021). According to Daissaoui *et al.* (2020), an intelligent building system is one that integrates intelligent building management systems and big data analytics to maximise performance and energy management. Modern technology has been incorporated into buildings and their services to create the idea of "smart buildings." Advanced technology includes things like big data analytics, cloud and fog computing, sensor deployment, and Internet of Things. The complex network of interconnected, functional elements in a smart building is addressed with the help of the Internet of Things (Risteska-Stojkoska and Trivodaliev, 2017). The data collected by these devices can also be used to optimize building performance and identify areas for improvement. According to a study by Verma *et al.* (2019), the various applications of Internet of Things in buildings include lighting, natural day lighting, water management, cooking gas management, air quality and ventilation, load control, heating, cooling, and load management. Therefore, by leveraging Internet of Things technology, smart buildings can reduce energy consumption, improve building management, and create a more comfortable and efficient environment for occupants.

Numerous studies on smart cities have been conducted in recent years and more studies are needed to determine how Internet of Things may be applied to smart buildings in the construction industry (Minoli *et al.*, 2017). Even though Internet of Things research is well established, there are few studies concentrating on the application of Internet of Things in the building industry (Jia *et al.*, 2019). The study's goal is to identify Internet of Things and smart buildings during the past twelve years using bibliometric data. Thus, the study is driven to address the following four major research concerns:

I. identify research development in Internet of things enabled smart buildings;

II. highlight the most productive Internet of things research in smart buildings in terms of authors, journals, document and countries.

III. identify Internet of things clusters in smart buildings research.

IV. determine the current areas of Internet of things applications in smart buildings and illustrate a system of internet of things applications in a smart building.

2. Methodology

A systematic review is an essential technique for identifying significant knowledge gaps and research needs, according to a study by Adegoriola *et al.* (2021). A hybrid scientometric and meta-synthesis method using bibliometric analysis is utilised to analyse the available publications on Internet of Things and Smart buildings to circumvent the drawbacks of the traditional review methodology. Figure 1 displays the recommended reporting items for systematic reviews and meta-analysis (PRISMA) procedure used for this study.

2.1 Search Strategy

A search strategy was developed to identify the relevant literature. The study analyses the most significant research databases, including Scopus and Web of Science (WOS) before selecting the optimal database for this investigation. Scopus and the WOS are the two most comprehensive databases for searching the literature in a variety of scientific subjects (Tanko and Mbugua, 2022). However, the Scopus database, according to many authors, is the most complete source of citations and abstracts for literature searches (Zakka *et al.*, 2021, Tanko *et al.*, 2022). During the initial examination, the Scopus database was discovered to be the largest and most appropriate databank. All searches spanned from the beginning until 1st February 2023, and included journal articles, conference papers, book chapters, reviews and books written in English Only.

The next step is to identify the appropriate search terms to use within the Scopus database using the TITLE-ABS-KEY. The following terms were looked up as keywords: “IoT-enabled Smart Buildings” (16 documents), “IoT-integrated Smart Buildings” (1 document), “IoT in Smart Buildings” (15 documents), “IoT” in “Smart Buildings” (1150 documents), “IoT” and “Smart Buildings” (1176 documents), “Internet of Things” and “Smart Building” (1316 documents), “IoT and Smart Buildings” (3 documents), and “IoT-based Smart Buildings” (16 documents). The search phrases "Internet of Things" and "Smart Building" were selected since they produced the most documents (1316) and took care of other related search terms. 2010 to 1st February 2023 served as the primary archival era for academic research outputs considered in this study. During this period, a comprehensive review of the existing literature on Internet of Things and Smart Buildings using the Scopus database was conducted. 1316 papers from the years 2010 to 2023 were automatically extracted from the database inception at 13:00 Singapore Time (SGT) on 1st February 2023.

2.2 Selection Criteria

The selection criteria were based on the PRISMA statement (Moher *et al*., 2009). The search mainly focused on the mapping of existing literature on Internet of Things and Smart Building in the field of Environmental Sciences; Social Sciences, Energy; Engineering; Computer Science; Business, Management and Accounting; Earth and Planetary Sciences; Material Sciences; and Economics, Econometrics, and finance. No country, author, source, or year was excluded. 1288 papers were screened excluding all medical and biological fields, articles in press, letters, editorial, conference reviews, undefined sources, and articles written in Chinese, German, Persian, Portuguese, and Spanish. The literature samples demonstrate that for more than ten years, research into Internet of Things and Smart Building has accelerated. Based on content similarity and issues addressed, the research articles can be categorised into various clusters and demonstrate a trend toward becoming themed. These articles were examined to demonstrate the clarity of the overall body of literature, research keywords, publication source, most productive and influential researchers, most cited articles, and countries actively involved in the study of "Internet of Things" and "Smart Building" by creating and generating maps for information mining. Journal publications, conference papers, book chapters, reviews and books make up 33.5%, 58.7%, 4%, 2.6%, and 1.1% respectively. It is important to note that journal publications and conference papers account for a total of 92.2% of the database.

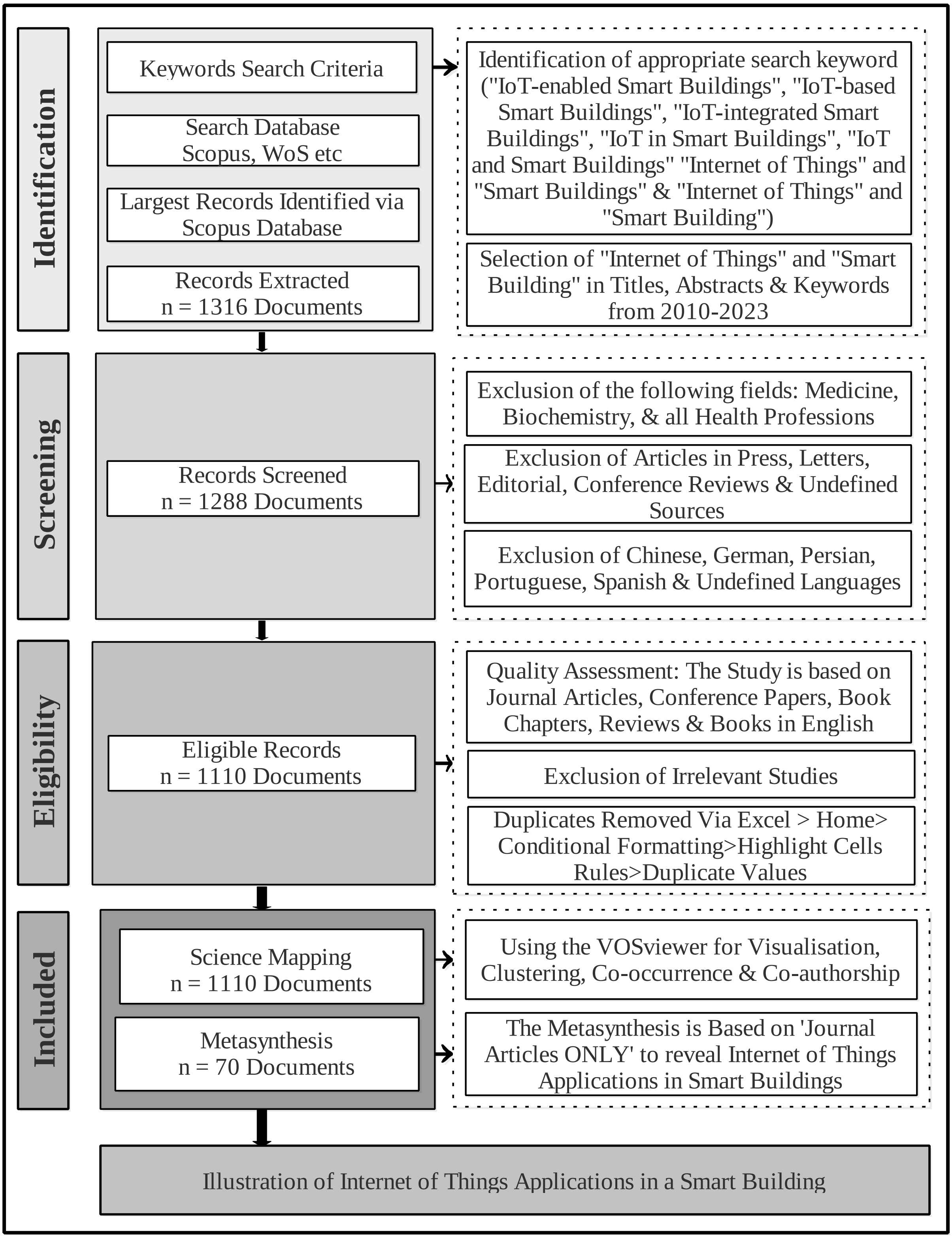

Figure 1. Prisma procedure of the study
Source (s): Figure by authors

2.3 Quality Assessment

The study is based only on journal publications, conference documents, book chapters, reviews and books written in English. For maintaining the quality of the paper, all duplications were thoroughly checked using Excel Conditional Formatting ribbon. The abstracts of the articles were checked for the analysis and screening of the articles to ensure the quality and relevance of the academic literature include in the systematic review. A careful examination of each paper was carried out at a later stage to exclude all irrelevant studies. A total of 1110 articles were selected after each article was assessed against the inclusion and exclusion criteria.

2.4 Science Mapping and Scientometric Analysis

Science mapping uses the co-occurrence weight and total link strength provided by the item to illustrate the influences and strengths of linkages among various article qualities (Tanko *et al.*, 2022). Network analysis commonly uses grouping, visualisation, and the evaluation of network metrics. A sort of big data analytics called scientometric mapping aggregates applications and resources that provide more details on the dependability and usability of the data utilised in strategic planning (Tanko, 2022). Consequently, scientometric analysis has been designed for the science mapping methodology. The risk of author bias becomes a problem as researchers find it increasingly difficult to manage the literature and conduct unbiased literature reviews as the quantity of scientific publications rises.

This study analysed 1110 selected documents using the "VOSviewer" software for visualisation, clustering, co-authorship, and co-occurrences. The VOSviewer is a text-mining application with user-friendly visualisation and bibliometrics capabilities that has been widely used in the field of building project management (Adegoriola *et al.*, 2021). It is a free computer programme that employs the VOS mapping approach to create and display massive bibliometric maps; "VOS" stands for "visualisation of similarities." The software has a strong emphasis on a graphic representation of bibliometric maps, in contrast to earlier tools used to map bibliometrics (van Eck and Waltman, 2010). It has been utilised in various review-based studies in the disciplines of construction engineering and project management (Shukra and Zhou, 2021). It is therefore worthwhile to consider utilising the "VOSviewer" to analyse and visualise key papers in the Internet of Things and smart buildings domain.

2.5 Metasynthesis

Lachal *et al.* (2017) described metasynthesis as the systematic review and integration of findings from qualitative studies. The authors highlighted six (6) steps in metasynthesis: define the research question and the inclusion criteria, select the studies, assess their quality, extract and present the formal data, analyze the data, and express the synthesis. In this paper, the article, year of publication, journal, and eight (8) IoT applications in Smart building of 70 studies were extracted and presented in a way that enables readers to form their own opinions about the studies included. The metasynthesis was based on journal publications whose abstracts and content were thoroughly checked for internet of things applications in smart buildings to ensure the quality and relevance of the studies.

3 Findings and Discussion

3.1 Bibliometrics and Scientometrics

3.1.1 Literature Sample

The publication years for the whole literature collection range from 2010 to 2023. Before research in the field gained substantial growth, the first publication on Internet of Things and smart buildings was discovered in 2010. A few other articles were then discovered between 2011 and 2012. The most fruitful years for this type of research were from 2013 to date. The forecast for more study publications in the upcoming years stems from the trend that scholars are becoming increasingly interested in Internet of Things and smart buildings.

3.1.2 *Sources of Documents*

The number of papers published, the total number of links a journal has to other peer-reviewed journals, and the number of citations it receives are indicators of its impact. The highest impact publication is IEEE Internet of Things Journal, which has a total link strength of 38, 33 documents, and 1755 citations. IEEE Access (total link strength 26, 37 documents, 1364 citations) and Automation in Construction (total link strength 21, 9 documents, 598 citations) are also leading journals with high publications on Internet of Things and Smart Buildings between 2013 and 2023.

3.1.3 *Articles with the Highest Citation*

The articles with the highest citation as well as their authors and year of publication were analysed. Minoli *et al.* (2017) had the highest single article citation of 458 on their work "IoT Considerations, Requirements, and Architectures for Smart Buildings-Energy Optimization and Next-Generation Building Management Systems followed by Plageras *et al.* (2018) with 356 citations on their research titled Efficient IoT-based Sensor BIG Data Collection–Processing and Analysis in Smart Buildings. Chen *et al.* (2017), Liu *et al.* (2019), Arasteh *et al.* (2016), Sadowski *et al.* (2018), and Mohammadi *et al.* (2018) had 304, 282, 277, 269, and 243 citations respectively.

3.1.4 *Authors with the Highest Citation*

The number of citations of a scholar shows the level of impact a scholar has on a particular field (Yu and Hayes, 2018). The study analysed various authors with their total citation in Internet of Things and Smart Buildings as extracted from the scopus database in the subject area. Skarmeta A.F. has a total citation of 465 and a document count of 10 giving him an average citation count of 47 per document. Following closely on the citation count are Moreno M.V., Spachos P., and Zhou Y., with citation scores of 358, 387, and 355 respectively. The findings revealed that Skarmeta A.F. is the most influential researcher in terms of citation and documents produced both as a single-author and a co-author. The results of the study revealed that the number of documents produced does not translate to impact as with Koshizuka N. who had over 10 documents with 45 citations compared to 17 other authors who had more than 100 citations with less than 10 documents.

3.1.5 *Countries with Highest Total Link Strength, Documents and Citations*

Countries with the strongest overall links as well as those where most studies were co-cited were analysed. With 396 total link strength, 219 total documents, and a total of 6546 citations, the United States has the highest overall link strength, documents, and co-citations. In terms of the total link strength, from second to fifth place, were India, China, Spain, and Australia. On the other hand, the United States (219), India (146), China (99), France (74), and the United Kingdom (65) had the highest number of documents. In terms of citations, the United States (6546), India (1830), Italy (1699), China (1585), and France (1290) had the highest number.

3.1.6 *Phases of Internet of Things Research Development in Smart Buildings*

The annual publishing volume between the first era (2010–2012) was 1-3 articles, which is incredibly low. During the development phase (2013–2021), the annual publishing volume climbed from 12 in 2013 to 177 and 184 in 2021 and 2022, respectively. Since 2013, the annual publication volume has increased in a quasilinear way as scholarly interest in "Internet of Things" and "Smart Buildings" has increased. The literature samples represent ten years of research in this area, with an increasing trend in publications. The pattern indicates that there was no "Internet of Things" and "Smart Building" research before 2010. However, there has been an increase in publications since 2013.

3.1.7 Most Productive Journals, Documents, Influential Authors, and Collaboration among Countries

IEEE internet of things journal and IEEE Access are the leading journals on Internet of Things and Smart Buildings research. The most cited articles are "IoT Considerations, Requirements, and

Architectures for Smart Buildings-Energy Optimization and Next-Generation Building Management Systems" and "Efficient IoT-Based Sensor BIG Data Collection–Processing and Analysis in Smart Buildings" authored by Minoli *et al.* (2017) and Plageras *et al.* (2018) respectively. However, Skarmeta A.F., Moreno M.V., Zamora M.A., Spachos P., and Zhou Y. have the highest citations in Internet of Things and Smart Buildings research. In terms of countries, the United States of America (USA), France, and China have the largest documents in this area of research. Although, the clusters of these countries and their neighbouring regions show a strong association. Mexico and the US are allies, as are China and South Korea, France and Germany, the UK and Greece, Italy and Spain, Australia and India, and Malaysia and Indonesia.

3.1.8 Clusters of Internet of Things Applications in Smart Buildings

Research on Internet of Things and Smart Buildings has identified several clusters as shown in Figures 2-6. The categorization of smart buildings is derived from keyword clustering, utilising the VOSviewer's keyword mapping methodology (Saputra & Ramadhan, 2023). In the cluster related to the Internet of Things, cluster 1 with the red colour in Figure 2, where only terms with a minimum of 20 co-occurrences have been highlighted, the main associated keywords are embedded systems, network security, IoT applications, Internet of things, smart environment, and blockchain. IoT devices require an internet connection and are embedded systems that communicate with sensors and actuators. These IoT gadgets are also known as IoT sensors (Elijah *et al.*, 2018).

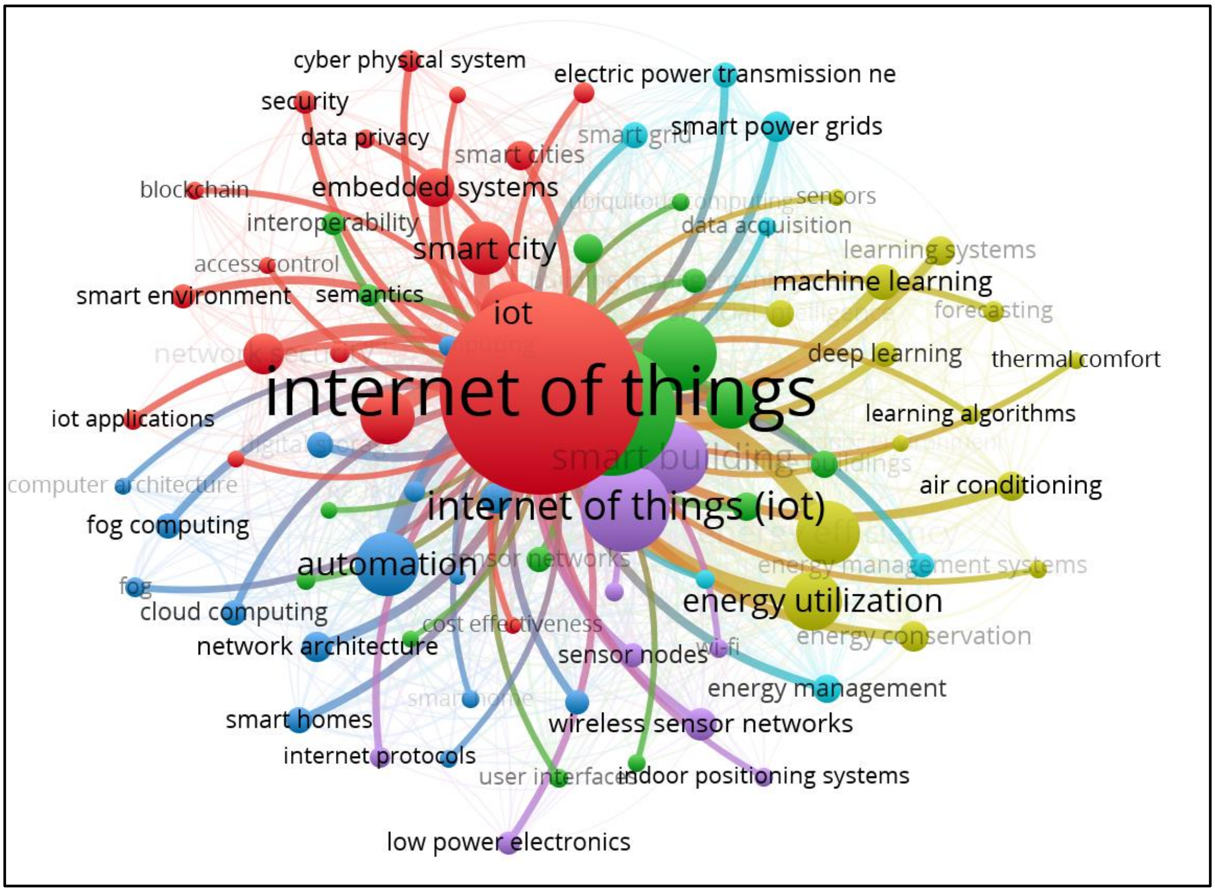

Figure 2. Cluster 1 - Internet of Things
Source (s): Figure by authors

The second cluster in Figure 3 is highlighted in yellow and focuses on energy efficiency, energy utilization, energy conservation, machine learning, air conditioning, and thermal comfort (all of which have at least 20 co-occurrences). The core components of an IoT-based system are sensors and actuators, sometimes referred to as the wireless sensor-actuator network (WSAN) (Rashid *et al.* 2019).

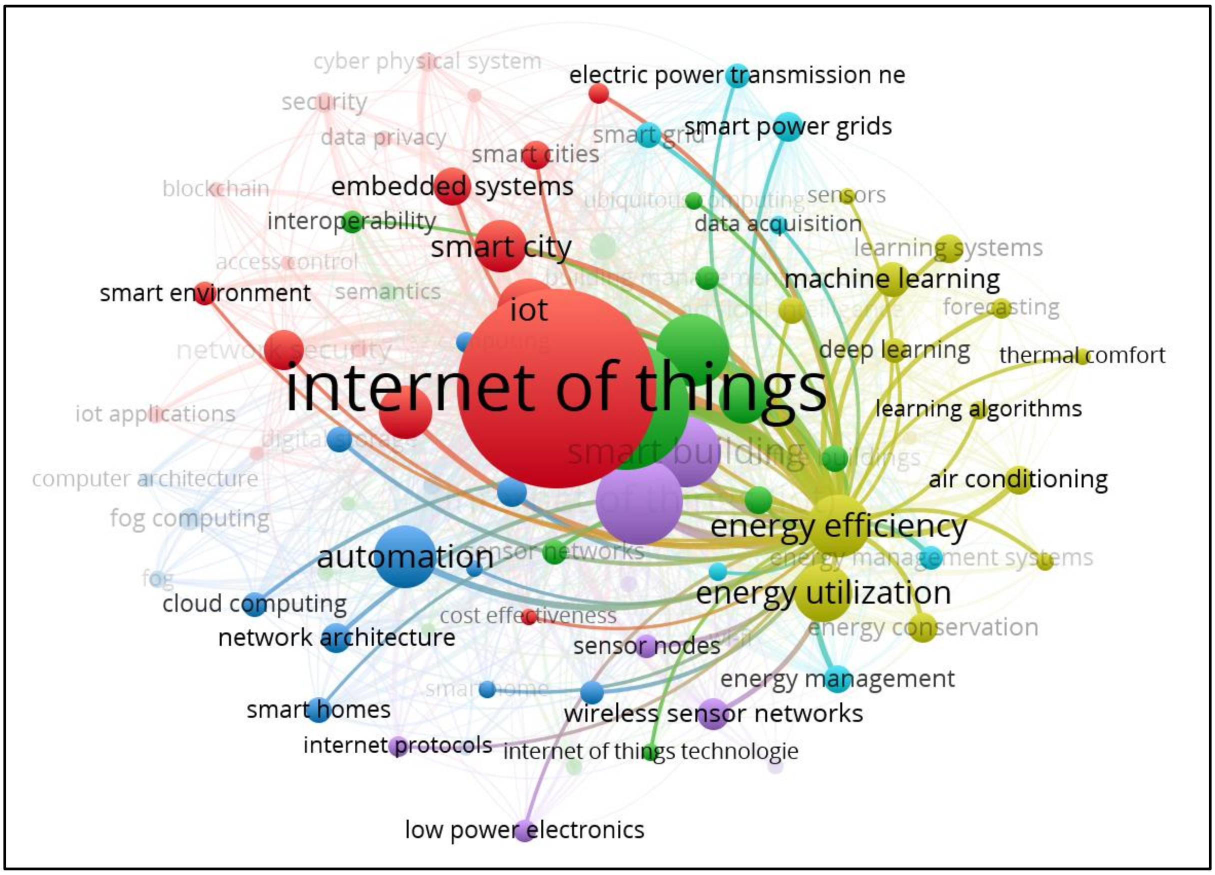

Figure 3. Cluster 2 – Energy Efficiency
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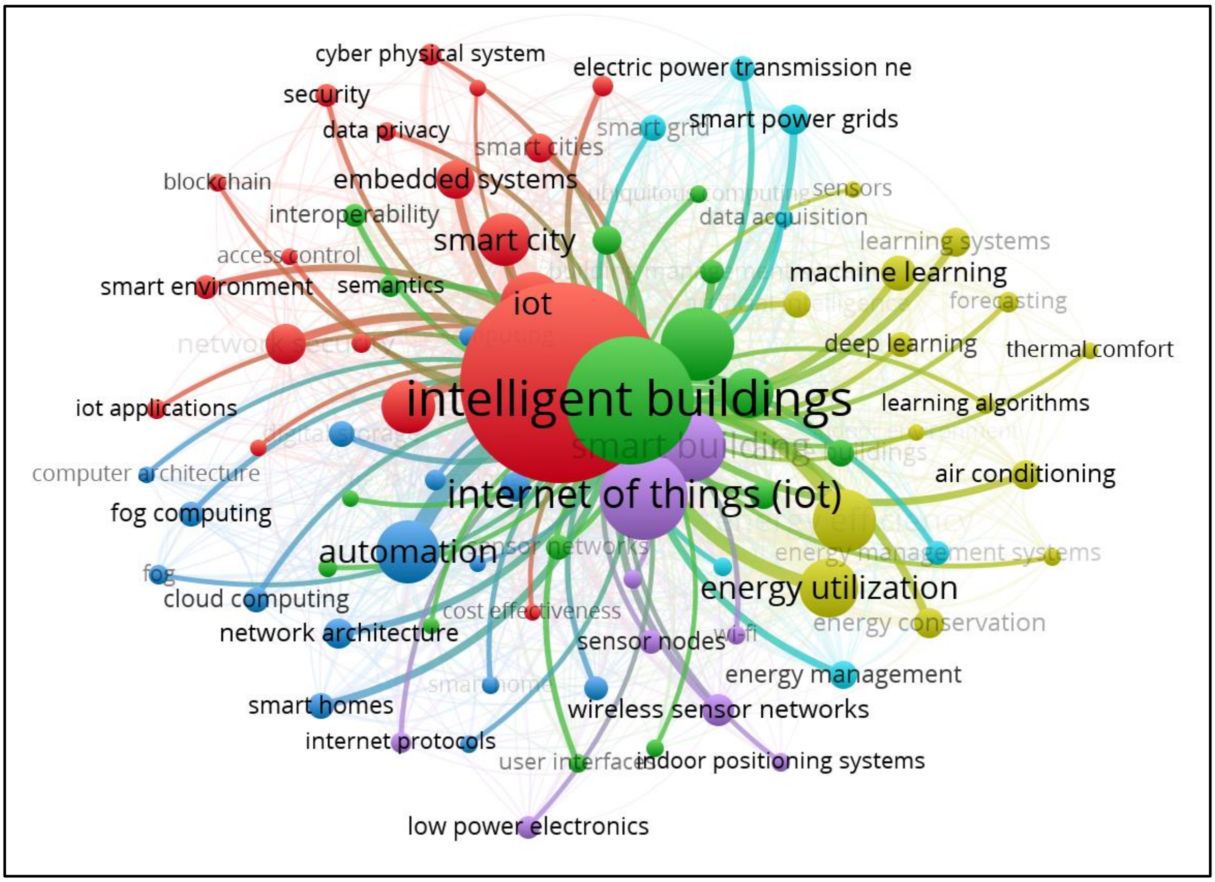

Figure 4. Cluster 3 - Intelligent Buildings
Source (s): Figure by authors

The third cluster in Figure 4 is related to intelligent buildings, building management systems, sensor networks, and user interfaces. Only keywords with at least 20 co-occurrences have been underlined in this cluster. The integration of wireless sensor networks, timers, and motion sensors in office spaces or sustainable buildings offers a practical tool to identify and respond to occupants while giving them feedback data to drive behavioural adjustments (Hernández-Ramos *et al.*, 2015).

The fourth cluster (highlighted in purple in Figure 5) is associated to smart building, wireless sensor networks, internet protocols, sensor nodes, WI-FI, and indoor positioning systems when keywords with at least 20 co-occurrences were highlighted in that cluster. This shows how Internet of Things technology have facilitated the development of applications to improve buildings and their surrounds. It improves energy efficiency, manages safety concerns, and provides a better foundation for the comfort, services, and quality of life of residents and businesses (Daissaoui *et al.*, 2020). Utilising a network of sensors and cameras, smart buildings are also capable of accurately computing the number of visitors and occupants present within a building at any given point in time (Saputra & Ramadhan, 2023)

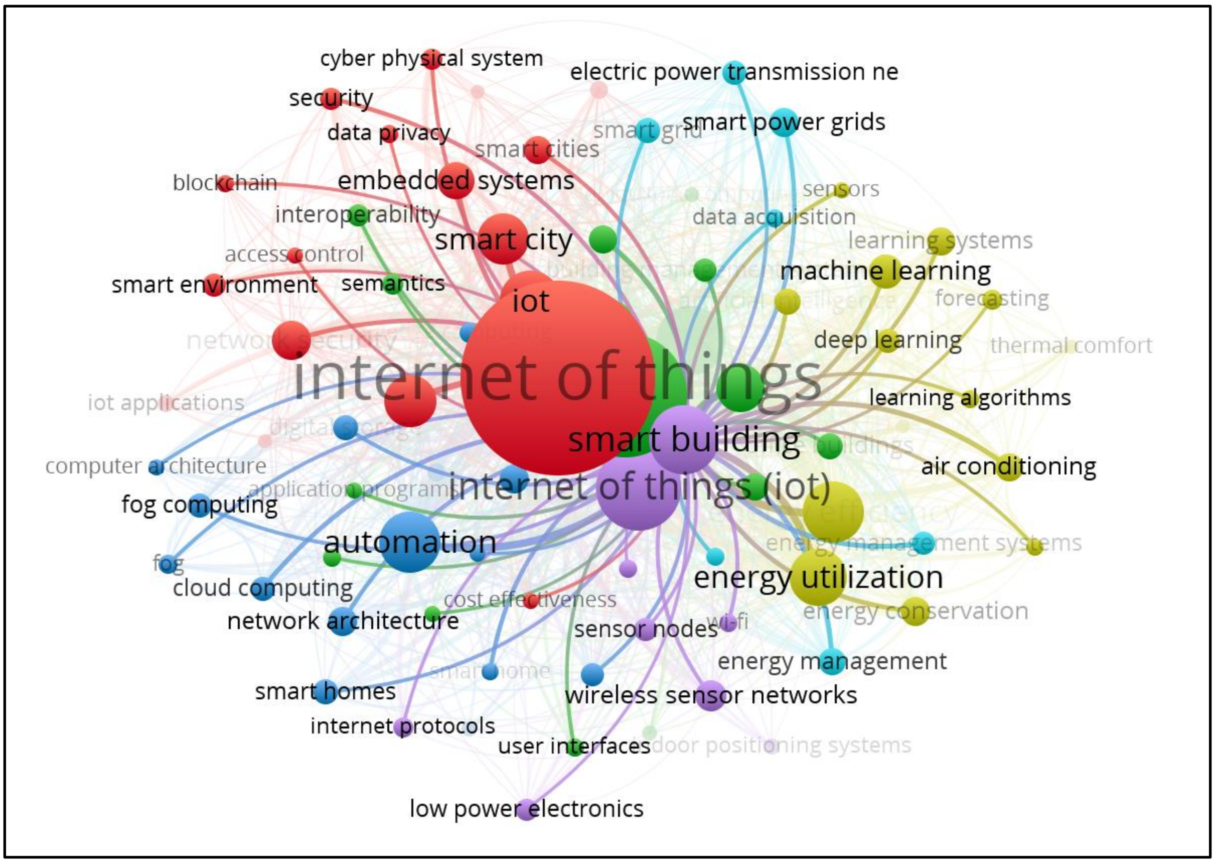

Figure 5. Cluster 4 - Smart Building
Source (s): Figure by authors

According to the blue cluster 5 in Figure 6, automation, network architecture, cloud computing, smart homes, and energy management are all essential components to address the difficulties of IoT-enabled smart buildings. Smart devices are becoming more and more important in networks that rely on automation and Internet platforms. Most of these gadgets are cell phones with incorporated software that enables users to track and assess remote actions in real-time. The automation and control of the appliance in the building is made possible by programmable hardware devices such as programmable logic controllers (PLC) and supervisory control and data acquisition (SCADA) that are connected to the internet. Examples of smart building control include the automation of waste systems, fire alarm systems, doors and lifts, cooling systems, and lighting points (Chiesa *et al.*, 2020).

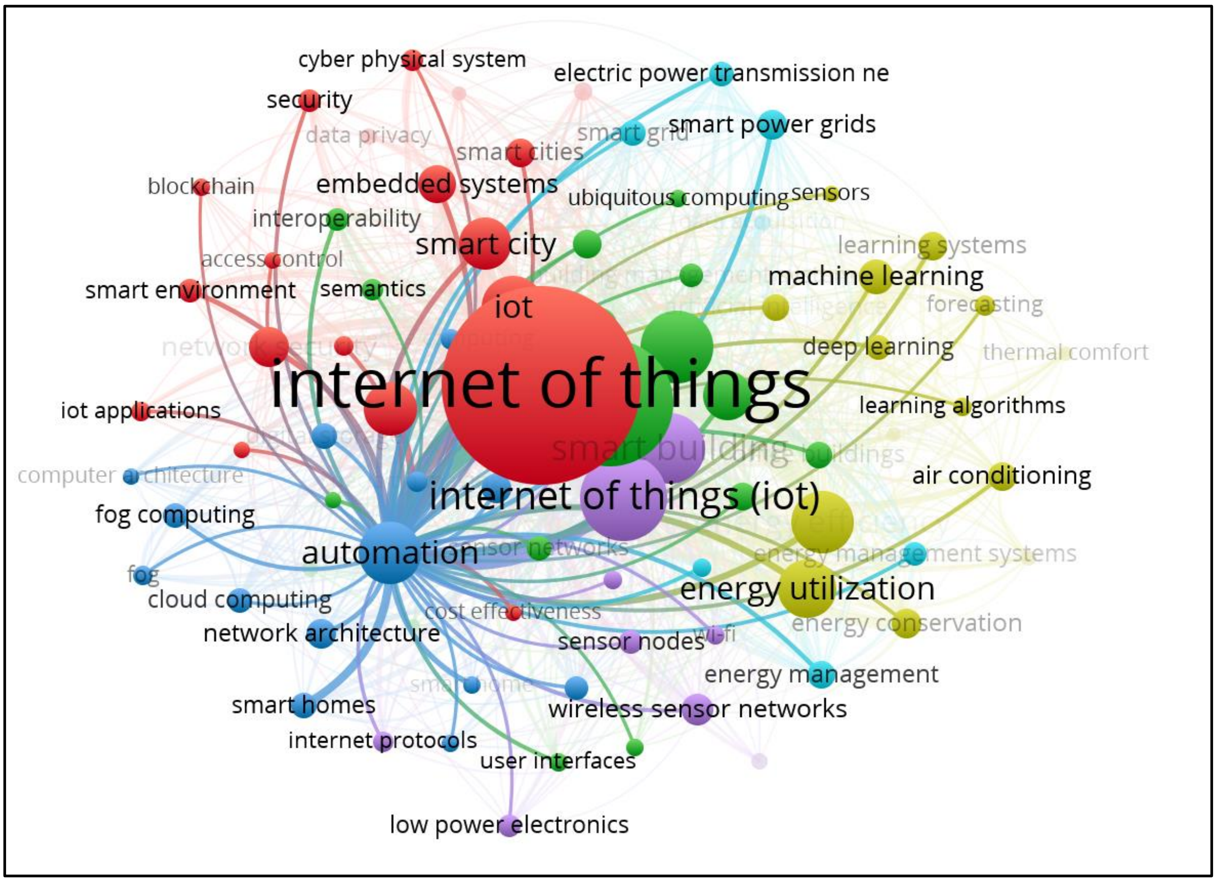

Figure 6. Cluster 5 – Automation
Source (s): Figure by authors

3.2 Metasynthesis

3.2.1 Internet of Things Applications in smart buildings

Table I shows 70 journal articles with eight (8) Internet of Things applications in Smart buildings. The results of the meta-synthesis provided an understanding on the number of journal articles and frequencies of Internet of Things applications in each article. Consequently, the weight of each Internet of Things application was analysed. A3-Heating, ventilation, and air conditioning System- HVAC was ranked 1st with the percentage score of 50.00 followed by A5-Location tracking & Human Activity Recognition and A1-Lighting & Electricity consumption management with the percentage scores of 44.00 and 37.14 respectively. The 4th, 5th, and 6th Internet of Things applications in smart buildings are A4-Crowd counting (12.86%), A2-Security & Crisis management (11.43%), and A7-Health Monitoring of Occupants & Building (10.00%). The least Internet of Things applications in smart buildings are A6-Home Appliances Automation (1.43%) and A8-Water consumption control (4.29%). According to Bhati *et al.* (2017), the following parameters can be seen in smart buildings: 1) appliance status, 2) occupancy, 3) utility usage, 4) activity tracking, and 5) user and contractor collaboration.

Figure 7 provides an illustration of the application of Internet of Things in smart buildings. Based on the analysis of journals presented in Section 3.2.1, the applications are categorized into two main groups: monitoring activities and automation activities.

Monitoring activities in smart buildings can provide building managers with several benefits such as optimizing building performance, reducing energy consumption and costs, and enhancing occupant comfort and safety. Kumar *et al*. (2021) reported the use of IoT for monitoring electrical appliances and HVAC to achieve energy efficiency. Automatic occupancy recognition, people counting, and occupant tracking for determining the comfort of occupants have been enabled by the use of IoT, as reported by Zou *et al*. (2018a) and Çiftler *et al*. (2018). Additionally, the IoT has facilitated the monitoring of indoor and outdoor environments in smart buildings, as highlighted by Bedi *et al*. (2020) and Floris *et al*. (2021). The data collected from the environment are utilized to optimize energy consumption and improve occupant comfort, as noted by Park and Rhee (2018). Furthermore, Jia *et al*. (2019) reported that the IoT enables remote operation and management of the entire life cycle of the structures for comfort, convenience, cost, and energy efficiency.

To enable monitoring activities in smart buildings, IoT sensor nodes and gateways are deployed for data collection and transmission to network and application servers. The collected data is then processed using machine learning and other artificial intelligence techniques (Balakumar *et al*., 2023). For instance, machine learning models can be used to determine energy usage patterns and forecast energy consumption. This involves training the machine model using accumulated data from IoT sensors.

Automation activities refer to the use of various IoT technological solutions to optimize and streamline building operations. Big data analysis is used to make decisions based on data acquired from the sensors. Smart control of devices in the building for fire, energy, and facility management is carried out using IoT technological solutions. Building appliances can be controlled remotely via data visualization from mobile or web applications. This is enabled by the transfer of data and network information between various sub-networks and communication technologies such as short-range (Wi-Fi and Bluetooth) and long-range (LoRa and Sigfox), as reported by Elijah *et al*. (2018).

Deploying IoT for monitoring and control activities can face some challenges, such as the extra cost of deploying IoT technologies such as sensor nodes, gateways, internet connectivity, and provision for uninterrupted power supply. Additionally, it requires building experts to have knowledge of how some of these technologies work and collaboration among different professional fields.

Table I. Metasynthesis of Internet of Things Applications in Smart Buildings

No	**Article**	**Year**	**Journal**	**IoT Applications in Smart Buildings**							
				A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
1	(Xu *et al.*, 2019)	2019	IEEE Int. of Things Journal	1							
2	(Hernández-Ramos *et al.*, 2015)	2015	Journal of Computer and System Sciences		1						
3	(Chiesa *et al.*, 2020)	2020	Automat. in Construction	1							
4	(Zou *et al.*, 2018a)	2018a	Energy and Buildings				1	1			
5	(Minoli *et al.*, 2017)	2017	IEEE Int. of Things Journal	1		1					
6	(Rahman *et al.*, 2020)	2020	IEEE Access							1	1
7	(Lin *et al.*, 2020)	2020	Energy and Buildings	1		1					
8	(Xiaoyi *et al.*, 2021)	2021	Environmental Impact Assessment Review	1		1					
9	(Zou *et al.*, 2018b)	2018 b	Energy and Buildings					1			
10	(Plageras *et al.*, 2018)	2018	Future Generation Computer Systems			1					
11	(Metallidou *et al.*, 2020)	2020	IEEE Access			1					
12	(Spachos *et al.*, 2021)	2021	Comp. Sci. - Networking & Internet Architecture					1			

13	(Zafari *et al.*, 2015)	2015	IEEE Int. of Things Journal					1			
14	(Kumar *et al.*, 2021)	2021	Computer Communications	1	1	1		1			
15	(Salikhov *et al.*, 2016)	2016	IEEE	1	1	1					
16	(Sruthi, 2019)	2019	Int. J. of Emerging Tech. & Innov. Engineering	1			1	1			
17	(Shah and Mishra, 2016)	2016	Procedia Technology	1		1				1	
18	(Hu, 2014)	2014	Applied Mechanics and Materials	1		1					
19	(Atayero *et al.*, 2017)	2017	Lecture Notes in Eng. and Computer Science	1			1	1			
20	(Saralegui *et al.*, 2017)	2017	WSEAS Transactions on Env. and Development				1	1		1	
21	(Primiceri and Visconti, 2017)	2017	ARPN J. of Engineering and Applied Sciences	1						1	
22	(Park and Rhee, 2018)	2018	Journal of Sensors			1					
23	(Elkhoukhi *et al.*, 2018)	2018	Procedia Computer Science				1	1			
24	(Lilis and Kayal, 2018)	2018	Automation in Construction	1	1	1					
25	(Rahim *et al.*, 2018)	2018	IEEE Access	1		1					
26	(Marinakis and Doukas, 2018)	2018	Sensors (Switzerland)	1		1		1			
27	(Kim *et al.*, 2018)	2018	Building and Environment			1		1			
28	(Çiftler *et al.*, 2018)	2018	IEEE Internet of Things Journal				1	1			
29	(Sadowski *et al.*, 2020)	2018	IEEE Access					1			
30	(van Rensburg *et al.*, 2018)	2018	IEEE J. of Emerging & Selected Topics in Power Electronics	1							
31	(Sharma *et al.*, 2018)	2018	Journal of Sensor and Actuator Networks	1							
32	(Jung *et al.*, 2018)	2018	Sensors (Switzerland)					1			
33	(Ansari *et al.*, 2017)	2017	J. of Inf. Technology Management	1	1	1			1		
34	(Ateeq *et al.*, 2019)	2019	Sensors (Switzerland)			1					
35	(Salih and Kuan, 2019)	2019	ARPN J. of Engineering and Applied Sciences					1			
36	(Liu *et al.*, 2019)	2019	IEEE Internet of Things Journal	1				1			
37	(Rashid *et al.*, 2019)	2019	Automation in Construction	1				1			
38	(Aryal *et al.*, 2019)	2019	Frontiers in Built Environment			1		1		1	
39	(Aguilera *et al.*, 2019)	2019	Journal of Building Engineering			1					
40	(Guidara *et al.*, 2019)	2019	Ad Hoc Networks					1			
41	(Spencer *et al.*, 2019)	2019	Personal and Ubiquitous Computing			1					
42	(Ha and Phung, 2019)	2019	IET Smart Cities	1							
43	(Shah *et al.*, 2020)	2020	IEEE Access	1		1				1	
44	(Carli *et al.*, 2020)	2020	Sensors (Switzerland)			1					

45	(Xu *et al.*, 2020)	2020	Computer Communications			1					
46	(Wu *et al.*, 2020)	2020	Sensors and Materials			1					
47	(Ahmadi *et al.*, 2020)	2020	Sustainability (Switzerland)	1		1					
48	(Bedi *et al.*, 2020)	2020	IEEE Internet of Things Journal			1					
49	(Kosovic *et al.*, 2020)	2020	Journal of Cleaner Production	1		1					
50	(Sadowski *et al.*, 2020)	2020	IEEE Internet of Things Journal					1			
51	(Chiesa *et al.*, 2020)	2020	Automation in Construction	1							
52	(Shirsat and Bhole, 2021)	2021	International Journal of Information Technology (Singapore)			1					
53	(Varma and Anand, 2021)	2021	Wireless Personal Communications					1			
54	(Anastasi *et al.*, 2021)	2021	Energies			1					
55	(Floris *et al.*, 2021)	2021	Energies			1	1	1			
56	(Elnour *et al.*, 2021)	2021	Sustainable Cities and Society		1	1					
57	(Talei *et al.*, 2021)	2021	Energies			1					
58	(Zhong *et al.*, 2021)	2021	IEEE Internet of Things Journal				1	1			1
59	(Khoche *et al.*, 2021)	2021	SN Computer Science		1			1		1	
60	(Fang *et al.*, 2021)	2021	Buildings							1	
61	(Li *et al.*, 2021a)	2021	Automation in Construction			1					
62	(Tekler *et al.*, 2022)	2022	Building and Environment			1	1	1			
63	(Wu *et al.*, 2022)	2022	Building and Environment					1			
64	(Imran *et al.*, 2022)	2022	Energy and Buildings	1		1					
65	(Xu *et al.*, 2022)	2022	Building and Environment	1							
66	(Li *et al.*, 2022)	2022	Building and Environment	1							
67	(Andrić et al., 2022)	2022	Journal of Cleaner Production								1
68	(Kumar *et al.*, 2022)	2022	Sustainable Energy Technologies and Assessments	1							
69	(Yasuoka et al., 2023)	2023	International Journal of Sustainability in Higher Education	1		1					
70	(Balakumar et al. 2023)	2023	Sustainable Cities and Society	1							
			Total	31	7	35	9	26	1	8	3

Notes: **A1**-Lighting & Electricity consumption management, **A2**-Security & Crisis management, **A3**-Heating, ventilation and air conditioning System- HVAC, **A4**-Crowd counting, **A5**-Location tracking & Human Activity Recognition, **A6**-Home Appliances Automation, **A7**-Health Monitoring of Occupants & Building, **A8**-Water consumption control; ‘‘1” means the article is related to the information in the corresponding section, T =Total

Source (s): Table by authors

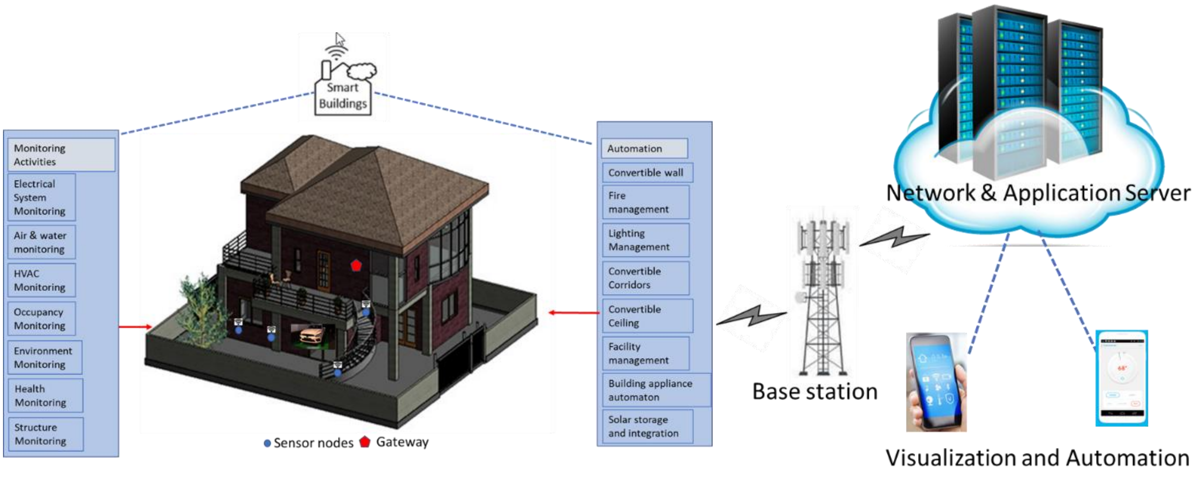

Figure 7. Illustration of Internet of Things applications in a Smart Building
Source (s): Figure by authors

Conclusions

The study identified two cycles for "Internet of Things" and "Smart Building" research based on the yearly publication volume. Internet of Things and Smart Buildings have drawn considerable scholarly interest since 2013, and the volume of publications has grown in a quasilinear pace each year. The average annual publication between 2013 and 2023 is 105 documents. The United States, India, China, France, and the United Kingdom are the top countries with the highest volume of publications in this field of research. The makeup of the five clusters of "Internet of Things" and "smart building" research is significantly influenced by their geographic location and revealed several themes through the keyword analysis. The study, which further identifies and illustrates IoT applications in a smart building can serve as a foundation for future research into IoT-enabled smart buildings as a starting point for policymakers to identify key themes in this field.

Despite the significance of this work, there are certain limitations. Most of the research utilised in the study came from the Scopus database with only English-language studies. The mixed review technique and scientific mapping using the "VOSviewer" software were the central points of this review. The status of "Internet of Things" and "Smart Building" might be examined further to see whether more research is required to overcome these limitations. These limitations indeed exist but have little impact on how current "Internet of Things" and "Smart Building" research is moving forward.

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