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Smart home and internet of things: A bibliometric study

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ABSTRACT

Background: The Internet of Things provides access to information anywhere at any time on any device and has changed all domains by addressing a variety of problems in society through real-time information from interconnected devices. Among these domains, smart homes are one of the most important areas that have been significantly affected by the Internet of Things. Smart homes connected to the IoT have led to the creation of the new domain, namely, smart home-Internet of Things.

Scope and approach: A bibliometric approach was followed in this study to analyze research articles in the smart home-Internet of Things area, by extracting papers presented at notable international conferences and published in respected journals. This study collects 2339 articles from the SCOPUS database, which were published from 2015 to 2019.

Findings: Publication trends, key areas, influential articles, publication venues, and several notable topics related to smart home-Internet of Things were explored. Moreover, this study confirms that there are notable improvements and developments in the area of smart home-Internet of Things, as well as smart home and Internet of Things.

Implications: The findings presented herein offer notable insights and emphasize learning points for future directions of smart home-Internet of Things. Moreover, both key trends and knowledge domains of smart home-Internet of Things were presented.

1. Introduction

Smart homes have attracted increasing interest from the viewpoints of both energy efficient construction and comfortable living. The availability of a number of ICTs and energy technologies enables residents to conveniently integrate technologies and services in their houses. A smart home is "*a residential environment with information and communication technologies, which provide suitable functions for the residents' convenience, security, entertainment, and comfort needs*" (Marikyan et al., 2019). The main concept of a smart home is the employment of well-designed management functions that provide residents with the ability to optimally control the maintenance of their houses.

The integration of recent and modern ICT and energy technologies in the housing context offers strong potential for new services and applications (Shapsough and Zualkernan, 2019). Among such technologies, ubiquitous computing technologies, which enable all objects to be connected anywhere and at any time, use tiny sensors to provide information to entire network systems to make the users form part of an all-connected-network. This means that the users are part of a system of interconnected computing machines for sending and receiving data via a network without traditional forms of communication. This is the main concept behind the IoT. Based on the IoT environment, users can interact with various devices and services in smart homes (Neagu et al., 2017).

Wang et al. (2021) conceptualized the fields of IoT, and extracted wireless sensor networks, and IoT security/privacy as the mainstreams of IoT. Then, they indicated that the emergence and applications of IoT have been consistently magnified in smart environments (e.g. smart city and smart home).

Singh et al. (2020) provided an overview of the emerged topics of IoT and farming. Based on the findings of a bibliometric analysis, the impacts of IoT on agricultural research have been tremendously grown. Moreover, they indicated that using IoT technologies and applications allow agricultural researchers to have an opportunity for exploring new research areas.

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Nomenclature

#	Number
CCIS	Communications in Computer and Information Science
ICT	Information and Communication Technologies
IoT	Internet of Things
LNCS	Lecture Notes in Computer Science
LNEE	Lecture Notes in Electrical Engineering
LNICST	Lecture Notes of the Institute for Computer sciences, Social informatics and Telecommunications engineering
SHIoT	Smart Home IoT

Because IoT has consistently affected and reshaped our society such as urban areas, farming, transportation, housing environments and healthcare systems, utilizing IoT into smart home areas establishes an unique domain of smart home with IoT (SHIoT).

Smart homes and the IoT have consistently affected our lives via services that are connected anywhere and at any time. Given this trend, several scholars have argued that a smart home, which is defined as "*the network of physical devices that provide electronic, sensor, software, and network connectivity inside a home*" (Alaa et al., 2017), is an IoT domain because it integrates home automation systems with the IoT. Smart home systems consist of a large number of sensors and switches that are connected to the main gateway, which is the main control system users access via their digital devices such as smartphones, or desktop personal computers (Galinina et al., 2015).

Khalaf et al. (2019) examined notable approaches to apply the concept of the IoT to smart home applications. This implies that new emerging markets and research areas, such as the SHIoT, are presented as upcoming research areas. Several studies investigated the utilization of IoT services and products in smart home environments and the elimination of technical and related applicable problems hindering the diffusion of SHIoT, and considered methods to improve both the efficiency and feasibility of implementing SHIoT (Park et al., 2017).

Thus, the current study aims to present notable insights into future research areas by understanding the current status and research environments. This approach can shed light on the contributions and efforts of researchers in the areas of SHIoT, provide an overview of coherent research trends, and reveal emerging features and directions of SHIoT. This paper presents a bibliometric analysis of research articles related to SHIoT based on several research points.

The remainder of this paper is organized in the following structure: The overview of a bibliometric analysis is examined. After the study methodology with the research topics is described, the results of the bibliometric analysis are presented. The implications are then discussed, followed by a description of the limitations of the study and the concluding remarks.

2. Bibliometric analysis

Bibliometric analysis, which is defined as "*a part of scientometrics for utilizing mathematical and statistical methods to analyze scientific activities in a research field*" (Aparicio et al., 2019), is one of the innovative techniques for providing the current trends and improvements of specific knowledge domains. It is employed to explain the developments and extent of the selected knowledge areas (Kim et al., 2021).

Bibliometric analysis presents a bird's-eye view of a specific knowledge field, which is categorized by articles, sources, authors, nations and categories (Merigó and Yang, 2017). In general, there are two leading approaches of bibliometric analyses, graphical mapping and performance analysis (Aparicio et al., 2019). Among them, the current study employs the performance analysis for presenting the number of scientific production including the numbers of publications, citations, related organizations, and so on (Yu and Liao, 2016). Table 1 shows the list of prior studies, which employed a bibliometric analysis with consideration of smart home and IoT.

Among the articles in the list (Table 1), the following references are notable academic foundations of the current study with the development of SHIoT.

- Kamran et al. (2020): an examination of the blockchain and IoT domain with considerations of 151 articles extracted by Web of Science.
- Huang et al. (2018): an analysis of a number of articles from 2000 to 2018 in smart health domain with Web of Science.
- Grooby et al. (2019): an investigation of 906 academic articles indexed by Web of Science from 2008 to 2017, which addressed both authentication and access control issues in IoT devices.
- Muhuri et al. (2019): an examination of industry 4.0 issues including IoT and smart cities with 194 (Web of Science), and 1425 documents (Scopus).

3. Study methodology

The study methodology comprises four stages: presentation of the research questions, data gathering, preprocessing, and data analytics. All the procedures and approaches are validated and reflect prior research pertaining to the IoT and bibliometric analysis (Kamran et al., 2020).

3.1. Research topics

The purpose of the study is to use a bibliometric approach to examine SHIoT articles listed in the Scopus database. This was achieved by addressing the following aims, which were generated on the basis of existing bibliometric research studies on smart homes and IoT (Ruiz-Rosero et al., 2017; Stojkoska and Trivodaliev, 2017; Nobre and Tavares, 2017):

- **Trend of publications on SHIoT**: to identify future research areas of SHIoT;
- **Key research areas of SHIoT**: to present the current status of research efforts in each area of SHIoT, considering the number of articles;
- **Influential articles in SHIoT**: to aid the research design and the methodologies that were employed and presented by well-defined studies in SHIoT based on the number of citations per article;
- **Popular venues for SHIoT articles**: to determine the most suitable journals for SHIoT articles and increase the number of future citations;
- **Countries and funding agencies that support SHIoT research**: to help researchers start collaborations or initiate SHIoT research; and
- **Future directions of SHIoT research**: to help researchers explore and define research statements related to SHIoT.

Table 1
The list of prior bibliometric research on smart home and IoT.

Year (Source)	Relevance to IoT	Relevance to smart home	Specific domain	Number of collected articles
2016 (Gunasekaran et al., 2016)	High	Low	Network science	923
2017 (Mora et al., 2017)	Medium	Medium	Smart city	1,067
2017 (Ben-Daya et al., 2019)	High	Low	Supply chain management (SCM)	166
2018 (Cobo et al., 2018)	Medium	Medium	industry 4.0	333
2018 (Huang et al., 2018)	Low	High	Smart health	6291
2019 (Bouzembrak et al., 2019)	High	Low	Food safety	927
2019 (Grooby et al., 2019)	High	Medium	Authentication/access control	906
2019 (Parlina et al., 2019)	Medium	High	Smart city	201
2019 (Muhuri et al., 2019)	High	Medium	industry 4.0	1,425
2020 (Wang et al., 2020)	Low	Medium	Smart grid	3,558
2020 (Janik et al., 2020)	Medium	High	Smart and sustainable city	5,976
2020 (Moreno-Guerrero et al., 2020)	High	Low	Edge computing	1,171
2020 (Rejeb et al., 2020)	High	Low	SCM/logistics	807
2020 (Kamran et al., 2020)	High	Low	Blockchain	157

3.2. Data gathering/preprocessing

The aforementioned research aims were addressed by employing the Scopus database, a leading abstract and citation database that indexes influential peer-reviewed research papers. Appropriate query terms were then constructed to extract research articles resorting under each of the aforementioned categories (Table 2). Based on several prior studies on IoT and bibliometric analysis (Kamran et al., 2020; Firdaus et al., 2019; Muhuri et al., 2019), five years were selected as the data gathering period. After entering multiple term-sets for the period of January 2015 to December 2019, we extracted the title, authors, keywords, source title, publication data, research supporting agencies, topic, area, and abstract.

We excluded editorial materials from the analysis, considering prior bibliometric studies (Hönekopp and Khan, 2012; Haslam and Lusher, 2011; Vogel, 2012). Moreover, all the abbreviations in the collected sections were replaced by their full definitions. Then, four experts in computer science, smart home and IoT conducted a filtering procedure to explore whether each article addresses IoT, smart home, or SHIoT.

3.3. Data analytics

After data preprocessing, we investigated the current trends in terms of academic articles, sections, well-employed publishing venues, leading organizations, countries, and agencies that support SHIoT research. Moreover, both the citations and keywords of SHIoT articles were analyzed.

4. Bibliometric investigation

This section describes the design of the research method we used to respond to each research question in Section 3.1. First, publication trends of SHIoT research are considered. Table 3 presents the total number of research articles as a function of time in the fields of SHIoT, smart homes, and IoT. From 2015 to 2019, 2339, 6689, and 56,016 articles were published in the areas of SHIoT, smart homes, and IoT, respectively. Although the percentage of SHIoT articles in the IoT domain remained constant, that of SHIoT articles in the smart home domain significantly increased from 2015 (18.43%) to 2019 (43.70%). This indicates that the number of articles concerning smart homes remained constant, whereas the number of articles covering SHIoT research increased from 2015 to 2019 (by more than 4.5 times). The social and industrial effects of smart home and IoT domains are increasingly becoming important, and the importance of SHIoT has also increased in both domains (Table 3).

Second, we explored the academic categories to which articles relating to SHIoT belong. As presented in Fig. 1, the leading category is “Computer Science” with 1890 articles (80.8%). This is followed by “Engineering” with 1093 articles (46.7%). In addition to these two categories, both “Mathematics” (363 articles, 15.5%) and “Physics and Astronomy” (257 articles, 11.0%) are other notable categories concerned with SHIoT. Table 4 lists the interdisciplinary research areas associated with SHIoT. This trend has its origins in the characteristics of IoT and smart homes, and shows that eight categories (“Computer Science,” “Engineering,” “Mathematics,” “Energy,” “Physics and Astronomy,” “Social Sciences,” “Decision Sciences,” and “Medicine”) constitute more than 5% of the total number of articles associated with IoT and smart homes, respectively (Fig. 1).

Third, the top 10 resources for articles associated with SHIoT (Fig. 2), smart homes, and IoT are presented in Table 5. *LNCS*, *ACM International Conference Proceeding Series*, and *Advances in Intelligent Systems and Computing* are the general venues for the most notable proceedings of international conferences on SHIoT, IoT, and smart homes, whereas the *IEEE Internet of Things Journal*, *IEEE Access*, and *Sensors* are popular journals targeted by those who are active in these areas.

Fourth, the top research countries and funding agencies appear in Table 6. Researchers in China published the most articles on IoT (9226, 16.47%), whereas the United States produced the highest number of publications on smart homes (938, 14.02%). Along with research on smart homes, the United States was the most productive with respect to SHIoT (346, 14.79%). Table 7 lists the top

Table 2
Selection criteria and search query.

Category	Description
Selection Standard	**Document Type**: “Article” OR ‘Book Chapter” OR “Data Paper” or ‘Early Access” **Language**: “English” **Publication Year**: “2019” OR ‘2018″ OR “2017” OR “2016” OR “2015″
Search Query	**SHIoT**: (“smart home”) AND (“internet of things” OR “IoT” OR “internet of thing” OR “IoTs”) **smart home**: “smart home” **IoT**: “internet of things” OR “IoT” OR “internet of thing” OR “IoTs”

Table 3
Total number and time trend of SHIoT research within the domains of smart homes and IoT.

Year	Total # of SHIoT articles	Ratio of SHIoT articles in IoT domain	Total # of IoT articles	Ratio of SHIoT articles in smart home domain	Total # of smart home articles
2015	157	3.92%	4,005	18.43%	852
2016	322	4.45%	7,231	27.90%	1,154
2017	478	4.34%	11,004	35.78%	1,336
2018	667	4.12%	16,182	38.98%	1,711
2019	715	4.06%	17,594	43.70%	1,636

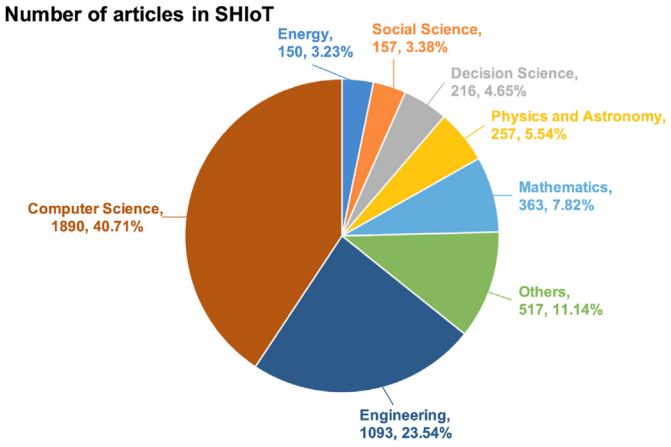

Fig. 1. Categories of articles concerned with SHIoT and the proportion of articles they contain.

research funding and supporting agencies that offer the most funding programs in SHIoT, IoT, and smart homes. Two agencies in the list are from China and administer 102 programs for research funding, and 165 programs are run by four agencies that provide research funding in South Korea. Table 8 presents a list of top research organizations working in SHIoT areas, based on the number of articles published. Three South Korean organizations, the Electronics and Telecommunications Research Institute (27), Kyungpook National University (21), and the Korea Advanced Institute of Science and Technology (16) published a total of 64 articles in SHIoT areas.

Fifth, a citation analysis was conducted and the results are presented in Table 9, which lists the most-cited articles in the areas of SHIoT. The article that attracted the most citations overall is concerned with edge computing, a core paradigm on distributed computational paradigms in smart objects within the IoT environment (Shi et al., 2016). After this article appeared in 2016, it attracted 1165 citations from 2016 to 2019. The paper with the second highest number of citations reports the use of blockchain technologies to address security and privacy issues of IoT in the smart home environment (Dorri et al., 2017b). This article was

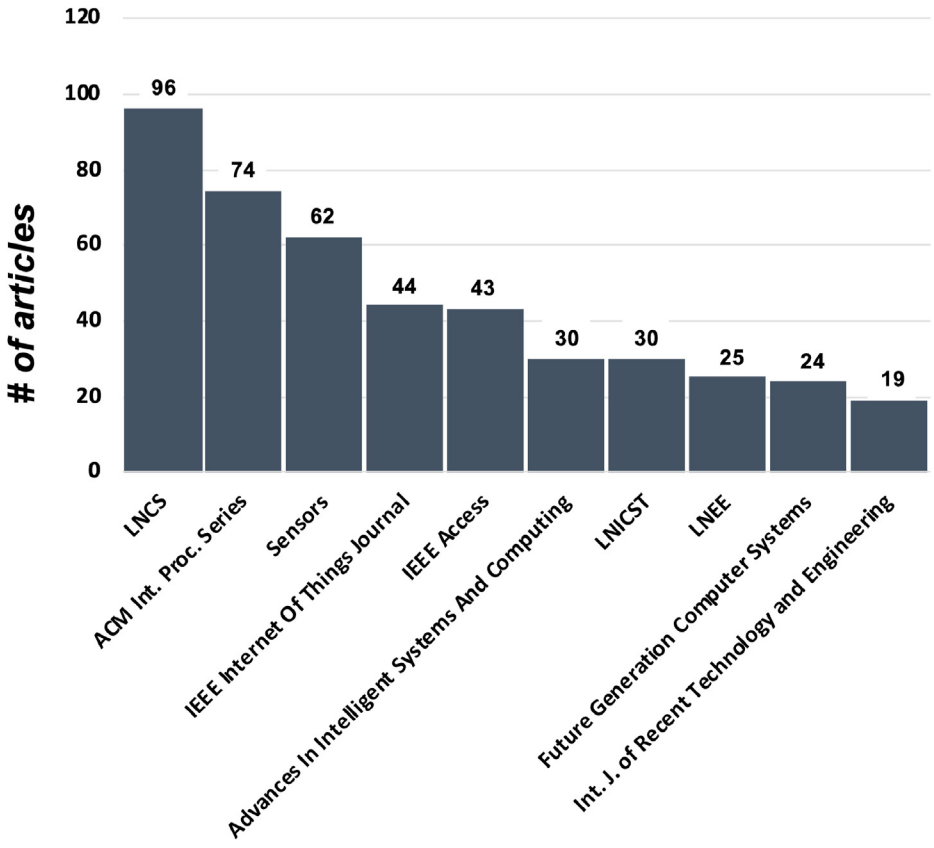

Fig. 2. Top resources for SHIoT articles.

Table 4
Categories of subject areas relating to articles concerned with SHIoT, including IoT and smart homes.

SHIoT			smart home			IoT		
Subject area	# of articles	Proportion	Subject area	# of articles	Proportion	Subject area	# of articles	Proportion
Computer Science	1,890	80.80%	Computer Science	4,916	73.49%	Computer Science	43,658	77.94%
Engineering	1,093	46.73%	Engineering	3,214	48.05%	Engineering	26,038	46.48%
Mathematics	363	15.52%	Mathematics	1,172	17.52%	Mathematics	8,405	15.00%
Physics and Astronomy	257	10.99%	Energy	687	10.27%	Physics and Astronomy	6,134	10.95%
Decision Sciences	216	9.23%	Physics and Astronomy	673	10.06%	Decision Sciences	5,360	9.57%
Social Sciences	157	6.71%	Social Sciences	471	7.04%	Social Sciences	4,070	7.27%
Energy	150	6.41%	Decision Sciences	451	6.74%	Materials Science	3,793	6.77%
Materials Science	97	4.15%	Medicine	335	5.01%	Energy	3,127	5.58%
Biochemistry, Genetics and Molecular Biology	77	3.29%	Materials Science	282	4.22%	Business, Management and Accounting	2,393	4.27%
Business, Management and Accounting	77	3.29%	Biochemistry, Genetics and Molecular Biology	197	2.95%	Chemistry	1,754	3.13%
Chemistry	77	3.29%	Environmental Science	183	2.74%	Medicine	1,577	2.82%
Medicine	76	3.25%	Business, Management and Accounting	173	2.59%	Biochemistry, Genetics and Molecular Biology	1,352	2.41%
Environmental Science	39	1.67%	Chemistry	165	2.47%	Environmental Science	1,106	1.97%
Chemical Engineering	19	0.81%	Health Professions	77	1.15%	Chemical Engineering	631	1.13%
Health Professions	13	0.56%	Chemical Engineering	73	1.09%	Health Professions	623	1.11%
Agricultural and Biological Sciences	8	0.34%	Arts and Humanities	67	1.00%	Earth and Planetary Sciences	423	0.76%
Economics, Econometrics and Finance	7	0.30%	Psychology	64	0.96%	Economics, Econometrics and Finance	343	0.61%
Multidisciplinary	7	0.30%	Neuroscience	29	0.43%	Agricultural and Biological Sciences	340	0.61%
Psychology	6	0.26%	Agricultural and Biological Sciences	27	0.40%	Arts and Humanities	186	0.33%
Arts and Humanities	4	0.17%	Earth and Planetary Sciences	27	0.40%	Multidisciplinary	169	0.30%
Earth and Planetary Sciences	4	0.17%	Multidisciplinary	27	0.40%	Psychology	111	0.20%
Neuroscience	4	0.17%	Nursing	26	0.39%	Pharmacology, Toxicology and Pharmaceutics	94	0.17%
Immunology and Microbiology	2	0.09%	Economics, Econometrics and Finance	21	0.31%	Neuroscience	85	0.15%
			Pharmacology, Toxicology and Pharmaceutics	8	0.12%	Nursing	23	0.04%
			Immunology and Microbiology	3	0.04%	Immunology and Microbiology	18	0.03%
						Veterinary	5	0.01%
						Dentistry	4	0.01%
						Undefined	2	0.004%

Table 5
Top sources of articles relating to SHIoT, smart homes, and IoT.

SHIoT		smart home		IoT	
Title	# of articles	Title	# of articles	Title	# of articles
LNCS	96	LNCS	327	LNCS	1,867
ACM International Conference Proceeding Series	74	ACM International Conference Proceeding Series	185	ACM International Conference Proceeding Series	1,629
Sensors	62	Sensors	131	IEEE Internet Of Things Journal	1,247
IEEE Internet Of Things Journal	44	Advances In Intelligent Systems And Computing	112	IEEE Access	1,223
IEEE Access	43	IEEE Access	87	Sensors	1,008
Advances In Intelligent Systems And Computing	30	LNEE	62	Advances In Intelligent Systems And Computing	790
LNICST	30	LNICST	59	LNICST	771
LNEE	25	Energies	52	CCIS	607
Future Generation Computer Systems	24	IEEE Internet Of Things Journal	51	Procedia Computer Science	535
International Journal Of Innovative Technology And Exploring Engineering	19	CCIS	48	Proceedings of the International Workshop On Structural Health Monitoring	420

published in 2017, and generated in 327 citations. Interestingly, the most-cited articles were published by researchers from various countries, although the top five countries in terms of the number of articles concerned with SHIoT were responsible for more than 55% of the articles.

Sixth, a keyword analysis was conducted (Fig. 3). The top 20 keywords associated with SHIoT were identified after excluding the keywords “smart home” and “IoT.” Table 10 summarizes the most frequently employed keywords in SHIoT articles. The term “automation,” which is one of the most general concepts in academic research, is used most frequently (1978 times). Both intelligent buildings (1546) and domestic appliances (194) related to housing and construction areas are also present in the list, whereas the network-related terms “network security” (234), “internet” (189), and “security” (171) are often used as keywords. This indicates that the majority of recent research carried out in the SHIoT area is

Table 6
Countries that produce the most articles reporting research relating to SHIoT, IoT, and smart homes.

SHIoT			IoT			smart home		
Nations	# of articles	Proportion	Nations	# of articles	Proportion	Nations	# of articles	Proportion
United States	346	14.79%	China	9,226	16.47%	United States	938	14.02%
India	325	13.89%	United States	8,506	15.18%	China	841	12.57%
China	265	11.33%	India	7,598	13.56%	India	676	10.11%
South Korea	221	9.45%	United Kingdom	3,331	5.95%	United Kingdom	449	6.71%
United Kingdom	159	6.80%	South Korea	3,262	5.82%	Germany	412	6.16%
Germany	122	5.22%	Italy	3,056	5.46%	South Korea	411	6.14%
Taiwan	107	4.57%	Germany	2,594	4.63%	Italy	309	4.62%
Italy	104	4.45%	France	2,170	3.87%	France	268	4.01%
Australia	77	3.29%	Japan	1,835	3.28%	Canada	249	3.72%
France	63	2.69%	Spain	1,603	2.86%	Taiwan	214	3.20%

Table 7
Top research funding and supporting agencies for SHIoT, IoT, and smart homes.

SHIoT			smart home			IoT		
Supporting agencies	# of articles	Proportion	Supporting agencies	# of articles	Proportion	Supporting agencies	# of articles	Proportion
National Natural Science Foundation of China, China	85	3.63%	National Natural Science Foundation of China, China	3,899	6.96%	National Natural Science Foundation of China, China	286	4.28%
Ministry of Science, ICT and Future Planning, South Korea	60	2.57%	National Research Foundation of South Korea, South Korea	986	1.76%	National Science Foundation, US	114	1.70%
National Research Foundation of South Korea, South Korea	55	2.35%	Ministry of Science, ICT and Future Planning, South Korea	927	1.65%	National Research Foundation of South Korea, South Korea	104	1.55%
National Science Foundation, US	46	1.97%	National Science Foundation, US	925	1.65%	Ministry of Science, ICT and Future Planning, South Korea	98	1.47%
Ministry of Science and Technology, Taiwan	39	1.67%	Fundamental Research Funds for the Central Universities, China	767	1.37%	Ministry of Science and Technology, Taiwan	70	1.05%
Institute for Information and Communications Technology Promotion, South Korea	30	1.28%	European Commission, EU	606	1.08%	Fundamental Research Funds for the Central Universities, China	69	1.03%
Engineering and Physical Sciences Research Council, UK	21	0.90%	Ministry of Science and Technology, Taiwan	484	0.86%	Engineering and Physical Sciences Research Council, UK	63	0.94%
Ministry of Education, South Korea	20	0.86%	National Basic Research Program of China, China	435	0.78%	European Commission, EU	51	0.76%
Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil	19	0.81%	European Regional Development Fund, EU	417	0.74%	Ministry of Education, South Korea	45	0.67%
Fundamental Research Funds for the Central Universities, China	17	0.73%	Ministry of Education, South Korea	403	0.72%	European Regional Development Fund, EU	44	0.66%

Table 8
Top research organizations with the greatest number of articles relating to SHIoT.

Organization	# of articles
Electronics and Telecommunications Research Institute, South Korea	27
King Saud University, Saudi Arabia	23
Vellore Institute of Technology, India	21
Kyungpook National University, South Korea	21
University of New South Wales, Australia	20
National Chiao Tung University, Taiwan	18
COMSATS University Islamabad, Pakistan	17
CNRS Centre National de la Recherche Scientifique, France	14

mainly associated with security, automation, and network issues in the area of construction. In addition to this, smart or system-oriented keywords, “smart city” (151), “smart-home system” (103), “embedded systems” (95), and “learning systems” (94) show that systematic issues with intelligent approaches are other important research areas in SHIoT.

5. Discussion

This paper presents a bibliometric analysis of research articles related to SHIoT based on several research points. In this section, the results are discussed in terms of each of these points.

The analysis described herein reveals the current trend with respect to publications on SHIoT. The results show that the number of SHIoT articles published annually is currently increasing. In 2015, only 157 articles were published, whereas more than 700 articles appeared in 2019. Moreover, in 2015, articles related to smart homes amounted to 18.43% of all of those in the SHIoT context and this proportion increased to approximately 44% in 2019. This indicates that SHIoT has become a significant emerging topic in the smart home domain in recent years.

The SHIoT research areas of key importance are listed in Table 4. All articles are classified based on the categories suggested by Scopus. Naturally, “Computer Science” (1,980, 80.80%) and

Table 9
Most-cited articles by researchers focusing on SHIoT.

Authors	Title	Year	Source title	Cited by	Country
Shi W., Cao J., Zhang Q., Li Y., Xu L.	Edge Computing: Vision and Challenges	2016	IEEE Internet of Things Journal	1,165	United States
Dorri A., Kanhere S.S., Jurdak R., Gauravaram P.	Blockchain for IoT security and privacy: The case study of a smart home Dorri et al., 2017b	2017	2017 IEEE International Conference on Pervasive Computing and Communications Workshops, PerCom Workshops 2017	327	Australia
Risteska Stojkoska B.L., Trivodaliev K.V.	A review of Internet of Things for smart home: Challenges and solutions Stojkoska and Trivodaliev, 2017	2017	Journal of Cleaner Production	295	Macedonia
Khan M.A., Salah K.	IoT security: Review, blockchain solutions, and open challenges (Khan and Salah, 2018)	2018	Future Generation Computer Systems	256	Pakistan and United Arab Emirates
Díaz M., Martín C., Rubio B.	State-of-the-art, challenges, and open issues in the integration of Internet of things and cloud computing (Díaz et al., 2016)	2016	Journal of Network and Computer Applications	254	Spain
Rathore M.M., Ahmad A., Paul A., Rho S.	Urban planning and building smart cities based on the Internet of Things using Big Data analytics (Rathore et al., 2016)	2016	Computer Networks	236	South Korea
Rahmani A.M., Gia T.N., Negash B., Anzanpour A., Azimi I., Jiang M., Liljeberg P.	Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach (Rahmani et al., 2018)	2018	Future Generation Computer Systems	207	United States, Austria and Finland
Perera C., Liu C.H., Jayawardena S.	The Emerging Internet of Things Marketplace from an Industrial Perspective: A Survey (Perera et al., 2015)	2015	IEEE Transactions on Emerging Topics in Computing	180	Australia and China
Dorri A., Kanhere S.S., Jurdak R.	Towards an optimized blockchain for IoT (Dorri et al., 2017a)	2017	Proceedings - 2017 IEEE/ACM 2nd International Conference on Internet-of-Things Design and Implementation, IoTDI 2017 (part of CPS Week)	156	Australia
Kaiwartya O., Abdullah A.H., Cao Y., Altameem A., Prasad M., Lin C.-T., Liu X.	Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects (Kaiwartya et al., 2016)	2016	IEEE Access	152	Malaysia, United Kingdom, Saudi Arabia, Taiwan and China

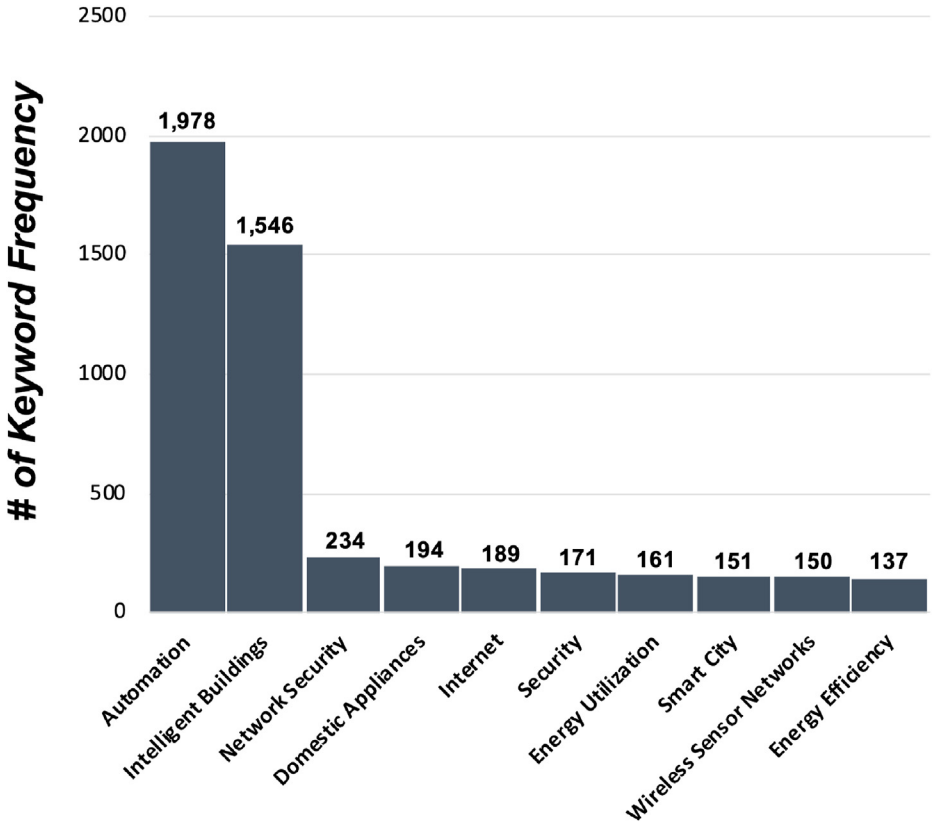

Fig. 3. Top keywords used in SHIoT articles.

Table 10
Top keywords employed in research papers.

Keyword	Frequency count	Ratio
Automation	1,978	16.42%
Intelligent Buildings	1,546	12.83%
Network Security	234	1.94%
Domestic Appliances	194	1.61%
Internet	189	1.57%
Security	171	1.42%
Energy Utilization	161	1.34%
Smart City	151	1.25%
Wireless Sensor Networks	150	1.24%
Energy Efficiency	137	1.14%
Data Privacy	124	1.03%
Big Data	120	1.00%
Network Architecture	119	0.99%
Artificial Intelligence	114	0.95%
Authentication	110	0.91%
Gateways (computer networks)	107	0.89%
Smart Home Systems	103	0.85%
Home Automation	99	0.82%
Embedded Systems	95	0.79%
Learning Systems	94	0.78%
Others	6,053	50.24%

"Engineering" (1,093, 46.73%) are the most notable research areas of SHIoT, similar to the results obtained for smart homes and the IoT. Interestingly, "Decision Sciences" is one of the top listed research areas for SHIoT articles. This implies that customers consider SHIoT as a service that provides various useful functions to enhance their lives.

The most-cited articles in SHIoT are presented in Table 9. "*Edge Computing: Vision and Challenges*" authored by Shi, Cao, Zhang, Li, and Xu is the most-cited article relating to SHIoT (1165, February 1, 2020) (Shi et al., 2016) and was published in the *IEEE Internet of Things Journal* in 2016. Three studies were reported by researchers in China, whereas two studies were produced by Australia. Moreover, the sources of the most-cited articles do not overlap, indicating that SHIoT is a multidisciplinary research area.

The top 10 venues for SHIoT articles are provided in Table 5. Both *Lecture Notes in Computer Science* (LNCS, 96) and *ACM International Conference Proceeding Series* (74) are the most frequently used venues for researchers, because they are associated with a large number of international conferences focusing on smart homes and IoT.

The top funding agencies are presented in Table 7. Two Chinese agencies that support research, the National Natural Science Foundation of China and Fundamental Research Funds for the Central Universities, have supported more than 5% of articles related to SHIoT (355). Moreover, two government divisions and one supporting agency in South Korea have supported the research reported in more than 3.5% of articles concerned with SHIoT (247). The countries that have produced the most research related to SHIoT are the United States (346, 14.8%) and India (325, 13.9%). Two northeast Asian countries, China (265, 11.3%) and South Korea (221, 9.4%), are emerging with an increasing number of research outputs in SHIoT.

Based on the results, this study provides notable information on which to base future research of SHIoT. Table 10 reveals the core dimensions of SHIoT: network, household, systems, and security. The network dimension can be divided into several connection-oriented subcategories: wireless sensor networks, network architecture, internet, and gateways. Moreover, the security dimension covers hot topics such as network security, privacy, and authentication. The third key dimension is the household context, which includes domestic appliances, home automation, intelligent buildings, and energy efficiency. The last dimension, systems, includes smart home systems, embedded systems, and learning systems. In addition, multi-dimensional topics, which could be considered to form research directions of the future, are smart cities, artificial intelligence, big data, and energy utilization. Thus, in the SHIoT area, multi-dimensional research is becoming more prominent.

6. Conclusion

The bibliometric approach used in this study indicated that SHIoT has become an emerging research area in the last five years, based on the number of articles and citations. Although the majority of SHIoT research articles were generated from within the disciplines of computer science and engineering, other research areas have also significantly focused on SHIoT. "*Edge Computing: Vision and Challenges*," which presents the concept of edge computing, trends, future research directions, and key issues relating to IoT in various contexts and was reported in the *IEEE Internet of Things Journal*, is the most cited and influential article in SHIoT (Shi et al., 2016). Naturally, computer science and engineering are the top research areas for SHIoT. However, mathematics, physics and astronomy, the decision sciences, and the social sciences are also major research disciplines associated with SHIoT. This signifies that researchers engaged in multidisciplinary research should be sought as collaborators to ensure successful research progress in SHIoT.

With respect to research venues, LNCS and ACM International Conference Proceeding Series, which are collections of articles presented at conferences, are considered the most visited for SHIoT research. This indicates that SHIoT is a rapidly advancing research area that relies on state-of-the-art technology.

Responding to the defined objectives, it is reported that the objective presented in this study have great interests in both researchers and organizations. These interests shed lights on the importance and growth of SHIoT, based on the findings and implications of the current study. Key implications are presented as follows:

- The effects and convergence of IoT have emerged to smart homes.
- The segmented and diverse research topics of smart homes and IoT have been magnified and presented.
- The majority of developed nations and leading affiliations in ICT play a leading role in SHIoT.

Moreover, the bibliometric investigations provides notable contributions to accelerating scientific and practical knowledge on SHIoT, since the concept of SHIoT created the direction for future research. Based on the implications provided by the analysis, this study provides several future research directions.

The rise of SHIoT has presented a number of opportunities for significantly affecting our society. First, the paradigms of IoT consistently affect the developments of SHIoT. Thus, applying newly developed IoT can change the future of smart homes and their effects on our society. It means that research on the integration between smart homes and IoT, and utilizing new IoT on smart home environments should be considerably and consistently highlighted.

Second, other technical issues including artificial intelligence and data science can be applied to SHIoT. Because a number of machine learning and deep learning techniques fully affect our society, the techniques can also contribute to the future research issues in SHIoT. It means that the rapid growth and developments of data science and artificial intelligence techniques allow future researchers to utilize a huge amount of undefined new dataset for

SHIoT contexts.

Third, both standardization and globalization are consistently enhanced. Currently, two leading nations, the United States and China, play a notable role in vitalizing the contexts of SHIoT. Because the complexity of scientific research makes academic researchers to eliminate a number of obstacles in future research, the trend of international cooperation and scientific relationships is inevitable and strengthened. In case of the consistent developments for SHIoT, nations, organizations and scholars have to work together for addressing the limitations and challenges.

Although the results of this study are based on the Scopus dataset, certain limitations remain. First, the study relies on a single research database; thus, other important research articles or venues associated with SHIoT may have been excluded. Future research would therefore need to include other research databases (e.g., Web of Science). Second, domestic publications were not considered in the analysis. Because researchers from several nations have English as their first language, the number of publications from these countries may be large. Future research would have to additionally include domestic research databases. For instance, we employ additional and associated research topics with SHIoT (e.g. smart city and artificial intelligence).

CRediT authorship contribution statement

Wonyoung Choi: Investigation, Writing – original draft, Writing – review & editing. **Jisu Kim:** Resources, Writing – original draft, Writing – review & editing, Visualization. **SangEun Lee:** Data curation, Writing – review & editing. **Eunil Park:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2021.126908.

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