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BIG DATA IN SMART CITIES: A SYSTEMATIC MAPPING REVIEW

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Abstract

Big data is an emerging area of research and its prospective applications in smart cities are extensively recognized. In this study, we provide a breadth-first review of the domain "Big Data in Smart Cities" by applying the formal research method of systematic mapping. We investigated the primary sources of publication, research growth, maturity level of the research area, prominent research themes, type of analytics applied, and the areas of smart cities where big data research is produced. Consequently, we identified that empirical research in the domain has been progressing since 2013. The IEEE Access journal and IEEE Smart Cities Conference are the leading sources of literature containing 10.34% and 13.88% of the publications, respectively. The current state of the research is semi-matured where research type of 46.15% of the publications is solution and experience, and contribution type of 60% of the publications is architecture, platform, and framework. Prescriptive is least whereas predictive is the most applied type of analytics in smart cities as it has been stated in 43.08% of the publications. Overall, 33.85%, 21.54%, 13.85%, 12.31%, 7.69%, 6.15%, and 4.61% of the research produced in the domain focused on smart transportation, smart environment, smart governance, smart healthcare, smart energy, smart education, and smart safety, respectively. Besides the requirement for producing validation and evaluation research in the areas of smart transportation and smart environment, there is a need for more research efforts in the areas of smart healthcare, smart governance, smart safety, smart education, and smart energy. Furthermore, the potential of prescriptive analytics in smart cities is also an area of research that needs to be explored.

Keywords: Big data technology, Mapping review, Smart cities.

1. Introduction

Big Data Analytics (BDA) enables smart cities to acquire incredible insights from immense volume of data generated via heterogeneous sources such as Internet-of-Things (IoT) integrated sensors, Radio-Frequency Identification (RFID) tags, Global Positioning Systems (GPS), smartphones, Bluetooth devices, etc. [1]. The efficient utilization and analysis of big data are crucial success factors in smart cities and other service domains. With BDA, smart cities can effectually manage the waste collection, diminish air-pollution, improve the quality of healthcare and transportation, ensure efficient utilization of energy, undertake predictive safety measures, and construct effective governance strategies. The essential sectors of smart cities such as smart healthcare, smart education, smart environment, smart energy, smart transportation, smart governance, and smart safety have the potential to revolutionize the human lifestyle and living standard. Smart healthcare facilitates the real-time monitoring of patients health by gathering and analyzing data from sensors connected to patients to detect potential health issues and undertake timely actions.

The smart environment enables the cities to predict ecological conditions that could greatly assist in improving agriculture and eradicating pollution. With the presence of smart transportation, authorities can identify new mobility patterns by analyzing real-time data collected through on-vehicle devices, smart traffic lights, smartphones and other communication devices to reduce congestion and accidents. Smart education involves the analysis of large datasets that enable the practitioners to discover learners core areas of improvement. Smart governance empowers governments to identify the citizens' concerns related to social care, healthcare, education, housing, policing, etc. Through smart energy, governments can monitor the levels of energy usage to predict outage and to undertake efficient energy consumption plans. Smart safety assists in the prediction of natural disasters such as floods, earthquake, pollution, and storms on a daily or on-demand basis to save lives and resources [2]. The data generated in smart cities are analysed in real-time to make effective decisions and discover hidden patterns. The traditional data mining techniques have experienced challenges to analyze exponentially growing and rapidly generated data [3]. Governments have embraced Big Data Technologies (BDTs) in smart cities to achieve modern sustainability goals [2].

BDTs in smart cities is an emerging interdisciplinary research area that incorporates topics such as statistical methods, text and data analytics, business intelligence, decision automation, etc. [1]. At this stage, it is imperative to review, evaluate and identify gaps in the research domain. By applying the formal method of systematic mapping, we extracted certain attributes to address the research questions of this study by identifying and analyzing the research growth, leading publishers and maturity level of the research, type of analytics applied, and areas of smart cities where big data research is produced. The extracted attributes are recorded in the Appendix table. The research methodology employed in this research is based on the systematic mapping process applied by O'Donovan et al. [4] and Petersen et al. [5]. To the best of our knowledge, this is the first Systematic Mapping Review (SMR) in the domain of big data in smart cities that covers the breadth of research to unveil essential insights by addressing, analyzing and discussing results of the research questions discussed in section 2.2. The findings of this study could be used by the researchers to produce experiential research in the domain of big data in smart cities. The rest of this paper is organized as follows. Section 2 describes the research methodology by focusing on the entire systematic mapping process. Section 3 addresses the threats to the validity of the research. Section 4 presents the analysis of results. Section 5 concludes the research with a discussion on its limitations and future direction.

2. Research Methodology

SMR focuses on providing an extensive overview of a research domain. It discovers evidence on a research topic and determines its quantity [5]. SMR methodology was applied in this research because it provides a well-organized approach to synthesize information. It enabled us to report the breadth of research activities. The methodology of this research initiated by setting the research questions that served as the basis to start the succeeding steps. The main stages of the research methodology are further described in the following sub-sections.

2.1. The mapping process

This research is based on searching publications using the well-recognized literature sources such as IEEE Xplore, Springer Link, ACM Digital Library, Web of Science, Scopus, Science Direct, and Google Scholar. After trying several keywords, ‘Big data’ and ‘Smart cities’ were selected as the primary search terms to conduct the search process. However, wildcard symbol (*) was used with the string to broaden the search scope and to eliminate irrelevant publications. The search was only limited to journal and conference publications as they are mostly peer-reviewed as compared to sources such as book chapters, magazines, white papers, etc. As a result of the search process, 408 publications were retrieved from the databases as depicted in Table 1.

Table 1. Search results from the literature sources.

Database	Number of Publications
Scopus	92
Web of Science	62
IEEE Xplore	61
ACM Digital Library	48
Science Direct	55
Springer Link	51
Google Scholar	39

Furthermore, as shown in Fig. 1, after applying the exclusion filters, 49 papers were considered to be relevant which were further processed using the snowballing method to identify additional papers. We obtained 29 papers through the snowballing process which reduced to 16 after applying the exclusion filters. Consequently, the final list comprised of 65 papers. The exclusion filters applied in this research are stated as follows:

(a) Eliminate the duplicate and irrelevant publications that do not contain the words ‘big data’, ‘smart cities’, ‘smart transportation’, ‘smart education’, ‘smart governance’, ‘smart energy’, ‘smart safety’, ‘smart environment’ or ‘smart healthcare’ in their title, abstract or meta-data of the document.

(b) Eliminate the publications that do not focus on big data in smart cities as their primary research aim.

(c) Eliminate the publications that only discuss applications of big data in smart cities without contributing or appropriately investigating the research domain.

The purpose of applying exclusion filters was to identify the publications relevant to the scope of this research. The final list of publications was deeply analyzed to extract the required attributes that were accumulated, visualized and mapped in a method to address the research questions modeled for this study.

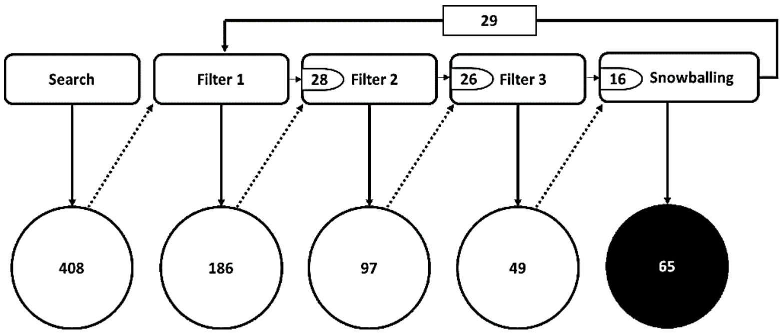

Fig. 1. The systematic mapping process.

2.2. Research questions

This research explored the use of BDTs in smart cities and focused on analyzing big data research contributions produced to assist smart cities in achieving sustainability goals. The guiding question of the research is stated as follows:

How are BDTs being used in smart cities?

The main question is broken down into four sub-questions to cover the breadth of research by considering the research aim. The sub-questions are described as follows:

2.2.1. What is the publication-fora relating to big data in smart cities?

The objective of this question is to illustrate the research growth timeline and to identify primary sources of literature in the domain. This question is based on the assumption that research growth is an indication of interest in the research area, and primary sources of the literature are the peer-reviewed conferences and journals with the highest frequency of publication.

2.2.2. What is the maturity level of the research domain?

The objective of this question is to illustrate the maturity level of the research area. Addressing this question will reveal the strengths and limitations of the domain that would provide an opportunity to the researchers for producing significant publications. The types of research and contribution determine the maturity level of the area [4]. In this research, we extracted the research type from the publications by considering the definition of each type such as validation, evaluation, solution, philosophical, opinion, and experience, provided by Wieringa et al. [6]. Based on those definitions, we assume that a domain with more publications of type philosophical and opinion that usually propose conceptual ideas is an indication of a new area of research. A domain with more publications of type experience and solution is an emerging or semi-matured area of research as such papers produce approaches with proof-of-concept and implementation. A domain with more publications of type validation and evaluation that produce novel contributions using well-defined methodologies is qualified to be a fully matured area of research.

Moreover, we analyzed this question by contribution type. Research can produce various types of contributions such as framework, model, methodology, theory, process, platform, architecture, tool, etc. [4]. In this research, the type of contribution was extracted from each publication by using a qualitative research method termed as Keywording [5]. The analysis of this question by contribution type is based on the assumption that a domain with more of early research contributions such as conceptual theories, architectures, and frameworks without supporting implementation is an indication of a new area of research. A domain with more contributions of type system architectures, frameworks, theories, and platforms with basic implementation or proof of concepts is a semi-matured area of research since such type of contributions are usually implemented to prove achievement of the objectives. A research domain with the high percentage of contributions such as models, methodologies, processes, and tools is qualified as a fully matured area of research as these contributions are thoroughly validated and evaluated.

2.2.3. What types of analytics are being applied in smart cities?

The objective of this question is to identify and analyze the importance of BDA in smart cities. The identification of the analytics type discussed in the research papers provides an understanding of various experiments being conducted, problems being solved or insights being unveiled. To address this question, we extracted the type of analytics applied or discussed from all the publications by using the classification scheme and definition of analytics types such as descriptive, predictive or prescriptive provided by Delen et al. [7]. We extracted the most advanced analytics type when a research paper discussed the application of multiple analytics types. For instance, if a paper applied all three types of analytics such as descriptive, predictive and prescriptive, the advanced level of analytics extracted would be prescriptive.

2.2.4. What are the current state and future direction of big data research in smart cities?

The objective of this question is to determine where and how big data research is produced in smart cities. The analysis of this question identifies the current state of research, highlights research themes, and recognizes the future avenues of research in the domain. Nuaimi et al. [2] identified the smart education, smart energy, smart environment, smart governance, smart healthcare, smart safety, and smart transportation as the main areas of smart cities where BDTs are used. We extracted area in smart cities from all the publications by considering the definitions provided by Nuaimi et al. [2].

3. Threats to Validity of Research

Likewise any secondary research process, there could be threats to the validity of this research. We undertook effective measures at each stage of the study to mitigate probable threats. The execution of a well-defined search strategy is one of the critical steps in conducting an SMR. Since this process is time-consuming and error-prone, it required careful planning and implementation. Although we formulated the search string after an in-depth discussion, there were chances of missing out the relevant papers if the search terms were not effective. We compared the results retrieved via automated search with the journal as well as conference archives to ensure the retrieval of most accurate papers. The selection of literature sources could also be a threat to validity if certain important sources were omitted. We selected the literature sources based on our prior research experience.

Moreover, we assume that omitted publications would be captured using indexing services such as Scopus and Web of Science or through snowballing. Although the exclusion filters were set to omit irrelevant papers, there was a probability of excluding relevant papers as well if criteria filters are not accurate enough. However, the precise search terms of this study 'big data' and 'smart cities' when used with synonyms and wildcard string reduced the chances of publications being omitted. Furthermore, the classification of research papers, i.e., extraction of required parameters from the papers was a critical step in this research as imprecise or biased extraction of data could lead to inaccurate analysis. To curb this threat, all the authors of this research were engaged in classifying the papers, and we compared the results generated from each author to identify the most appropriate parameters from the publications.

4. Results and Discussion

4.1. Research growth timeline and primary sources of publication

Figure 2 shows the annual growth of publications related to big data in smart cities. The results depict that interest in the research area has been emerging since 2013. The publications in 2014 and 2015 rapidly increased by 133.33% and 128.57%, respectively as compared to their preceding year. During the 2014 and 2015, the research growth was very high due to the newly gained popularity of the domain. With continuous growth in the domain, publications increased by 12.5% in 2016, and 16.66% in 2017 as compared to their preceding year. However, after the rapid emergence of publications in 2014 and 2015, the recent years 2016 and 2017 demonstrate research growth stability. It is important to mention that due to planned initiation of the research documentation, the search process was conducted until the mid of December 2017. Therefore, the research growth in 2017 is expected to be slightly higher than the results mentioned in Fig. 2.

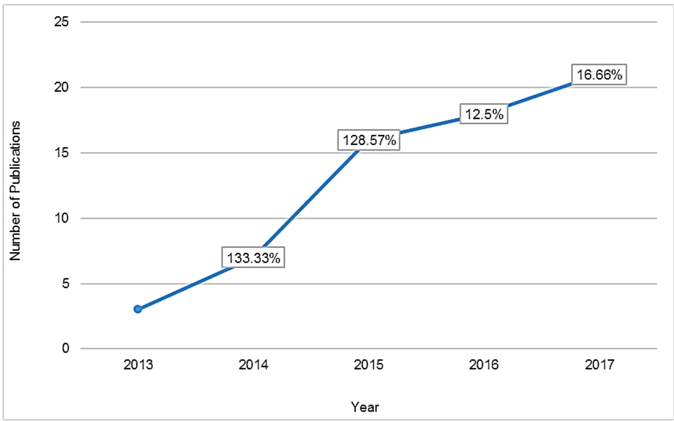

Fig. 2. Year-on-year growth.

Figure 3 portrays the analysis of publications by conference and journal types. The conference publications have surpassed the journal publications with inflation of 10.76%. From 2013 to 2017, 55.38% of the research, i.e., 36 papers were published in the conference proceedings, and 44.62% of the research, i.e., 29 papers were published in journals. The journal publications are directly proportional to the progress of research in the area. In 2017, 76.19% papers published in journals. Such progression portrays an increase in research interest and maturity level of contributions in the domain. Furthermore, four journals are responsible for publishing 9 papers, i.e., 31.03% of the research from the overall journal publications.

The IEEE Access is leading as the top journal with 10.34% of publications, followed by Future Generation Computer Systems, Big Data Research, and Sensors each publishing 6.89% of the research. The most current publisher of the big data research in smart cities is IEEE Access since all of its papers are published in 2017. A sample of papers published in the leading four journals focused on the following research themes:

- Providing improved crime rate predictions in smart cities [8].
- Enhancing the performance of mobile smart healthcare applications in a smart city environment [9].
- Enabling smart urban planning in smart cities using BDA [10].
- Reducing the emission of CO_2 and travel time by identifying congested routes [11].
- Integrating IoT with machine learning in smart cities for detecting traffic, and pollution generated from the vehicles [12].
- Big data for supporting low-carbon road transport policies in Europe [13].

Moreover, three conferences are responsible for publishing 9 papers, i.e., 25% of the research from the overall conference publications. The IEEE International Smart Cities Conference is leading as the top publisher with 13.88% of the publications followed by IEEE/ACM International Conference on Utility and Cloud Computing, and International Conference on Ambient Systems, Networks and Technologies, each publishing 5.55% of the research respectively. A sample of papers published in the leading three conferences focused on the following research themes:

- Applying smart learning environments in the context of smart city governance processes [14].
- Developing green and ecological cities with efficient use of energy [15].
- Using BDA to gain knowledge about road accidents [16].
- Implementation of a BDA system for the government to measure citizens' perception of security [17].
- A three-layer management system with an emphasis on bus transportation to support smart urban mobility [18].

It is imperative to mention that research in the domain of big data in smart cities exists before 2013. However, the results of this research are generated according to the exclusion filters that are well-established to achieve the aim of this research.

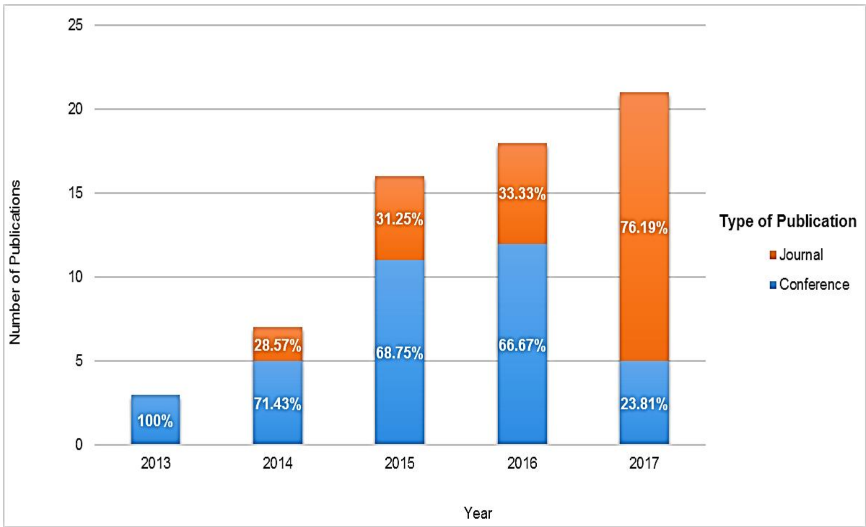

Fig. 3. Publications in journals and conferences.

4.2. Maturity level of the research domain

Figure 4 shows the classification of the publications by research type. The results depict that majority, i.e., 26.15% of the research conducted is of type solution followed by philosophical and experience with 24.61% and 20%, respectively. There is a lack of evaluation and validation type research that collectively comprise 29.23%. The 46.15% of the research is of type solution and experience.

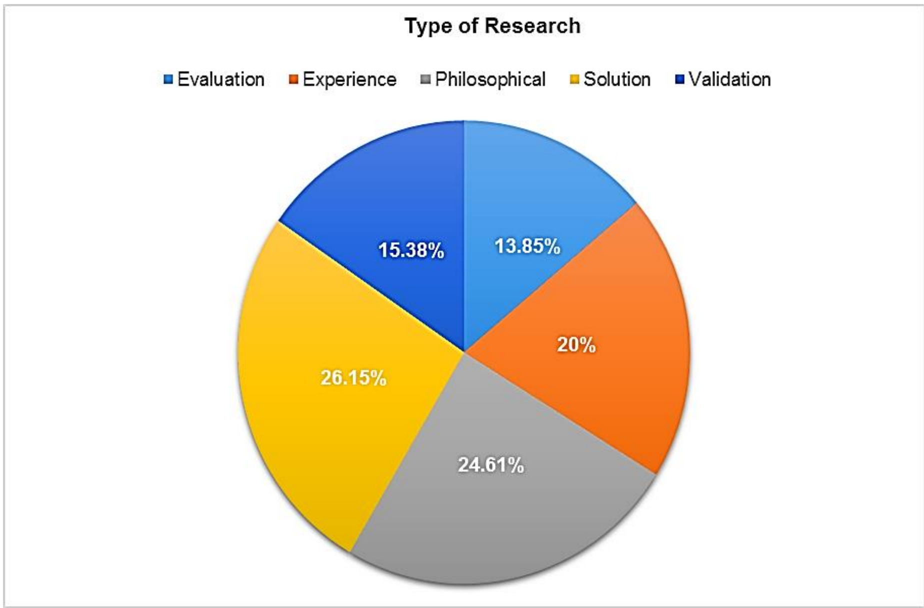

Fig. 4. Research type.

Furthermore, Fig. 5 shows the popularity of research type by year. Despite the overall lead by solution-based research, in 2015, there has been a rise in philosophical research that comprises 43.75% of the publications. The examples of philosophical research in the domain include the publications by [19-23]. In recent years 2016 and 2017, there has been an increase in evaluation and validation research. It is important to mention that the absence of opinion-based research is due to the exclusion criteria filters of this study that focuses on including studies with the potential to answer the research questions. Therefore, we eliminated the opinion-based publications that only discussed the applications of big data in smart cities without contributing to the research area. At present, most of the research publications in the area are producing new solutions and performing experiments to address the challenges of smart cities using BDTs.

Noteworthy examples of solution-based research in the domain include the publications by [10, 24-27], whereas examples of experience research include the publications by [28-32]. Considering the analysis criteria for research question 2 as discussed in the section 2, the analysis by research type indicates that the current state of the research domain is semi-matured and gradually moving towards being a fully matured area of research as witnessed by the 33.33% growth in the production of evaluation and validation type research in 2017. The findings imply that there is a need for novel techniques with complete validation and evaluation in the area of big data in smart cities. Some noteworthy examples of validation research in the domain include the publications by [33-37], whereas examples of evaluation research include the publications by [9, 11, 13, 38, 39].

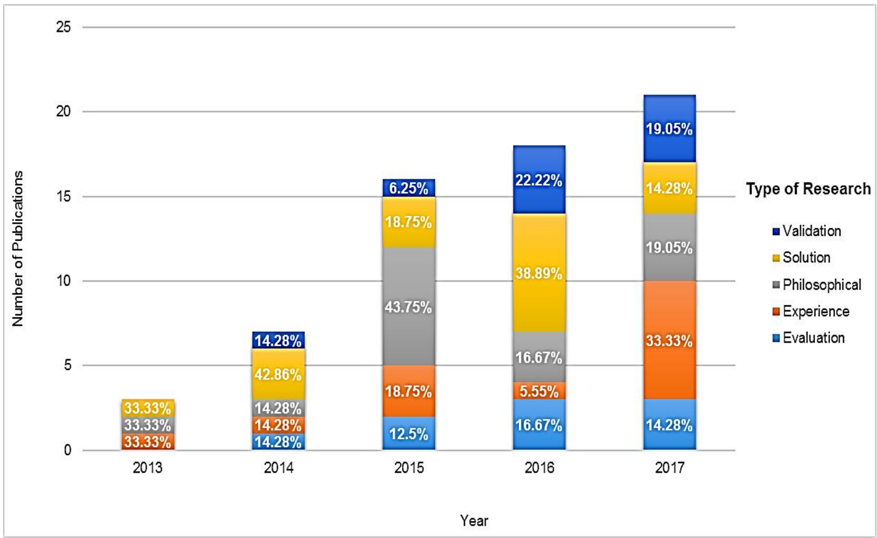

Fig. 5. Research type by year.

Moreover, the analysis of this question by contribution type as shown in Fig. 6, reveals that the top three contributions produced in the domain are architecture (27.68%), framework (20%), and platform (12.31%) which comprise of the 60% of the overall contributions. Theory is the fourth most produced contribution that was reported in 10.77% of the publications. Furthermore, Fig. 6 portrays that contributions such as architecture, framework, platform, and theory have been produced more in conferences as compared to journals, whereas contributions such as model, tool, and process have been produced more in journals. The findings imply that usually evaluation and validation research in the area are published in journals, whereas solution and philosophical research are published in conferences.

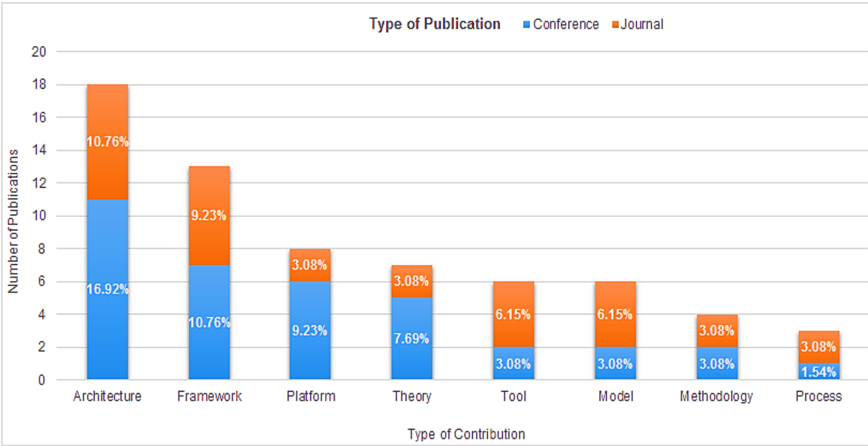

Fig. 6. Research contribution by publication type.

The yearly analysis of research contributions shown in Fig. 7 portrays that the growth of conceptual as well as implemented architectures and frameworks increased in 2015. In 2016, tools and processes have increased, and in 2017, 42.85% of the publications have produced contributions of type model, tool, and process. The analysis of this question by contribution type complies with the analysis by research type, which identified that despite the overall lead by solution-based research, in 2015, there was a rise in philosophical research. In 2016 and 2017, there has been an increase in experience, evaluation as well as validation research.

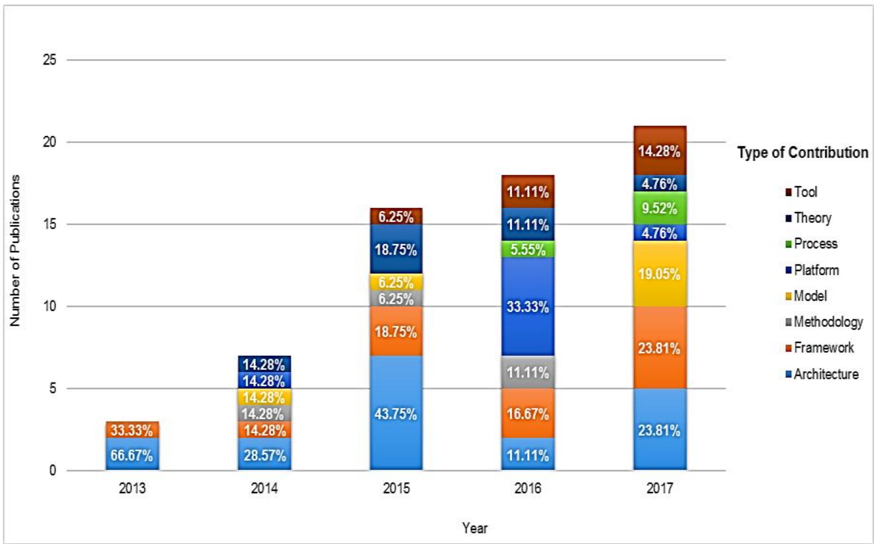

Fig. 7. Research contribution by year.

Considering the analysis criteria of this question by research and contribution type as discussed in section 2, we conclude that the current state of the research domain is semi-matured as it contains a higher percentage of architecture, framework, and platform type contributions. Moreover, the 46.15% of the research is of type solution and experience. There is a need to produce novel contributions such as models, tools, processes, and methodologies in research publications of type evaluation and validation.

4.3. Types of analytics

Figure 8 depicts that 58.46% of the research carried out in the domain applied or discussed the applications of an analytics type, and 41.54% of the research focused on BDTs without considering analytics as their primary objective. The findings unveil that apart from analytics, BDTs in smart cities have been used for a variety of other reasons. Some noteworthy examples of such research efforts include the followings:

- Expediting the identification of points-of-interest in smart cities by integrating MongoDB as a storage and processing engine in the ParticipAct backend [28].
- Using a virtual machine migration model containing the capability of executing big data-intensive healthcare tasks to improve the performance of smart healthcare applications in a smart city [9].
- Overcoming the performance bottlenecks in large-scale smart city installations by combining big data processing tools with ontology-based reasoning [40].
- Ensuring the use of healthcare system by providing autonomous sources and backpropagations of big data MapReduce framework [41].
- Storing big data using a monitoring-oriented cloud architecture to facilitate smart environments [42].

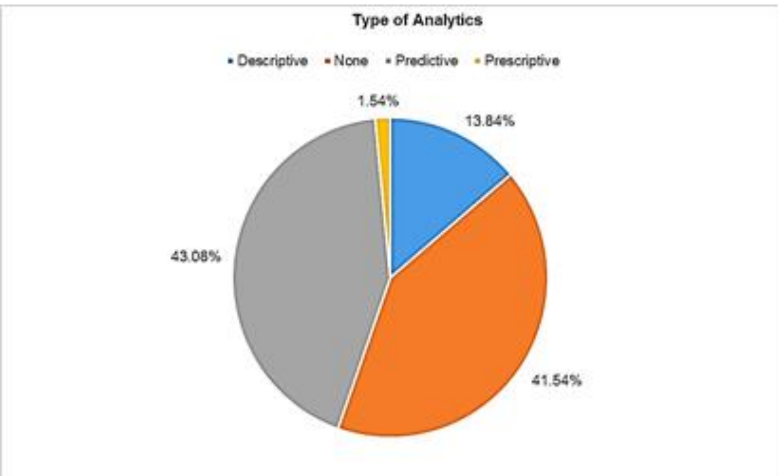

Fig. 8. Analytics type.

As shown in Fig. 8, 43.08% of the research publications focused on predictive and 13.84% on descriptive analytics. Figure 9 shows the yearly statistics of the analytics applied from 2013 to 2017. There are three papers in this study from the year 2013, and only one of them applied analytics that is of type predictive. On a yearly basis, predictive is most applied analytics type. It is applied in smart cities for various cases such as the followings:

- To predict health-shocks based on large-scale health informatics datasets [43].
- To predict and classify the journey time by discovering patterns in traffic volumes [16].
- To predict information relating to water reservoirs for maintaining the required levels of water according to citizens requirements [10].
- To identify the risk of students failing the course [27].
- To identify and predict criminal incidents using the data of 411 complaints [44].

Descriptive analytics is applied in smart cities for various cases such as the followings:

- Monitoring the city traffic to detect bike-riders without a helmet [31].
- Analysis of the data such as the economy, safety, crime, and employment to measure positive and negative trends [45].
- Hazardous events detection to monitor pipeline safety [46].
- Monitoring the mobility of vehicles to identify the congested areas [47].

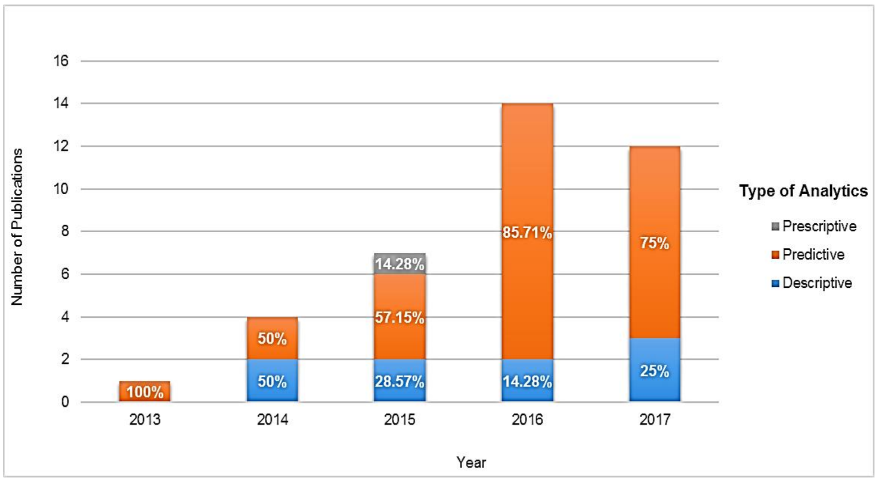

Fig. 9. Analytics type by year.

Analysis of this question shows that there is a lack of research focusing on prescriptive analytics. Only one publication of 2015 applied prescriptive analytics to describe how the recent health trends are affecting the position of states in the US [48]. The insufficiency of prescriptive analytics applications could be due to its complexity, as it requires combinations of techniques and tools such as machine learning, computational modeling procedures, business rules and expertise in the subject matter [4]. It is further emphasized by Sivarajah et al. [49] that there is insufficient research on prescriptive analytics in the real world.

4.4. Current state and future direction of big data research in smart cities

Smart transportation is ranked as the top area of smart cities by being the focus of 22, i.e., 33.85% of big data research publications. Figure 10 depicts that the majority of the contributions produced in this area are of type tool (22.72%), and architecture (18.18%). Furthermore, Fig. 11 shows that most, i.e., 63.64% of the research produced in this area is of type experience and validation, each with equal distribution of 31.82%. The year of publication represented by a reference number in the Appendix table demonstrates that most research produced in this area was during 2016 and 2017. The research in the area of big data in smart transportation focused on the following themes:

- Big data for IoT services in smart cities to detect traffic congestion [50].
- Estimation of mobility direction of a people flux by using live 3G radio access network and smartphones [35].
- Computing mobility patterns for smart cities using the big data generated from the network of Vodafone Italy Telco operator [33].
- Managing big real-time data to support intelligent transportation for smart cities [51].
- A BDA platform for smart transportation [24].
- A big data architecture to identify delay profiles in flights [52].
- Big data in smart cities to analyze the correlation between traffic, temperature, season, and working day [53].
- Real-time smart traffic management system for smart cities by using IoT and big data [36].
- Visual BDA for traffic monitoring in a smart city [31].
- Real world applications using parallel computing techniques in dynamic traffic assignment [54].
- Traffic flow prediction based on the location of big data [55].
- Modeling road congestion using ontologies for BDA in smart cities [16].
- Traffic pattern modeling, trajectory classification and vehicle tracking within urban intersections [37].
- Cell phone big data to compute mobility scenarios for future smart cities [56].
- Framework for planning transportation in a smart city [21].
- Big data approach for smart transportation management for a bus network [18].
- Traffic congestion detection through connected vehicles and big data [11].
- Benchmarking real-time vehicle data streaming models for a smart city [32].
- Spatio-temporal analysis of passenger travel patterns in massive smart card data [57].
- Real-time video processing for traffic control in a smart city using the Hadoop ecosystem with GPUs [58].
- Big data framework for providing better transportation services to the citizens [59].
- Real-time streaming mobility analytics by deploying distributed streaming algorithms [30].

Smart environment is ranked as the second area of smart cities by being the focus of 14, i.e., 21.54% of big data research publications. Figure 10 depicts that the majority of the contributions produced in this area are of type architecture

(50%) and methodology (21.43%). Figure 11 shows that most of the research produced in this area is of type experience (28.57%) and solution (35.71%). The year of publication represented by a reference number in the Appendix table demonstrates that most research produced in the area was during 2016 and 2017.

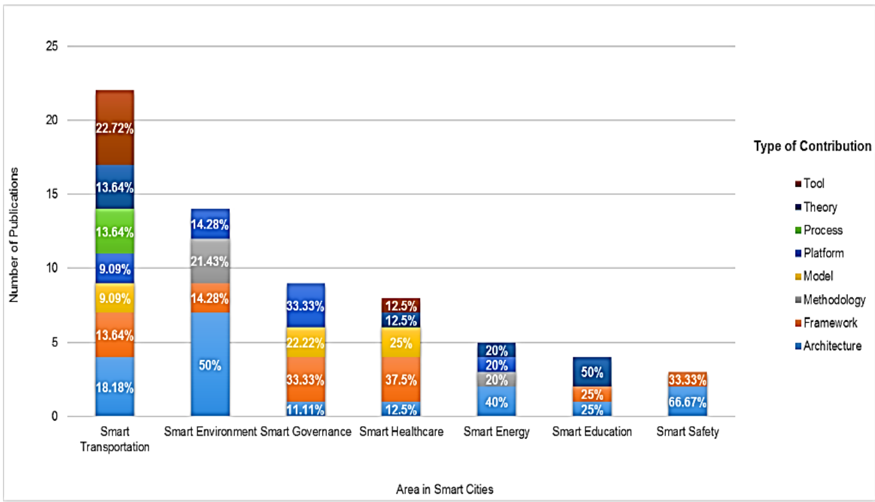

Fig. 10. Areas in smart cities and contribution type.

The research in the area of big data in smart environment focused on the following themes:

- Big data for supporting low-carbon road transport policies in Europe [13].
- Big data storage in the cloud for smart environment monitoring [42].
- BDA towards efficient waste management in Stockholm [25].
- Weather and pollution planning in smart cities based on the IoT using BDA [39].
- Smart planning in solid waste management for a sustainable smart city [60].
- CleanWiFi network for air quality monitoring, community internet access and environmental education in smart cities [29].
- An ecosystem of ICT solutions to distribute geo-referenced information about the influence of pollution and micro-climatic conditions on the quality of life in smart cities [61].
- Integrated architecture for data processing for smart cities [47].
- BDA and IoT for urban planning with the focus on environmental issues [10].
- Management of smart environments using IoT [62].
- A big data framework for urban noise analysis and management in smart cities [63].
- Utilizing cloud computing with big data for climate studies, geospatial knowledge mining, land cover simulation and dust storm modeling [64].
- Development of environmental awareness in smart cities [28].
- Semantic smart cities framework for pollution detection from vehicles [12].

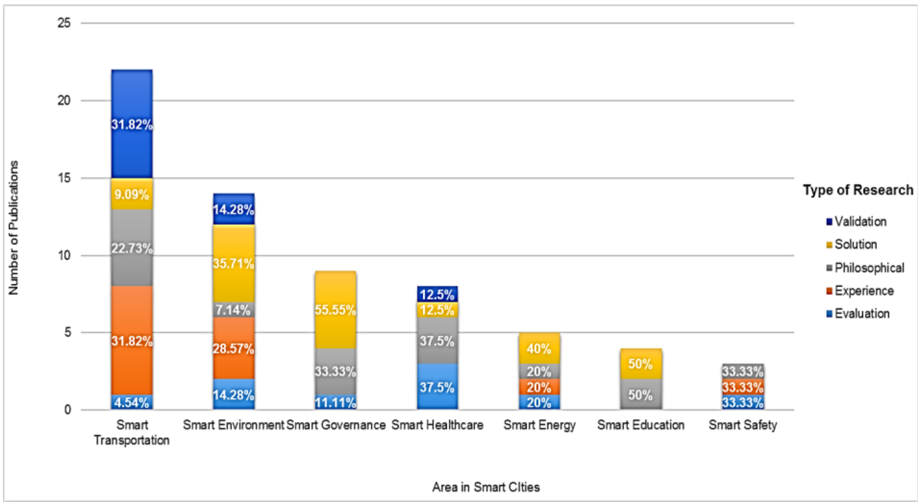

Fig. 11. Areas in smart cities and research type.

Smart governance is ranked as the third area of smart cities by being the focus of 9, i.e., 13.85% of big data research publications. Figure 10 depicts that the majority of the contributions produced in this area are of type framework (33.33%), platform (33.33%), and model (22.22%). Figure 11 shows that most of the research produced in the area is of type solution (55.55%) and philosophical (33.33%). The year of publication represented by a reference number in the Appendix table demonstrates that most research produced in the area was during 2016. The research in the area of big data in smart governance focused on the following themes:

- Towards cloud-based BDA for smart future cities [45].
- Big data-based smart city platform for real-time crime analysis [44].
- A BDA system to analyze citizens' perception of security [17].
- Towards a smart learning environment for smart city governance [14].
- Smart cities data security and privacy management [20].
- Safety, security, and privacy in smart cities [65].
- Mobility management platform for growing efficient and balanced smart city ecosystem [66].
- A dynamic network model for crime analytics in the smart city [8].
- A smart city middleware from sensors to big data [19].

Smart healthcare is ranked as the fourth area of smart cities by being the focus of 8, i.e., 12.31% of big data research publications. Figure 10 depicts that the majority of the contributions produced in this area are of type framework (37.5%) and model (25%). Figure 11 shows that 75% of the research produced in this areas is of type evaluation and philosophical. The year of publication represented by a reference number in the Appendix table demonstrates that most of the research produced in the area was during 2017. The research in the area of big data in smart healthcare focused on the following themes:

- Mobile cloud-based big healthcare data processing in smart cities [9].

- Mining human activity patterns from smart home big data for healthcare applications [67].
- A voice pathology detection paradigm for smart cities [34].
- Creating smart and healthy cities by exploring the potentials of emerging technologies and social innovation for urban efficiency [68].
- Enhancement of backpropagation using BDA in smart hospital initiatives [41].
- Cloud-enabled data analytics and visualization framework for health-shocks prediction [43].
- Big data enabled health paradigm within smart cities [23].
- Assessing the quality of healthcare service using BDA [48].

There is a lack of research produced in the areas of smart energy, smart education, and smart safety which have been the focus of only 7.69%, 6.15%, and 4.61% big data research publications, respectively. Figure 10 depicts that majority, i.e., 40%, of the contributions produced in the area of smart energy are of type architecture. Figure 11 shows that most, i.e., 40% of the research produced in the area of smart energy is of type solution. The year of publication represented by a reference number in the Appendix table demonstrates that most research produced in the area was during 2014. The research in the area of big data in smart energy focused on the following themes:

- An architecture for energy optimization and efficient processing of sensor data in smart cities [40].
- City intelligent energy and transportation network policy [15].
- Hybrid navigation system based on open data, augmented reality, and big data applications for the smart cities [69].
- Big data in large-scale intelligent smart city installations [70].
- A multifaceted approach to smart energy city using BDA [22].

Figure 10 depicts that the majority of the contributions produced in the area of smart education are of type theory (50%), architecture (25%), and framework (25%). Figure 11 shows that the overall research produced in this area is of type solution and philosophical. The research produced in this area is very limited. The year of publication represented by a reference number in the Appendix table demonstrates that most research produced in this area was during 2015. The research in the area of big data in smart education focused on the following themes:

- Schooling smart citizens through computational urbanism [71].
- Contextualization framework for smart learning analytics [27].
- Big data for institutional planning, decision support and academic excellence [72].
- Novel continuous learning and collaborative decision-making mechanism for the real-time cooperation of humanoid service robots [26].

Figure 10 depicts that 33.33% and 66.67% of the contributions produced in the area of smart safety are of type framework and architecture, respectively. As shown in Fig. 11, this area contains an equal distribution of the research publications of type evaluation, experience, and philosophical. The year of publication represented by a reference number in the Appendix table demonstrates that most research produced in the area was during 2017. The research in the area of big data in smart safety focused on the following themes:

- Hierarchical distributed computing architecture for big data analysis in smart cities [38].
- Smart city with Chinese characteristics against the background of big data [73].
- Incorporating intelligence in fog computing for big data analysis in smart cities [46].

The analysis of this question reveals that big data research in smart transportation and smart environment is rapidly emerging. However, there is a lack of evaluation research with contributions of type models, processes, and methodologies in smart transportation, whereas smart environment lacks research of type evaluation as well as validation. The high percentage of philosophical and solution type research produced in smart governance indicates the presence of early research efforts with conceptual solutions, and the area has moved towards mature contribution such as models. Alternatively, 25% percentage of model type contributions and 37.5% of evaluation type research are indications of substantial research being produced in smart healthcare. With the growing interest in 2017, the frequency of big data research in smart healthcare may rapidly increase in subsequent years. There is a lack of big data research in bottom three areas and contributions are not sound enough. The majority of the contributions produced in these three areas are of type architecture, framework, theory, and platform except for 20% methodology type contributions in smart energy. At present, there is utmost need to produce more big data research in these areas to address a variety of problems in smart cities.

5. Conclusion

Although, this study provides an opportunity for the researchers to fulfill the research gaps in the area of big data in smart cities. However, it has limitations regarding literature sources. For instance, the scope of this study only covers the selection of peer-reviewed journal and conference publications. Therefore, our results are missing the probable publications from other sources such as book chapters, magazines, newsletters, white papers, etc. Moreover, the analysis of the research questions is based on schemes of research type, analytics type and areas in smart cities published by other authors. These schemes may not cover all the aspects of taxonomy, but it was essential for us to follow existing well-established schemes to limit the coverage of this study. We selected the literature sources and classification criteria after conducting a comprehensive investigation.

The overall findings of this study as shown in Fig. 12 can serve as an excellent platform for further investigation and future work in the domain. We identified that there is substantial big data research produced in the areas of smart transportation and smart environment. Besides the requirement for producing validation and evaluation research in the areas of smart transportation and smart environment, there is a need for more research efforts in the areas of smart healthcare, smart governance, smart safety, smart education, and smart energy. Furthermore, the potential of prescriptive analytics in the smart cities is also an area of research that needs to be explored as we identified that predictive is the most whereas prescriptive is the least applied type of analytics in smart cities.

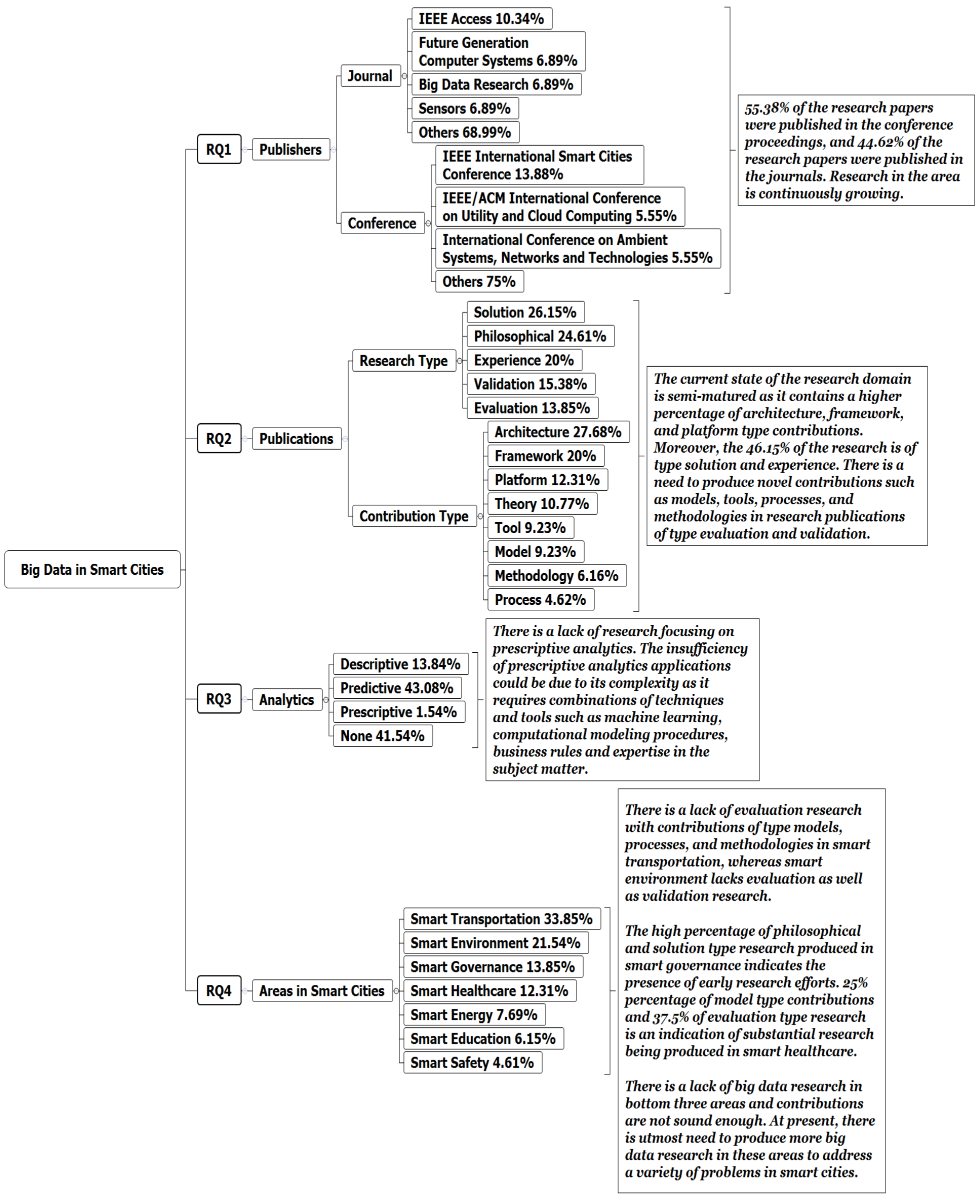

Fig. 12. Summary of research findings.

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Appendix

Classification of Publications

The following Appendix table contains the attributes extracted from each publication. The factors such as the title, year, type, and source of publication are stated in the list of references.

Publication (Title, year, type, and source) specified in reference no:	Type of research	Type of contribution	Type of analytics	Area in smart cities
[8]	Evaluation	Model	Predictive	Smart Governance
[9]	Evaluation	Model	None	Smart Healthcare
[10]	Solution	Architecture	Descriptive	Smart Environment
[11]	Evaluation	Tool	Predictive	Smart Transportation
[12]	Solution	Framework	Predictive	Smart Environment
[13]	Evaluation	Methodology	Predictive	Smart Environment
[14]	Philosophical	Framework	None	Smart Governance
[15]	Solution	Platform	Descriptive	Smart Energy
[16]	Experience	Model	Predictive	Smart Transportation
[17]	Solution	Platform	Predictive	Smart Governance
[18]	Solution	Platform	Predictive	Smart Transportation
[19]	Philosophical	Framework	None	Smart Governance
[20]	Philosophical	Framework	None	Smart Governance
[21]	Philosophical	Framework	None	Smart Transportation
[22]	Philosophical	Theory	None	Smart Energy
[23]	Philosophical	Framework	None	Smart Healthcare
[24]	Solution	Platform	Predictive	Smart Transportation
[25]	Validation	Methodology	Predictive	Smart Environment
[26]	Solution	Framework	Descriptive	Smart Education
[27]	Solution	Architecture	Predictive	Smart Education
[28]	Experience	Architecture	None	Smart Environment
[29]	Experience	Architecture	None	Smart Environment

[30]	Experience	Architecture	Predictive	Smart Transportation
[31]	Experience	Framework	Descriptive	Smart Transportation
[32]	Experience	Tool	Descriptive	Smart Transportation
[33]	Validation	Process	Predictive	Smart Transportation
[34]	Validation	Framework	None	Smart Healthcare
[35]	Validation	Model	Predictive	Smart Transportation
[36]	Validation	Tool	Predictive	Smart Transportation
[37]	Validation	Tool	Predictive	Smart Transportation
[38]	Evaluation	Architecture	Predictive	Smart Safety
[39]	Evaluation	Architecture	Predictive	Smart Environment
[40]	Evaluation	Architecture	None	Smart Energy
[41]	Philosophical	Architecture	None	Smart Healthcare
[42]	Philosophical	Architecture	None	Smart Environment
[43]	Evaluation	Framework	Predictive	Smart Healthcare
[44]	Solution	Platform	Predictive	Smart Governance
[45]	Solution	Architecture	Descriptive	Smart Governance
[46]	Experience	Architecture	Descriptive	Smart Safety
[47]	Experience	Architecture	Predictive	Smart Environment
[48]	Solution	Tool	Prescriptive	Smart Healthcare
[50]	Experience	Theory	Predictive	Smart Transportation
[51]	Philosophical	Architecture	None	Smart Transportation
[52]	Validation	Architecture	Descriptive	Smart Transportation
[53]	Experience	Theory	Predictive	Smart Transportation
[54]	Philosophical	Theory	None	Smart Transportation
[55]	Philosophical	Architecture	None	Smart Transportation
[56]	Validation	Process	Predictive	Smart Transportation
[57]	Experience	Process	Predictive	Smart Transportation
[58]	Validation	Tool	None	Smart Transportation
[59]	Philosophical	Framework	None	Smart Transportation
[60]	Solution	Platform	Predictive	Smart Environment
[61]	Solution	Platform	None	Smart Environment
[62]	Solution	Architecture	Descriptive	Smart Environment
[63]	Experience	Framework	Predictive	Smart Environment
[64]	Validation	Methodology	Predictive	Smart Environment
[65]	Solution	Model	None	Smart Governance
[66]	Solution	Platform	None	Smart Governance
[67]	Evaluation	Model	Predictive	Smart Healthcare
[68]	Philosophical	Theory	None	Smart Healthcare
[69]	Solution	Architecture	None	Smart Energy
[70]	Experience	Methodology	None	Smart Energy
[71]	Philosophical	Theory	None	Smart Education
[72]	Philosophical	Theory	None	Smart Education
[73]	Philosophical	Framework	None	Smart Safety