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Towards a Service-Oriented Architecture for the Energy Efficiency of Buildings: A Systematic Review

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ABSTRACT Currently, smart buildings generate large amounts of data due to the many devices and equipment available. Hence, buildings implement building management systems (BMSs), which monitor, control, manage and analyze each of these components. However, current BMSs are incapable of managing a massive amount of data (big data) and therefore cannot extract knowledge or make intelligent decisions in quasi real time. In addition, there are serious limitations to integrating BMSs with other services since they generally use proprietary software. In this sense, service-oriented architecture (SOA) is an architectural style that allows one to build distributed systems and provide functionalities such as services to end users or other types of services. Therefore, an SOA has the great advantage of allowing the expansion of the functionalities of BMSs. In fact, there are several studies that address SOAs for building management. However, we have not found any description or systematic analysis in the literature that allows the development of a versatile and interoperable SOA focused on the energy efficiency of buildings and that can integrate massive data analysis features. For these reasons, this study seeks to fill this knowledge gap and, more specifically, to identify and analyze the various software requirements proposed in the literature and the characteristics of big data that allow for improving the energy efficiency of buildings. To this end, we performed an in-depth review of the literature according to the methodology proposed by Kitchenham. As a result of this review, we provide researchers with a specific vision of the requirements and characteristics to consider for software development aimed at the energy efficiency of unique or historic buildings.

INDEX TERMS Big data applications, buildings, energy efficiency, energy management, management information systems, service-oriented systems engineering, software architecture.

I. INTRODUCTION

Buildings are responsible for more than a third of the world's total energy consumption [1]–[4]. Therefore, reducing the energy consumption of buildings is a global problem. That is why countries are implementing strategies to make buildings more efficient and reduce excessive energy consumption. For example, in the design phase, Zero Energy Buildings (ZEBs) [5]–[7] have gained special attention in recent years as they make use of renewable energy sources [8], [9], thus allowing the energy efficiency indexes of a building to be improved [10]–[12]. However, in the operation phase, it is not a simple task when dealing especially with historical or unique buildings, so that immediate actions are based on reducing energy consumption [13].

In this sense, heating, ventilation and air conditioning (HVAC) systems contribute a significant part of the building's total energy consumption [14]. In addition, it is affected by various factors [15]. Consequently, to effectively improve energy efficiency and reduce energy consumption in buildings, we have conducted several investigations [16]–[18] with the aim of optimizing the performance of HVAC systems in historic or unique buildings.

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On the other hand, HVAC systems are tuned by building management system (BMS), whose purpose mainly consists of monitoring, managing, controlling and analyzing the different equipments (HVAC systems, elevators, lighting, etc.) and devices (sensors, actuators, etc.) of a building [19]. However, being a proprietary software system, the BMS presents serious limitations for the integration with other components or services, so it can crash when managing a large amount of data (big data) [20]–[23]. Hence, it is necessary to implement a software architecture capable of supporting different functionalities for the intelligent management of the building.

For this reason, components (services) must be able to be integrated and deployed in versatile way within a software architecture. Hence, we are conducting a project called ''Intelligent management system for optimizing energy consumption in building air conditioning'', driven by a consortium of Spanish universities under the Smart Energy Campus of International Excellence [24]. The goal is to develop an autonomous BMS using a versatile software architecture, which allows the energy efficiency of HVAC systems in historic or unique buildings to be improved.

In this perspective, service-oriented architecture (SOA) offers an architectural design focus suitable for the design and development of distributed systems that offer different capabilities, including end-user services and others [25]–[27]. As it can be inferred, SOA could expand the traditional features of a BMS in a way that would improve the management of the building's equipment and devices and consequently improve the energy efficiency of the building. However, before considering this in depth, it is first necessary to identify the software functionalities (features) that are best adapted to these systems.

In fact, several studies have addressed different features for an SOA aimed at building management. However, at this time, we have not found any article that provides an overview or a systematic analysis of the different features necessary for an SOA aimed at energy efficiency in buildings.

For such reasons, we conducted a systematic literature review (SLR) using the methodological procedure proposed by Kitchenham [28]. Specifically, we identify and analyze the different requirements (functional and non-functional) for a service-oriented architecture that incorporates the features (interoperability and versatility) as well as big data characteristics that will result in improved energy efficiency for buildings. We asked a series of research questions and conducted an extensive search process that allowed us to find answers to our questions. As a result, this SLR can provide researchers with a general idea of the requirements and characteristics on which investigations should focus to adapt and develop software architectures and new technologies in this field.

This article is organized as follows: Section II briefly describes the related work and the motivation of the study conducted. Section III describes the methodological procedure used for the compilation of studies, the research questions, search engine, search strategy and selection criteria. Section IV summarizes the process of applying the methodology obtained through the SLR. Section V shows the results and relevant papers that answer the research questions. Section VI presents the discussion of the results. Section VII outlines some directions for future research; and finally, Section VIII provides the conclusions derived from this study.

II. RELATED WORK AND MOTIVATION

In this section we describe some of the different software functionalities (features) that are either proposed or incorporated in the documents found. Additionally, we explain the motivation for conducting this SLR.

A. RELATED WORKS

In [29], an SOA was used in the industrial system of systems (SoS) since it provides an excellent platform to develop systems and allows the encapsulation, reuse and composition of components (services). The authors claim that services can be essential to get the desired information as in the case of the energy consumption of equipments in an industrial factory.

For its part, in [30] an SOA was adopted for the management of home energy systems which have heterogeneous components and are subject to different standards, requirements and technologies. This is mainly due to the fact that SOA allows the interoperability and flexibility issues present in the home to be addressed.

On the other hand, in [25] the SOA-based approach was used to enable the interoperability of heterogeneous smart home systems. They developed a simulator in which they incorporated different services, optimization criteria and modes of operation in order to measure the energy consumed by the smart home.

Meanwhile, in [31] they described the implementation of an SOA-based infrastructure using a service-based software layer that allows information to be obtained from various data sources that is, in turn, consumed by other applications within a factory. This allowed them to monitor the operational performance and energy consumed in one business and to meet the requirements of other applications.

Finally, in [32] an SOA was proposed for the building service integration, since SOA provides flexibility, extensibility, open design and interoperability. Therefore, business applications can be highly adaptable. The authors note that this approach would facilitate the integration of BMS and management applications along with other functions in order to share, monitor, control and manage the business environment. Table 1 shows each of the software approaches and functionalities (features) applied by the different investigations cited.

It should be noted that the aforementioned works have outlined various SOA-based approaches to building energy management and have addressed one or more features. Within this context, one of the most mentioned ones is interoperability; therefore, SOA brings in this important feature that we want to address in our investigation.

Conversely, flexibility is another feature mentioned in the studies, which is defined as the capacity of services or

TABLE 1. Summary of the approaches and software functionalities in the cited works.

Approach	Software Functionality	Refs.
Several industrial sectors	Reusability and Composition	[29]
Household management	Interoperability and Flexibility	[30]
Household management	Interoperability	[25]
Manufacturing enterprises	Interoperability	[31]
Building services integration	Flexibility, Extensibility, Open design and Interoperability	[32]
Building energy efficiency	Interoperability and Versatillity	Our work

systems to adapt to changes within a given infrastructure (a language, a database, an operating system, among others) [33]. As it can be inferred, flexibility is similar to versatility; however, for our own work, the latter is defined as the ability to build, integrate and implement components (services) that are independently and completely decoupled in different containers or servers, different languages, operating systems, databases, to mention a few [34].

B. MOTIVATION

On this basis, the abovementioned works do not identify or report versatility. Therefore, this motivated us to conduct an SLR in order to identify the studies that consider this feature through the software requirements that they propose or report in the studies, as well as the big data characteristics that best represent the energy management of buildings.

In this respect, our study provides a new perspective compared to what has been described in previous studies when addressing software functionalities. This analysis will solve several needs. In the first place, each component will be able to focus on specific building systems monitoring, automation, and control tasks, which may require CPU or GPU dependent processing (e.g. neural networks, genetic algorithms, etc.). In second place, it is necessary to control and manage the collection of large volumes of data generated from different sources and types of data (big data). Last but not least, it is necessary to integrate and implement each of the services in a scalable, interoperable and versatile way to form an agile and efficient data management system.

For these reasons, we consider that the most suitable features to carry out our study are interoperability and versatility, since they would allow us to satisfy the needs raised for the development and deployment of a service-oriented architecture in the context of energy efficiency of buildings.

III. METHODOLOGY

The methodological approach used for this study was that proposed by Kitchenham [28]. We limited our SLR to the context of the service-oriented architecture and the characteristics of big data applicable to the energy management of buildings. In the following sections, we describe the steps of the methodology employed, including the research questions we sought to answer through this study and the search strategy used to compile the different works for the SLR; establish the criteria for the selection of the studies; and finally describe the data extraction process that will be conducted to answer the research questions.

A. RESEARCH QUESTIONS

In this work, we focused on the requirements (functional and non-functional) for an SOA and the characteristics of big data applicable to energy management that has been developed for the energy efficiency of buildings. For this reason, Table 2 describes the research questions to be answered.

TABLE 2. Research questions for systematic review.

RQ1	What characteristics best represent an architecture that enables the management and application of big data to the energy management of buildings?
RQ2	What are the functional and non-functional requirements for the types of software architectures used in the energy management of buildings?
RQ3	What implementations of service-oriented software architectures have been developed for the energy efficiency of buildings?

B. SEARCH STRATEGY

1) SEARCH KEYWORDS

To construct a search string, it was necessary to perform an in-depth study of the state-of-the-art research based on the following keywords: building energy efficiency, building energy consumption, energy efficient building, software architecture, service-oriented architecture, SOA, and big data. All of these terms are related to a specific problem addressed.

Then, we built a search string combining the indicated words with different Boolean operators as follows:

(“building energy efficiency” OR “building energy consumption” OR “energy efficient building”) AND (“software architecture” OR “service-oriented architecture” OR “Big data” OR “SOA”)

2) DATA SOURCES

To collect as many relevant studies as possible, we selected the main scientific databases (Scopus, Google Scholar, Web of Science, Science Direct, IEEE Xplore, SpringerLink, and ACM Digital Lib). Some of the criteria used to select these databases were as follows: (i) to retrieve the largest number of studies regarding service-oriented software architectures, (ii) to recover the largest number of studies regarding the energy efficiency of buildings, and (iii) to cover most of the journals with an impact factor.

3) SEARCH PROCEDURE

The following procedure was used to select the main sources for our research. First, the search string was executed in each of the search engines of the selected scientific databases. Second, the titles and abstracts of the articles were prefiltered by applying the selection criteria. Third, a complete review of each of the preselected articles was performed, considering the selection criteria, to collect the sources that provide

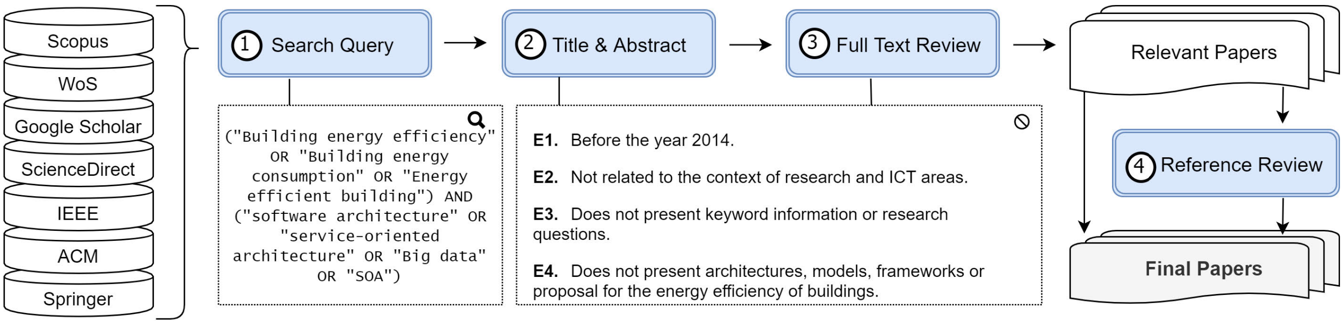

FIGURE 1. **Diagram of the search procedure for the SLR execution.**

relevant information for the research questions. Fourth, the full texts were thoroughly reviewed, and we retrieved the most appropriate references for our study that provided important information and that were pre-dated 2014 to add to these articles. This procedure is shown in Fig. 1.

C. SELECTION OF STUDIES

To identify the relevant articles in the second and third steps of the search procedure, we set the following exclusion criteria for use with the protocol defined above:

E1. Before the year 2014.

E2. Not related to the context of the research and ICT areas.

E3. Does not present keyword information or research questions.

E4. Does not present architectures, models, frameworks or proposals for the energy efficiency of buildings.

D. DATA EXTRACTION

We documented the entire search process with all records stored in a reference manager. Similarly, we noted the exclusion criteria for each of the excluded works. Additionally, each of the full texts was recovered only if it passed the prefiltering stage. Once this was done, we created a form where we collected the following information for each of these works:

- Does the article present concepts or definitions of the keywords?
- Does the article present characteristics of an architecture based on big data?
- Does the article present the characteristics that represent a software architecture that incorporates the use of big data for energy management?
- Does the article present the functional and non-functional requirements of software architectures aimed at the energy and building sector?
- Does the article mention or consider the limitations of service-oriented software designs, proposals, models, frameworks, platforms or architectures focused on the energy efficiency of buildings?
- In what aspect of energy efficiency is the service-oriented architecture used?

Considering this information, we answered each of the research questions posed.

IV. EXECUTION OF THE REVIEW

The search procedure was conducted in two phases. In the first phase, the relevant sources describing the articles collected in each scientific database were identified. The exclusion criteria were also applied to obtain articles that provided relevant information to answer the research questions. In the second phase, we considered the most relevant references obtained in the first phase. These phases are described below.

A. FIRST PHASE: IDENTIFYING THE RELEVANT SOURCES

Fig. 2 summarizes the numbers of articles obtained after excluding the studies found in the scientific databases. As a complement, Fig. 2 also shows the selection criteria for both the pre-filtering (only the titles and abstracts of the articles were considered) and the complete revision of the texts.

Considering this, the first exclusion criterion (E1) was applied only in the pre-filtering stage, which allowed us to exclude more than 600 publications that were outside the range of the selected years. The second exclusion criterion (E2) led to more than 3,600 exclusions, leaving those retained as the most representative since it made it easier for us to exclude articles that were outside the context of the investigation. The third exclusion criterion (E3) allowed us to discard more than 1,000 articles that did not have information on the selected keywords or RQs. Finally, the fourth exclusion criterion (E4) was especially useful since it allowed us to discard more than 300 publications without any reference to designs, proposals, models, frameworks or architectures.

B. SECOND PHASE: REVISION OF THE REFERENCES

In this second phase, all the references presented in the articles obtained in the first phase were reviewed to identify the useful information in them. We considered only those articles that satisfied each of the exclusion criteria with the exception of E1 since it applied only to the first phase. Finally, we managed to find 15 articles with information relevant to our research context, resulting in a total of 97 articles. In Fig. 3, the process of executing the SLR is summarized, and each of the phases described above is detailed.

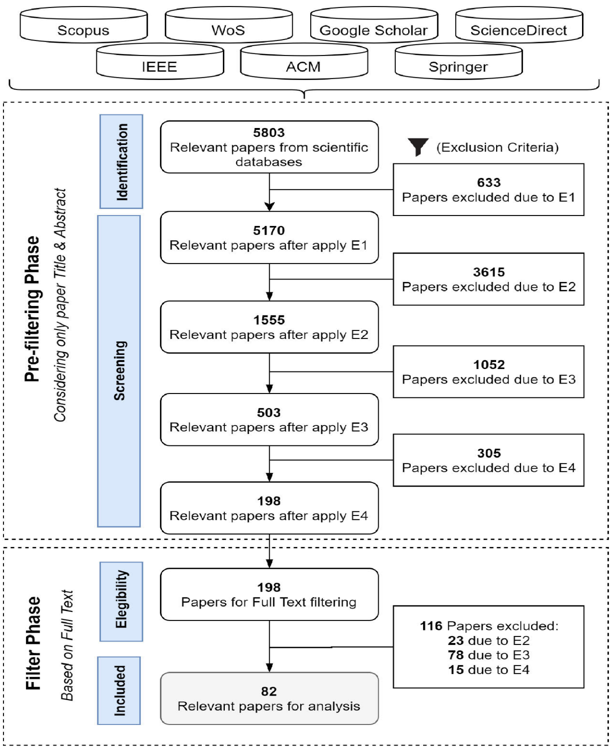

FIGURE 2. Results of the first phase after applying each selection criterion.

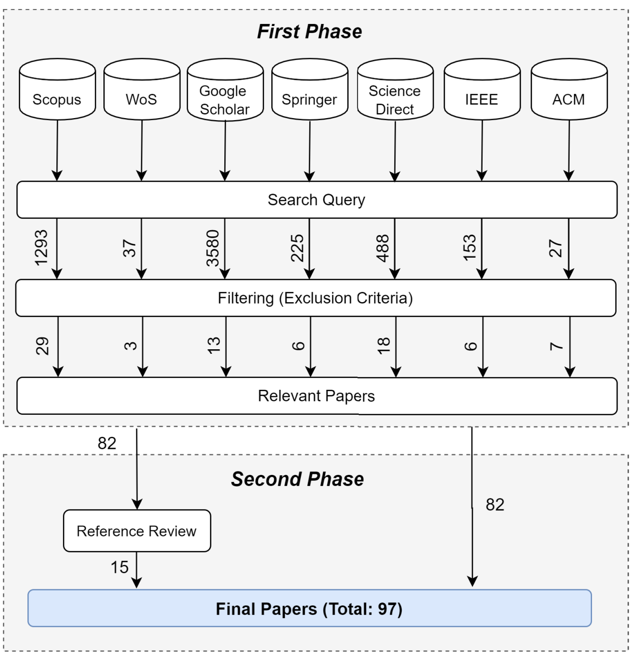

FIGURE 3. Summary of the SLR execution, showing the numbers of papers obtained in each phase.

V. RESULTS

This section presents the results of the relevant papers selected in terms of the publication year and publication type. In addition, this section also presents the answers to each research question posed, such as the various terminologies and existing concepts regarding the application of the concepts of big data and service-oriented architecture to various approaches, applications and styles of software architectures used in the context of the energy efficiency of buildings. As a complement, the various applications and approaches that were found, which were analyzed and classified in a prior study [35] and in this study, are shown in the Annex (Table 6).

A. RELEVANT WORKS BY YEAR

Fig. 4 describes the papers in terms of years of publication. We see that there are articles published in years prior to the exclusion criterion (E1) established above. The explanation for this is that the review of the references and analysis of the works published prior to criterion E1 allowed us to determine the theoretical basis necessary for our study context. Furthermore, we found that there was growing interest in the scientific community in the development of service-oriented architectures for energy efficient buildings. In addition, a decrease in the number of studies starting in 2019 was observed due to new trends and innovations that are emerging in the context of software architectures. An obvious example is the new microservice paradigm [36]–[38].

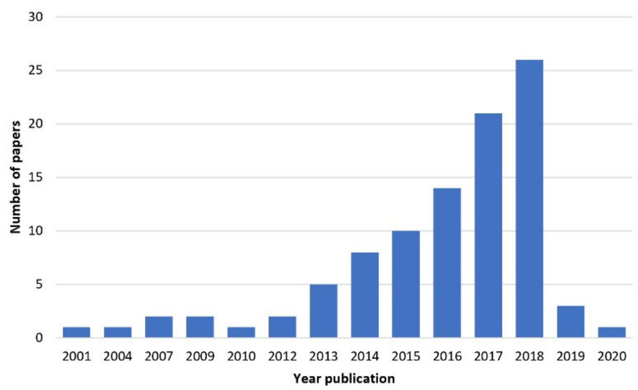

FIGURE 4. Number of papers by year of publication. Reviewed until September 2020.

B. RELEVANT WORKS BY TYPE OF PUBLICATION

Fig. 5 shows the distribution of the relevant works based on the publication type, highlighting journals with 57 relevant works, followed by conference proceedings with 24 works and books with 13 works. Finally, the publication types with the fewest works that were considered were two web pages and one general documents.

C. RQ1. WHAT CHARACTERISTICS BEST REPRESENT AN ARCHITECTURE THAT ENABLES THE MANAGEMENT AND APPLICATION OF BIG DATA TO THE ENERGY MANAGEMENT OF BUILDINGS?

The SLR allowed us to retrieve a large number of relevant studies to answer this research question.

It is true that the characteristics of big data found in the literature vary considerably. First, Laney [39] conceptualized

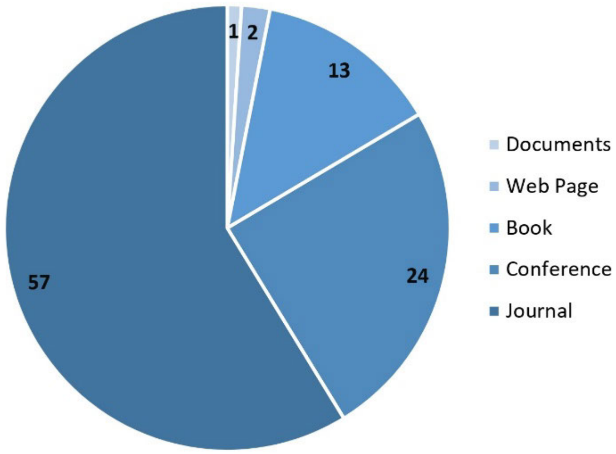

FIGURE 5. Number of papers by type of publication.

big data in terms of its three main characteristics (volume, velocity, and variety). Subsequently, other studies [40]–[49] analyzed seven characteristics. Some studies even considered more than 13 characteristics [42], [44], [50]–[68]. However, it was found that the four classic characteristics of big data, including volume, variety, velocity and value, are the ones that best represent the energy management of buildings [23], [43], [69]–[71]. Another important big data characteristic to consider in addition to the four mentioned above is veracity [42], [44]. In the current SLR being conducted, these five big data characteristics (see Fig. 6) are a set of functional requirements that a service-oriented architecture must integrate.

These characteristics are briefly defined below within the building energy efficiency field.

- ***Volume:*** Buildings constantly provide enormous amounts of data that come from various devices (sensors, smart meters, actuators, etc.) and equipment (HVAC, lighting, communications, etc.). In this sense, modern software architectures use technologies or services to handle massive data, as is the case with Industry 4.0 and the increasingly widespread use of Internet of Things (IoT) devices [72]. For all these reasons, this characteristic is of great relevance for the efficient energy management of buildings due to the large volume of information to be analyzed.
- ***Velocity:*** Developing and implementing services capable of rapidly collecting, analyzing and processing large amounts of data will offer several opportunities for improvements in building management. Therefore, these services must be able to handle data in different time intervals [70], allowing decision making in real time or near real time.
- ***Variety:*** Building data show a high degree of variety. In general, these data are structured (building energy consumption data, historical databases, etc.), semi-structured (meteorological data, schedule of different uses of the building, etc.) and unstructured (data on the behaviors and patterns of the occupants of buildings, etc.) [43], [73]. Therefore, the development of a service-oriented architecture would allow the integration and processing of the different types, sources and forms of data.
- ***Value:*** It is possible to implement intelligent strategies for the treatment of the collected data using algorithmic methods, allowing the acquisition of valuable knowledge that allows the optimization and improvement of the energy use of buildings [23]. In fact, these strategies can be implemented as services or software components that are in charge of detecting the energy consumption patterns of building equipment and generating and distributing energy according to demand (response to demand).
- ***Veracity:*** This characteristic refers to the noise present in the data. In the context of buildings, this noise is frequent due to failures or disconnections of the sensors or installed equipment. However, analyzing these data through various data mining techniques will offer the opportunity to detect hidden patterns and extract truthful and reliable information for decision making on the management of the building [42], [44].

D. RQ2. WHAT ARE THE FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS FOR THE TYPES OF SOFTWARE ARCHITECTURES USED IN THE ENERGY MANAGEMENT OF BUILDINGS?

A system architecture is an abstract model that represents the organization, behavior and collaboration between the components that make up a system [74]. In this sense, software architectures have different styles that define how their structure is organized [75]. To deepen these architectural styles, we reviewed the following works [74], [76].

In addition, functional requirements (FRs) describe how the systems should behave functionally, whereas non-functional requirements (NFRs) describe the restrictions on the services or functions offered by a system [77]–[80]. Therefore, to develop a service-oriented architecture (SOA) that incorporates the software features (interoperability and versatility) to improve the energy efficiency of buildings, it is of great importance to identify and to analyze the FRs and NFRs that were considered within the analyzed studies. Therefore, below, we briefly describe the requirements found.

1) FUNCTIONAL REQUIREMENTS

Table 3 summarizes each of the functional requirements reported in the analyzed studies. According to the review of the works, we recovered 32 works that presented different FRs. However, the various authors described them in different ways. Therefore, they were grouped according to the context or similarity of their focuses. Next, we describe each of these FRs:

FR1. ***Data sources layer:*** Most studies addressed this requirement, which includes all data, regardless of whether they are structured, semi-structured or

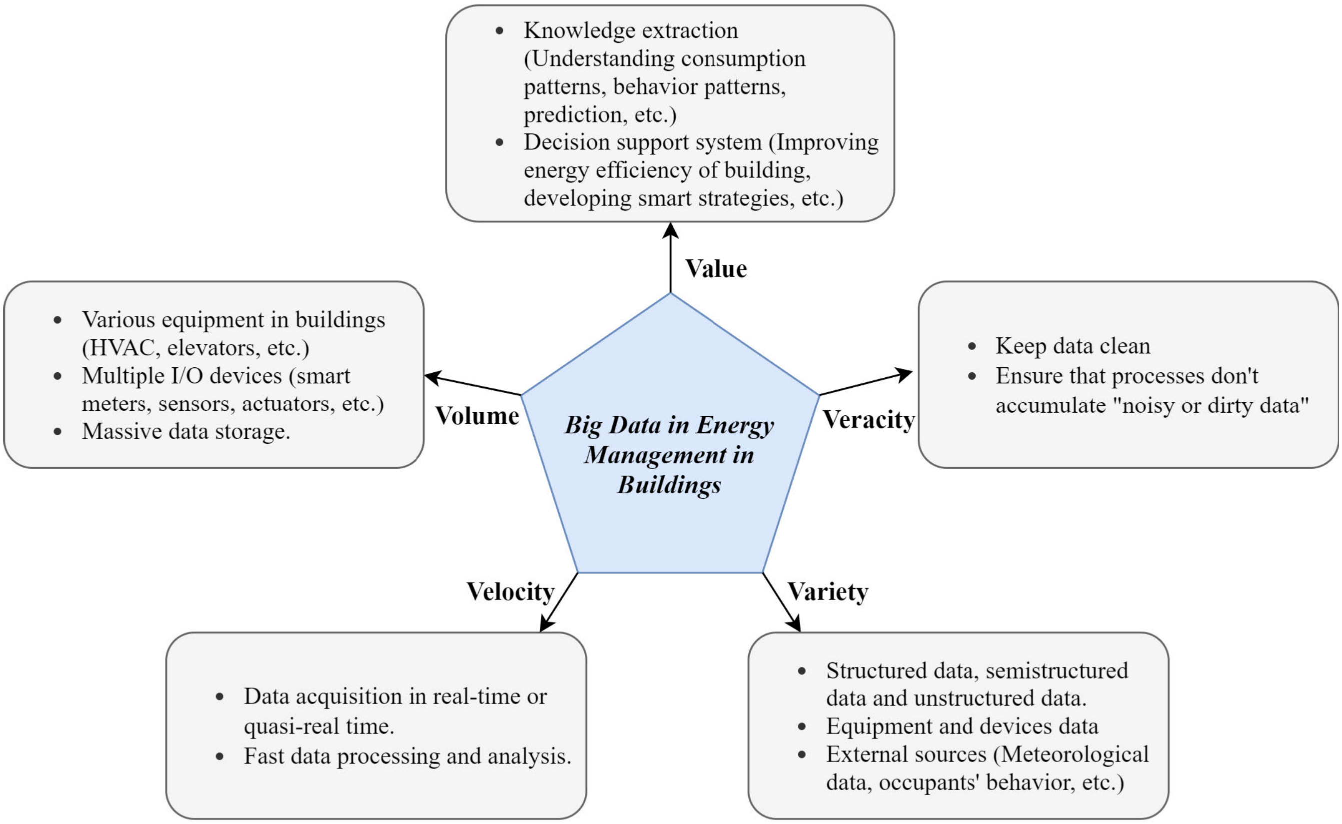

FIGURE 6. Characteristics of big data in energy management in buildings.

non-structured. Applications were based on different techniques for each type of data, as in the work of [81]; or they transformed analog to digital data, as in 82].

FR2. ***Networking layer:*** Not all the works that were analyzed study how to transmit or communicate the collected data. For example, in [82], the authors grouped the data based on explicit variables for further analysis; and in [83], the authors stated in their proposal that data must communicate correctly with the services. However, in [84], the authors used this layer as an intermediary between the data and the applications.

FR3. ***Data cleaning and preprocessing layer:*** Some of the investigations focused on data cleaning and processing. This layer is important since not all data are correct, and they generally come from various sources. In [82], the authors preprocess data that are out of range or have missing values. In addition, some works use techniques such as extraction, transformation and loading (ETL) in this layer to preprocess the data before they are loaded into the data storage layer [85]–[87].

FR3. ***Data storage and processing layer:*** Many works emphasize this layer since it is the key to maintaining the records and files to be processed later using analysis tools. Some studies [81], [82] proposed using various techniques and technologies for data storage such as HDFS, HBASE, and HIVE. Furthermore, in [101], the authors stated that there are multiple methods to store and process data (for example, centralized/distributed or locally/remotely).

FR4. ***Integration layer:*** Certain studies implemented this layer since it is used for M2M communications, as in [102]; incidentally, other studies used this layer as an intermediary layer between data and devices or services, as in [80], [88] and [103].

FR5. ***Data analysis layer:*** A large number of works considered this layer in their studies since it is the critical layer for analyzing and extracting the most knowledge from the collected data. In [64], the authors propose using Apache Spark since it is a very versatile tool for analyzing data distributed in clusters; some applications used cloud capabilities to analyze huge datasets [103], [104].

FR6. ***Application and presentation layer:*** A considerable number of articles analyzed and implemented this layer. For example, in [102], the application layer hosts business processes, protocols, and programming logic, while the presentation layer houses human task mediations such as business service registration and defining the interaction between services.

TABLE 3. Summary of the functional requirements reported.

Documents	Ref.	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8
K. Zhou et al., 2016	[43]	■	■	■	■	■	■	■	■
H. Daki et al., 2018	[81]	■			■	■			
X. He et al., 2018	[88]				■			■	
Y. Guo et al., 2018	[71]	■		■	■		■	■	
V. Marinakis et al., 2018	[64]	■		■	■		■	■	
S. Martin. et al., 2015	[84]	■	■					■	
D. Sembroiz et al., 2018	[89]	■	■			■		■	
Y. Simmhan et al., 2018	[90]	■	■	■			■	■	■
J. Chou et al., 2016	[91]	■					■	■	
H. Gökçe; K. Gökçe, 2013	[85]			■	■			■	
H. Gökçe; K. Gökçe, 2014	[92]	■						■	
H. Gökçe; K. Gökçe, 2014	[86]			■	■		■	■	
B. Cheng et al., 2015	[93]	■			■			■	
E. Gomes et al., 2016	[94]	■		■	■			■	
L. Linder et al., 2017	[95]	■			■			■	
M. Babar et al., 2017	[82]	■	■	■	■			■	■
C. Chilipirea et al., 2017	[96]	■		■	■	■	■	■	■
M. Malik et al., 2017	[97]	■			■	■			
I. Khajenasiri et al., 2017	[98]	■	■			■		■	
S. Lazarova-Molnar et al., 2017	[99]	■						■	
E. F. Zambom Santana et al., 2017	[83]	■	■	■	■	■	■	■	
L. Kallab et al., 2017	[100]	■	■		■	■	■	■	
E. H. A. Gomes et al., 2018	[65]	■		■	■		■	■	
A. M. Shahat Osman, 2019	[63]	■			■	■	■	■	
K. Vatanparvar et al., 2018	[101]	■			■	■	■		
H. Elhoseny et al., 2016	[102]	■				■		■	
N. Mohamed et al., 2018	[103]	■			■	■	■		
J. Al-Jaroodi et al., 2018	[104]	■			■	■	■		
M. Sinderen et al., 2010	[30]	■						■	■
R. Santos; P. Carreira, 2014	[105]	■						■	
P. Angulo et al., 2017	[31]	■	■					■	
V. Degelar et al., 2013	[21]	■			■			■	
	TOTAL	**29** ***(91%)***	**9** ***(28%)***	**11** ***(34%)***	**21** ***(66%)***	**13** ***(41%)***	**14** ***(44%)***	**26** ***(81%)***	**5** ***(16%)***

Legend: ■ "Reported" □ "Do not reported"

However, some studies used this layer to interact with users or automation applications through APIs or web applications [89], [93].

FR7. Decision maker layer: Some works considered this layer due to the importance of making decisions based on previously processed and analyzed data. Some develop applications so that the decisions are automated or manual (such as expert analysis) [43], [82], [90], [96].

According to the 32 works analyzed and summarized in Table 3, we observed that from 66% – 91% of the works implemented or analyzed the FRs' "data sources layer" (FR1), "data storage and processing layer" (FR4) and "application and presentation layer" (FR7). Therefore, these functional requirements exploit the functionalities for systems focused on the energy efficiency of buildings.

However, from 34% – 44% of the researchers expressed an interest in the functional requirements "data cleaning and preprocessing layer" (FR3), "integration layer" (FR5) and "data analysis layer" (FR6) since they represent important aspects that must be provided by a software architecture aimed at improving the energy efficiency of buildings.

Finally, the "networking layer" (FR2) and "decision-maker layer" (FR8) were considered by 16% – 28% of the works; these are the functional requirements least analyzed or implemented in the studies found.

In any case, the incorporation of all these functionalities (FR1 – FR8) in the architecture will be subject to the specific application on which it is focused.

2) NON-FUNCTIONAL REQUIREMENTS

Table 4 summarizes the articles retrieved with each of the NFRs reported in the analyzed studies. A software architecture aimed at the energy efficiency of buildings is related to some NFRs of large distributed systems (such as interoperability, scalability, and heterogeneity, among others) and

TABLE 4. Summary of the non-functional requirements reported.

Documents	Ref.	NFR1	NFR2	NFR3	NFR4	NFR5	NFR6
H. Daki et al., 2018	[81]	■	■				■
X. He et al., 2018	[88]	■	■				■
V. Marinakis et al., 2018	[64]	■		■			■
Y. Guo et al., 2018	[71]	■					■
S. Martin. et al., 2015	[84]			■			
M. A. Al Faruque et al., 2016	[107]	■		■		■	
D. Sembroiz et al., 2018	[89]	■		■	■	■	
Y. Simmhan et al., 2018	[90]	■		■		■	
J. Chou et al., 2016	[91]	■					
H. Gökçe; K. Gökçe, 2014	[92]			■			
H. Gökçe; K. Gökçe, 2014	[86]			■			
B. Cheng et al., 2015	[93]	■	■				
E. Gomes et al., 2016	[94]	■					
L. Linder et al., 2017	[95]	■	■	■		■	
M. Babar et al., 2017	[82]	■		■			
C. Chilipirea et al., 2017	[96]	■					■
L. Kallab et al., 2017	[100]	■	■	■			
M. Malik et al., 2017	[97]	■	■	■			
E. F. Santana et al., 2017	[83]	■		■		■	
E. H. A. Gomes et al., 2018	[65]						
A. M. Shahat Osman, 2019	[63]	■		■	■	■	
N. Mohamed et al., 2017	[108]			■	■	■	
K. Vatanparvar et al., 2018	[101]	■		■			
H. Elhoseny et al., 2016	[102]	■		■		■	
N. Mohamed et al., 2018	[103]	■		■		■	
J. Al-Jaroodi et al., 2018	[104]	■		■		■	
M. Sinderen et al., 2010	[30]			■			
R. Santos.; P. Carreira, 2014	[105]			■	■		
P. Angulo et al., 2017	[31]	■		■	■		■
	TOTAL	**22** *(76%)*	**6** *(21%)*	**21** *(72%)*	**5** *(17%)*	**9** *(31%)*	**5** *(17%)*

Legend: ■ "Reported" □ "Do not reported"

sensitive and personal data (such as security and privacy). Within this context, we retrieved 29 articles with

each of the non-functional requirements reported in the different studies, which we describe below:

NFR1. ***Scalability:*** A considerable number of studies considered this requirement due to the number of users and services that can access or use the infrastructure and the enormous amount of data it can store, which increases over time. In [93], the authors stated that a data repository can be expanded and supported by a cluster of CouchDB servers. In addition, the scalability of big data processing demands is provided by an HDFS [88].

NFR2. ***Processing:*** A few investigations mentioned this requirement. For example, in [80] and 87], the authors stated that technologies such as HBASE, which greatly improve data processing, were used since they offer real-time search mechanisms, caching, and server-side programming, among others.

NFR3. ***Interoperability:*** Many works analyzed this non-functional requirement since it is a crucial part of an architecture, giving systems the ability to exchange and share information regardless of the target language or system. Some of these studies adopted different techniques to conduct it, such as through web services [92]; however, in [101], the authors used fog computing to provide the necessary interoperability.

NFR4. ***Heterogeneity:*** A few studies analyzed this requirement. It applies to different areas, as stated in [89], where the authors presented this requirement as a challenge due to the various protocols and existing formats. However, in [63], the authors referred to the heterogeneity of the data source.

NFR5. ***Security and privacy:*** Although it is true that technology offers us great opportunities to process data, the data are at risk of being collected by agents that are external to the implemented architectures. Therefore, this requirement is of great importance since it protects sensitive and private information. For example, in [90] and [106], the authors mentioned some protocols that can be used for IoT architectures. In [107], the authors indicated that implementing a platform using fog computing provides the data privacy required for energy administration; in [63], the authors used Sentry, a service provided by Apache Hadoop, as a role-based authorization system for the data and metadata stored in clusters. In addition, SmartCityWare 108]; provides security mechanisms within its functions as a service.

NFR6. ***Fault tolerance:*** Fault tolerance is extremely important for a computer system since it allows a system to respond regardless of whether any of its components or services fail. For example, in [65], [80] and [87], the authors used a NoSQL database with fault tolerance support to correct faults. Similarly, in [96], the Hadoop framework was used due to the advantages it offers in terms of fault tolerance.

According to the 29 studies analyzed and summarized in Table 4, we observed that from 72% – 76% of the works implemented or analyzed the NFRs of ‘‘scalability’’ (NFR1) and ‘‘interoperability’’ (NFR3) for the most part. From this analysis, both non-functional requirements are relevant for an SOA focused on the energy efficiency of buildings since they would allow the management of energy services in the building. Especially, ‘‘interoperability’’ is a software feature of special interest for an SOA focused on the energy efficiency of buildings since it allows all interfaces to be fully understood and to work without restrictions with the subsystems, whether in implementation or access.

Furthermore, 31% of the studies considered ‘‘security and privacy’’ (NFR5) as an important non-functional requirement of the management system of the building components vulnerable to attacks. Therefore, it is important to develop smart strategies in this field.

Finally, the non-functional requirements ‘‘processing’’ (NFR2), ‘‘heterogeneity’’ (NFR4) and ‘‘fault tolerance’’ (NFR6) were considered by 17% – 21% of the studies. However, this does not mean that they are not relevant since in this review the use of these non-functional requirements in these works was still incipient.

E. RQ3. WHAT IMPLEMENTATIONS OF SERVICE-ORIENTED SOFTWARE ARCHITECTURES HAVE BEEN DEVELOPED FOR THE ENERGY EFFICIENCY OF BUILDINGS?

A service-oriented architecture (SOA) is defined as one approach, independent of the protocol of a computer, that allows the determination, recording and invoking of services [26], [27]. Therefore, an SOA can contribute greatly to the energy efficiency of buildings by favoring and supporting the characteristics of big data [35]. In addition, an SOA facilitates the exchange, communication and interaction between services and users, regardless of the protocols used by the building systems. Therefore, it enables other applications to have interoperability, flexibility and scalability [26], [27], [109]–[119].

To illustrate the potential of the combined use of an SOA and big data analysis in one system for the management of the energy efficiency of buildings, it is important for a system to analyze the data from the various devices and sensors and to make control decisions, including the establishment, change or reconfiguration of the operating parameters of energy systems, within the different sections of the building. The controllers act on functional rules based on the data collected and the data history. These are processed and organized by the various services, enabling the construction of a knowledge base used to develop maintenance plans, renew or improve equipment, etc. An SOA enables the continuous flow of data and information between applications or management services to optimize the energy efficiency.

Within this perspective, only 12 articles referred to the implementation of an SOA applied to building energy efficiency. Table 5 summarizes the corresponding implementations found in these studies.

TABLE 5. Summary of SOA implementation for building energy efficiency.

Documents	Ref.	Middleware-services	Web-services
V. Degeler et al., 2013	[21]	Reported	
M. van Sinderen et al. 2010	[30]	Reported	
P. Angulo et al. 2017	[31]		Reported
H. U. Gökçe et al. 2014	[86]		Reported
N. Mohamed et al. 2018	[103]	Reported	
H. Ufuk Gökçe et al. 2014	[92]		Reported
I. Khajenasiri et al. 2017	[98]	Reported	
R. Santos et al. 2014	[105]	Reported	
M. A. Al Faruque et al. 2016	[107]		Reported
N. Mohamed et al. 2017	[108]	Reported	
H. Zhao et al. 2015	[120]	Reported	
I. Petri, et al. 2015	[121]	Reported	
	TOTAL	8 *(67%)*	4 *(33%)*

Legend: [grey] ‘‘Reported’’ [white] ‘‘Do not reported’’

According to the 12 papers analyzed and summarized in Table 5, an SOA was implemented as a middleware service in 67% of the studies, while it was implemented as a web service in only 33% of the studies. However, these results indicate that SOA implementation in the studied context is in practice scarce since it is used only for the exchange of information of certain services, such as in [92], which developed a web service for the extraction of the data registered by sensors. However, there is a new paradigm called microservices, which presents various functionalities that would expand the functionalities of a software architecture aimed at the energy efficiency of buildings [36].

VI. DISCUSSION OF THE STATE-OF-THE-ART FINDINGS

This study has been conducted with the aim of identifying and analyzing the software requirements for a service-oriented architecture (SOA) that incorporates the software functionalities (interoperability and versatility) and big data characteristics that best represent the energy management of a building, thus contributing to its energy efficiency. The main findings obtained from the research questions posed are presented below.

A. FINDINGS RELATED TO RQ1

There are several significant findings applicable to RQ1. First, the results of this study indicate that the fundamental characteristics that best represent an architecture that enables the use of big data in the energy management of buildings are the velocity, volume, variety and value. These characteristics are of great importance and utility within this area since they are capable of supporting various processes, as indicated in [71]. Similarly, it is necessary to consider the problems presented by big data in this sector [23].

Furthermore, in the second finding, the building sector is too complex to analyze due to the large amount and types of data (stochastic or deterministic) it generates. Therefore, the characteristics of big data play an important role in the energy efficiency of buildings as they allow the application of analysis techniques to extract the value of these data. In addition, it makes it easier for building managers to make key decisions related to the energy efficiency of buildings [14], [23], [69], [122]–[125].

Regarding the third finding, another important characteristic of big data to consider within the energy management of buildings is the veracity [42], [44]. This characteristic is particularly relevant since buildings have many heterogeneous systems (data sources) that generate a large number of data types (structured data, unstructured data, real-time data, event data, etc.). In addition, they contain valuable information that is often wasted. Therefore, it is necessary to establish analysis tools or techniques that allow the extraction of significant information for better decision making.

Finally, we rely on these five big data characteristics (velocity, volume, variety, value and veracity) to define data management, but not data analysis, which will be addressed in future research.

B. FINDINGS RELATED TO RQ2

In this section, we discuss the findings most relevant to the requirements of software (functional and non-functional) found in the works cited.

1) FUNCTIONAL REQUIREMENTS

There are several interesting findings on this point. First, the works cited used functional requirements (FRs) according to the needs or context that were being addressed, such as in [82], [83], [90] and [96]. However, it is important to consider the possible bias in these results since these requirements were gathered according to the context in which the studies used them.

With regard to the second finding, it is important to consider the six FRs most cited in this study (FR1 and FR3–FR7). This finding reinforces our view on the requirements of software, specifically of the FRs, necessary for a software architecture that allows the integration of software services to support the energy efficiency of buildings.

2) NON-FUNCTIONAL REQUIREMENTS

There are several significant findings on this point. Regarding non-functional requirements (NFRs), a quite interesting finding is that of the six NFRs found in the work, more than 72% of the studies cited analyzed or implemented the NFRs for scalability and interoperability. These results can be explained by the fact that buildings contain a number of devices (sensors, actuators, etc.) and equipment (HVAC system, lighting, etc.), which in turn generate information. Therefore, they require software architectures that are scalable and interoperable [23], [95]. In summary, the two NFRs found are essential attributes for an architecture within the context studied. In other words, the NFRs make it possible to guarantee that the FRs are capable of processing or managing the user or service information.

In relation to the second finding, the analyzed studies coincide with previous research in highlighting the advantage of interoperability as a software functionality (feature) in service-oriented architectures. However, we do not clearly identify the versatility within these studies applied to the energy efficiency of buildings.

C. FINDINGS RELATED TO RQ3

There are several interesting findings applicable to RQ3. First, there is little evidence of the use of an SOA in the field of the energy efficiency of buildings. In fact, these studies used it as an information exchange layer to support some legacy services.

Another interesting finding was the identification of a second generation of SOA-based software architecture called the microservice architecture (MSA) [126]. This new software architectural style structures an application as a collection of small services [36]–[38]. Additionally, it has great advantages such as low coupling, scalability, being highly maintainable, being versatile and independently deploying services, among others [38]. Furthermore, we consider that an MSA can solve the versatility feature required in our study. Therefore, both generations (SOA and MSA) can provide great advantages, as described in [126].

D. THREATS TO VALIDITY

In this section, we discuss some of the threats to the validity of our study.

1) SEARCH STRATEGY

The most likely threat in this step is that some relevant documents may have been excluded. To reduce this threat, we used seven of the most important digital scientific databases for document retrieval. We adjusted each of the keywords in the different search engines. Similarly, we created different subgroups of these keywords to retrieve as many studies as possible. These keywords were corroborated among and approved by the authors.

2) SELECTION OF STUDIES

This threat to validity could be due to the authors' objective judgment in the selection of the studies. To mitigate this threat, we rigorously followed the selected review protocol. We validated each of the studies with the aforementioned selection criteria. Additionally, any study that raised questions regarding the criteria was discussed among the authors. Furthermore, we define the study period from 2014 to 2020 in criterion E1 since we want to know the new trends that have emerged on this matter. We are aware that there were proposals in previous years; however, we wanted to build on the new trends that exist for these technologies.

3) DATA EXTRACTION

Regarding data extraction, there may be biases in this process that affected the results and analysis of the selected works. To mitigate this, the different elements extracted in this SLR for each research question were discussed and verified among the authors, who reached an agreement on each of the elements obtained. Therefore, with these measures, the bias was reduced.

VII. RECOMMENDATIONS FOR FUTURE RESEARCH DIRECTIONS

In this section, we briefly discuss some recommendations for future research directions derived from the SLR.

A. DEMAND-SIDE MANAGEMENT

Demand-side management is a very important point to consider within the energy efficiency of buildings. Anticipating the demand peaks for energy using intelligent services (artificial intelligence, machine learning, etc.) would help improve the energy efficiency of a building and the economic costs, among other aspects. In addition to anticipating demand, the suppliers or producers of energy could reduce their power generation and, as a consequence, reduce their emissions [127]–[129].

Therefore, future research should focus on studying the necessary software requirements (FRs and NFRs) to establish a smarter software architecture for demand-side management. Additionally, it is necessary to develop techniques or tools that are capable of adapting to circumstances, such as the current circumstances caused by COVID-19, so that the system can be more efficient, faster and more reliable for the management of the demand side [130], [131].

B. NORMS, STANDARDS, DIRECTIVES AND INITIATIVES

Future studies on the different software service-oriented architectures that address the energy efficiency in buildings should analyze the technical algorithms that incorporate and identify the energy use of the equipment and optimize the energy of the building. These techniques are applied to energy performance models for buildings with different sizes, locations and sectors; they must contemplate the norms, standards, guidelines and initiatives proposed by various organizations worldwide [13], [132]–[135].

As an example, the UNE-EN 15251 standard proposes criteria for the energy management of buildings; therefore, it would be relevant to study how the different software service-oriented architectures identify the main foci of the consumption and energy generation in buildings, to study how parameters are monitored by analyzing the energy consumed based on the analysis of heterogeneous sources of data and to propose actions specific to minimizing the energy consumption. In addition, since the buildings have different energy use profiles, it is also necessary to use data and models that characterize the main contributors of energy consumption. For example, according to ASHRAE [136], in residential buildings, the energy consumed is primarily due to the equipment used by their occupants; in addition, in industrial buildings, the energy consumption is associated mostly with the operations of the machinery and industry infrastructure dedicated to production processes.

VIII. CONCLUSION AND FUTURE WORK

In this state-of-the-art study, we developed and executed an SLR following Kitchenham's methodological procedure to identify relevant works that analyze the software requirements for a service-oriented software architecture and the characteristics of big data that have been implemented in recent years to study energy-efficient buildings.

Once the SLR was conducted, we obtained a total of 97 relevant works that allowed us to generate favorable responses to our research questions.

We found that the characteristics of big data play essential roles in the development of a software architecture focused on the energy efficiency of buildings. Furthermore, the software requirements (FRs and NFRs) found, which to the best of our knowledge are classified for the first time herein, allowed us to provide a general idea of the necessary requirements for the development of software architectures in this area. In addition, it is important to highlight that these requirements must be considered in accordance with the needs to be solved and the area to which they are addressed. For example, the software requirements for a data center, factory, and office are not the same.

In addition, we detected that an SOA does comply with the functionality of interoperability software since several studies use it as an intermediary for the heterogeneous components or systems that buildings possess. Additionally, we did not find studies that consider the software functionality of versatility.

Considering this, we have identified a trend in the second generation of the service-oriented architecture (SOA), called the microservices architecture (MSA), which treats services in a distributed manner and translates into multiple benefits, as indicated in the work of [137]. Therefore, this MSA could support the software functionality of versatility within our study context.

TABLE 6. Summary of the findings in the literature.

Year	Authors	Approach	Application	Styles	Functional requirements	Non-Functional requirements	Ref.
2010	Sinderen, M. et al.	Architecture	Houseshold Energy Management	SOA	✓ Context sensor services ✓ Control process for decisions ✓ Applications	✓ Interoperability	[30]
2013	H. Gökçe; K. Gökçe	Architecture	Building monitoring and control	Layered	✓ ETL layer ✓ Data warehouse core layer ✓ Information representation layer	-	[85]
2013	Degelar, V. et al.	Architecture	Smart Environments	SOA	✓ Physical layer ✓ Data repository ✓ Composition layer for interface	-	[21]
2014	H. Gökçe; K. Gökçe	Architecture	Energy Efficient Building	Layered	✓ Data Layer ✓ Information Layer ✓ Tool layer	✓ Interoperability ✓ Scalability	[92]
2014	H. Gökçe; K. Gökçe	Architecture	Building monitoring, analysis and optimization	Layered	✓ Data warehouse core ✓ ETL ✓ Intelligent control module ✓ Information representation	✓ Interoperability ✓ Monitoring	[86]
2014	Santos, R.; Carreira, P.,	Architecture	Building Energy Management Systems	SOA	✓ Devices layer ✓ Application layer	✓ Interoperability ✓ Heterogeneity handling	[105]
2015	B. Cheng et al.	Architecture	Smart City	Layered	✓ Data collection ✓ Data storage ✓ Data processing ✓ Applications	✓ Interoperability ✓ Scalability ✓ Processing	[93]
2015	H. Zhao et al.	Framework	Building design	SOA	-	-	[120]
2015	S. Martin. et al.	Architecture	Smart Grid	Layered	✓ Data layer ✓ Communication Logic Layer ✓ Application Layer	✓ Interoperability ✓ Security ✓ Privacy	[84]
2015	I. Petri et al.	Platform	Energy Efficient Building	SOA	-	-	[121]
2016	E. Gomes et al.	Model	Smart City	Layered	✓ Data sources ✓ ETL ✓ Data warehouse ✓ Data processing ✓ Users Visualization	✓ Scalability	[94]
2016	K. Zhou et al.	Model	Smart Energy	Architecture for Big Data	✓ Data collection, transmission and storage ✓ Data cleaning and processing ✓ Data integration and feature selection ✓ Data mining and knowledge Discovery ✓ Representation, visualization and application ✓ Intelligent decision-making and real-time interaction ✓ Smart energy management	-	[43]
2016	J. Chou et al.	Framework	Energy Efficient Building		-	✓ Scalability ✓ Security	[91]
2016	H. Elhoseny et al.	Architecture	Smart City	SOA and Layered	✓ Data layer ✓ Integration layer ✓ Application layer ✓ Presentation layer	✓ Interoperability ✓ Scalability	[102]
2016	M. A. Al Faruque et al.	Platform	Energy management	Cloud computing	-	✓ Interoperability ✓ Scalability ✓ Privacy	[107]

TABLE 6. ***(Continued.)*** **Summary of the findings in the literature.**

2017	Angulo, P. et al.	Architecture	Building monitoring	SOA	✓ Sensor layer ✓ Communication layer ✓ Application	✓ Interoperability	[31]
2017	L. Linder et al.	Architecture	Smart Building	Layered	✓ Data sources ✓ Data storage and processing ✓ Application layer	✓ Interoperability ✓ Privacy ✓ Scalability ✓ Processing	[95]
2017	M. Babar et al.	Architecture	Smart City	Layered	✓ Data acquistion and aggregation module ✓ Data computation and processing module ✓ Decision and application module	✓ Interoperability ✓ Scalability ✓ Fault tolerance	[82]
2017	C. Chilipirea et al.	Architecture	Smart City	Layered	✓ Data sources ✓ Data normalization ✓ Data brokering ✓ Data storage ✓ Data analysis ✓ Data visualization ✓ Decisions	✓ Scalability ✓ Fault tolerance	[96]
2017	M. Malik et al.	Proposal	Energy data analysis	Layered	✓ Data collection ✓ Data distribution ✓ Data storage	✓ Interoperability ✓ Scalability ✓ Processing ✓ Fault tolerance	[97]
2017	I. Khajenasiri et al.	Model	Energy control	Layered	✓ Sensing layer ✓ Network layer ✓ Service layer ✓ Interface layer	-	[98]
2017	S. Lazarova-Molnar et al.	Framework	Building data analysis	Layered	✓ Data tier ✓ Application tier ✓ Presentation tier	-	[99]
2017	E. F. Zambom Santana et al.	Proposal	Smart City	Layered	✓ Cloud & Networking ✓ Middleware ✓ User Management ✓ Social Gateway ✓ Big Data Management ✓ Application	✓ Interoperability ✓ Scalability ✓ Security ✓ Privacy	[83]
2017	L. Kallab et al.	Framework	Building energy management	Layered	✓ Field Level ✓ Core Platform Level ✓ Management Level ✓ End-User Level	✓ Interoperability ✓ Scalability ✓ Processing ✓ Heterogeneous	[100]
2017	N. Mohamed et al.	Platform	Smart City	SOA	-	✓ Interoperability ✓ Security	[108]
2018	H. Daki et al.	Architecture	Storage system electrical	Architecture for Big Data	✓ Data collection ✓ Data integration ✓ Data storage	✓ Scalability ✓ Processing ✓ Fault tolerance	[81]
2018	X. He et al.	Architecture	Smart City	Architecture for Big Data	✓ Data storage plane ✓ Data processing plane ✓ Data application plane	✓ Scalability ✓ Processing ✓ Fault tolerance	[88]
2018	N. Mohamed et al.	Architecture	Smart Building	Cloud computing	-	-	[138]
2018	Y. Zhang et al.	Framework	Energy data analysis	-	-	-	[87]
2018	Y. Guo et al.	Platform	Energy management	Architecture for Big Data	✓ Data sources ✓ Data interface ✓ Big data management ✓ Analytic engine ✓ Application and display	✓ Scalability ✓ Heterogeneous	[71]
2018	E. H. A. Gomes et al.	Model	Smart City	Layered	✓ Data sources ✓ ETL ✓ Data storage ✓ Data processing ✓ Search and Analysis	✓ Scalability	[65]
2018	V. Marinakis et al.	Architecture	Smart Energy	Architecture for Big Data	✓ Data interoperability and semantification layer ✓ Data storage cluster	✓ Interoperability ✓ Scalability ✓ Fault tolerance	[64]

TABLE 6. *(Continued.)* Summary of the findings in the literature.

					✓ Analytics services		
2018	D. Sembroiz et al.	Architecture	Smart Building	Cloud computing	✓ Perception layer ✓ Network layer (Data aggregator) ✓ Middleware ✓ Application layer	✓ Interoperability ✓ Scalability ✓ Privacy ✓ Security ✓ Heterogeneous	[89]
2018	N. Mohamed et al.	Architecture	Smart Building	SOA and Layered	✓ Control layer ✓ Configuration layer ✓ Planning layer	✓ Interoperability ✓ Security ✓ Scalability	[103]
2018	J. Al-Jaroodi et al.	Architecture	Smart City	SOA and Layered	✓ Control layer ✓ Configuration layer ✓ Planning layer	✓ Interoperability ✓ Security ✓ Scalability	[104]
2018	Y. Simmhan et al.	Architecture	Smart City	Cloud computing	✓ Sensing and actuation ✓ Networking ✓ Data acquisition and curation ✓ Data analytics and visualization ✓ Decision making	✓ Scalability ✓ Security ✓ Privacy ✓ Interoperability	[90]
2018	K. Vatanparvar et al.	Architecture	Energy management	SOA	✓ IoT ✓ Fog computing ✓ Cloud computing	✓ Interoperability ✓ Scalability	[101]
2019	A. M. Shahat Osman	Framework	Smart City	Layered	✓ Platform layer ✓ Data processing layer	✓ Scalabilty ✓ Heterogeneous ✓ Privacy ✓ Security ✓ Interoperability	[63]
2019	Fiware Foundation	Framework	Internet of Future	-	-	-	[106]

Finally, these findings suggest that, in general, both generations can coexist in a so-called intergenerational architecture (SOA and MSA), which is why this issue will be addressed in future studies.

APPENDIX

See Table 6.

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REFERENCES

[1] S. S. K. Kwok and E. W. M. Lee, "A study of the importance of occupancy to building cooling load in prediction by intelligent approach," *Energy Convers. Manage.*, vol. 52, no. 7, pp. 2555–2564, Jul. 2011, doi: 10.1016/j.enconman.2011.02.002.

[2] H. Yoshino, T. Hong, and N. Nord, "IEA EBC annex 53: Total energy use in buildings—Analysis and evaluation methods," *Energy Buildings*, vol. 152, pp. 124–136, Oct. 2017, doi: 10.1016/j.enbuild.2017.07.038.

[3] L. Belussi, B. Barozzi, A. Bellazzi, L. Danza, A. Devitofrancesco, C. Fanciulli, M. Ghellere, G. Guazzi, I. Meroni, F. Salamone, F. Scamoni, and C. Scrosati, "A review of performance of zero energy buildings and energy efficiency solutions," *J. Building Eng.*, vol. 25, Sep. 2019, Art. no. 100772, doi: 10.1016/j.jobe.2019.100772.

[4] J. R. Vázquez-Canteli, S. Ulyanin, J. Kämpf, and Z. Nagy, "Fusing tensorflow with building energy simulation for intelligent energy management in smart cities," *Sustain. Cities Soc.*, vol. 45, pp. 243–257, Feb. 2019, doi: 10.1016/j.scs.2018.11.021.

[5] European Commission. (May 16, 2019). *Energy Performance of Buildings Directive*. Accessed: Sep. 09, 2020. [Online]. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[6] A. Magrini, G. Lentini, S. Cuman, A. Bodrato, and L. Marenco, "From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge—The most recent European trends with some notes on the energy analysis of a forerunner PEB example," *Develop. Built Environ.*, vol. 3, Aug. 2020, Art. no. 100019, doi: 10.1016/j.dibe.2020.100019.

[7] M. Economidou, V. Todeschi, P. Bertoldi, D. D'Agostino, P. Zangheri, and L. Castellazzi, "Review of 50 years of EU energy efficiency policies for buildings," *Energy Buildings*, vol. 225, Oct. 2020, Art. no. 110322, doi: 10.1016/j.enbuild.2020.110322.

[8] S. Asadi, M. Nazari-Heris, S. R. Nasab, H. Torabi, and M. Sharifironizi, "An updated review on net-zero energy and water buildings: Design and operation," in *Food-Energy-Water Nexus Resilience and Sustainable Development: Decision-Making Methods, Planning, and Trade-Off Analysis*, S. Asadi and B. Mohammadi-Ivatloo, Eds. Cham, Switzerland: Springer, 2020, pp. 267–290.

[9] D. D'Agostino, P. Zangheri, and L. Castellazzi, "Towards nearly zero energy buildings in Europe: A focus on retrofit in non-residential buildings," *Energies*, vol. 10, no. 1, Jan. 2017, Art. no. 1, doi: 10.3390/en10010117.

[10] N. N. A. Bakar, M. Y. Hassan, H. Abdullah, H. A. Rahman, M. P. Abdullah, F. Hussin, and M. Bandi, "Energy efficiency index as an indicator for measuring building energy performance: A review," *Renew. Sustain. Energy Rev.*, vol. 44, pp. 1–11, Apr. 2015, doi: 10.1016/j.rser.2014.12.018.

[11] N. N. A. Bakar, M. Y. Hassan, H. Abdullah, H. A. Rahman, M. P. Abdullah, F. Hussin, and M. Bandi, "Identification building energy saving using energy efficiency index approach," in *Proc. IEEE Int. Conf. Power Energy (PECon)*, Dec. 2014, pp. 366–370, doi: 10.1109/PECON.2014.7062472.

[12] M. V. Moreno, L. Dufour, A. F. Skarmeta, A. J. Jara, D. Genoud, B. Ladevie, and J.-J. Bezian, "Big data: The key to energy efficiency in smart buildings," *Soft Comput.*, vol. 20, no. 5, pp. 1749–1762, May 2016, doi: 10.1007/s00500-015-1679-4.

[13] *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency*, Eur. Parliament, Brussels, Belgium, 2012.

[14] A. Ridi, N. Zarkadis, G. Bovet, N. Morel, and J. Hennebert, "Towards reliable stochastic data-driven models applied to the energy saving in buildings," in *Proc. Int. Conf. Cleantech Smart Cities Buildings Nano Urban Scale*, Lausanne, Switzerland, Sep. 2013, pp. 1–7. Accessed: Sep. 9, 2020. [Online]. Available: https://hal.archives-ouvertes.fr/hal-00872270.

[15] C. Zhou, Z. Fang, X. Xu, X. Zhang, Y. Ding, X. Jiang, and Y. Ji, "Using long short-term memory networks to predict energy consumption of air-conditioning systems," *Sustain. Cities Soc.*, vol. 55, Apr. 2020, Art. no. 102000, doi: 10.1016/j.scs.2019.102000.

[16] J. Aguilar, A. Garcès-Jimènez, N. Gallego-Salvador, J. A. G. De Mesa, J. M. Gomez-Pulido, and À. J. Garcìa-Tejedor, "Autonomic management architecture for multi-HVAC systems in smart buildings," *IEEE Access*, vol. 7, pp. 123402–123415, 2019, doi: 10.1109/ACCESS.2019.2937639.

[17] L. Mendoza-Pittí, A. Garcès-Jimenez, J. Aguilar, J. M. Gómez-Pulido, and M. Vargas-Lombardo, "Proposal of physical models of multi-HVAC systems for energy efficiency in smart buildings," in *Proc. 7th Int. Eng., Sci. Technol. Conf. (IESTEC)*, Oct. 2019, pp. 641–646, doi: 10.1109/IESTEC46403.2019.00120.

[18] L. M. Escobar, J. Aguilar, A. Garcés-Jiménez, J. A. G. De Mesa, and J. M. Gomez-Pulido, "Advanced fuzzy-logic-based context-driven control for HVAC management systems in buildings," *IEEE Access*, vol. 8, pp. 16111–16126, 2020, doi: 10.1109/ACCESS.2020.2966545.

[19] H. V. V. Priyadarshana, W. K. I. Madushanaka, L. L. L. Anuruddha, G. T. Chathura, H. W. D. Hettiarachchi, and K. T. M. U. Hemapala, "Multi-agent controlled building management system," in *Proc. Innov. Power Adv. Comput. Technol. (i-PACT)*, Apr. 2017, pp. 1–5, doi: 10.1109/IPACT.2017.8244900.

[20] M. W. Ahmad, M. Mourshed, D. Mundow, M. Sisinni, and Y. Rezgui, "Building energy metering and environmental monitoring—A state-of-the-art review and directions for future research," *Energy Buildings*, vol. 120, pp. 85–102, May 2016, doi: 10.1016/j.enbuild.2016.03.059.

[21] V. Degeler, L. I. L. Gonzalez, M. Leva, P. Shrubsole, S. Bonomi, O. Amft, and A. Lazovik, "Service-oriented architecture for smart environments (short paper)," in *Proc. IEEE 6th Int. Conf. Service-Oriented Comput. Appl.*, Dec. 2013, pp. 99–104, doi: 10.1109/SOCA.2013.26.

[22] T. Teich, S. Wolf, T. Neumann, S. Junghans, and S. Franke, "Concept for a service-oriented architecture in building automation systems," *Procedia Eng.*, vol. 69, pp. 597–602, Jan. 2014, doi: 10.1016/j.proeng.2014.03.031.

[23] N. Koseleva and G. Ropaite, "Big data in building energy efficiency: Understanding of big data and main challenges," *Procedia Eng.*, vol. 172, pp. 544–549, Jan. 2017, doi: 10.1016/j.proeng.2017.02.064.

[24] *Proyecto CEI 'Energía Inteligente'*. Accessed: Sep. 09, 2020. [Online]. Available: https://www.campusenergiainteligente.es/en/presentacion/

[25] A. Chehri and H. T. Mouftah, "Service-oriented architecture for smart building energy management," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2013, pp. 4099–4103, doi: 10.1109/ICC.2013.6655203.

[26] M. P. Papazoglou and W.-J. van den Heuvel, "Service oriented architectures: Approaches, technologies and research issues," *VLDB J.*, vol. 16, no. 3, pp. 389–415, Jul. 2007, doi: 10.1007/s00778-007-0044-3.

[27] A. Bouguettaya *et al.*, "A service computing manifesto: The next 10 years," *Commun. ACM*, vol. 60, no. 4, Mar. 2017, doi: 10.1145/2983528.

[28] B. Kitchenham, "Procedures for performing systematic reviews," Dept. Comput. Sci., Keele Univ., Keele, U.K., Tech. Rep. TR/SE-0401, NICTA Tech. Rep. 0400011T.1, Aug. 2004, vol. 33.

[29] D. Mora, M. Taisch, A. W. Colombo, and J. M. Mendes, "Service-oriented architecture approach for industrial 'system of systems': State-of-the-art for energy management," in *Proc. IEEE 10th Int. Conf. Ind. Inform.*, Jul. 2012, pp. 1246–1251, doi: 10.1109/INDIN.2012.6301130.

[30] M. van Sinderen, M. Warnier, and B. Shishkov, "Service-oriented architecture for household energy management," in *Proc. 4th Int. Workshop Enterprise Syst. Technol.*, Athens, Greece, 2010, pp. 51–68, doi: 10.5220/0004465400510068.

[31] P. Angulo, C. C. Guzmán, G. Jiménez, and D. Romero, "A service-oriented architecture and its ICT-infrastructure to support eco-efficiency performance monitoring in manufacturing enterprises," *Int. J. Comput. Integr. Manuf.*, vol. 30, no. 1, pp. 202–214, Jan. 2017, doi: 10.1080/0951192X.2016.1145810.

[32] A. Malatras, A. H. Asgari, T. Baugé, and M. Irons, "A service-oriented architecture for building services integration," *J. Facilities Manage.*, vol. 6, no. 2, pp. 132–151, May 2008, doi: 10.1108/14725960810872659.

[33] A. Karlsen. (Jul. 18, 2019). *Flexibility—A Software Architecture Principle*. Accessed: Jan. 02, 2021. [Online]. Available: https://medium.com/faun/flexibility-a-software-architecture-principle-6eafe045a1d4

[34] H. Calderón-Gómez, L. Mendoza-Pitti, M. Vargas-Lombardo, J. M. Gomez-Pulido, J. L. Castillo-Sequera, J. Sanz-Moreno, and G. Sencion, "Telemonitoring system for infectious disease prediction in elderly people based on a novel microservice architecture," *IEEE Access*, vol. 8, pp. 118340–118354, 2020, doi: 10.1109/ACCESS.2020.3005638.

[35] L. Mendoza-Pittí, J. M. Gómez-Pulido, and M. Vargas-Lombardo, "Software architectures for energy efficiency of buildings: A systematic review," *Revista Iberica de Sistemas e Tecnologias de Informacao*, vol. 2019, no. E23, pp. 40–52, 2019.

[36] T. Cerny, M. J. Donahoo, and J. Pechanec, "Disambiguation and comparison of SOA, microservices and self-contained systems," in *Proc. Int. Conf. Res. Adapt. Convergent Syst. (RACS)*, Kraków, Poland, Sep. 2017, pp. 228–235, doi: 10.1145/3129676.3129682.

[37] F. Rademacher, S. Sachweh, and A. Zundorf, "Differences between model-driven development of service-oriented and microservice architecture," in *Proc. IEEE Int. Conf. Softw. Archit. Workshops (ICSAW)*, Apr. 2017, pp. 38–45, doi: 10.1109/ICSAW.2017.32.

[38] *What are Microservices?* Accessed: Sep. 28, 2019. [Online]. Available: http://microservices.io/index.html

[39] K. Krishnan, *3-D Data Management: Controlling Data Volume, Velocity, and Variety*. Amsterdam, The Netherlands: Morgan Kaufmann, 2013.

[40] M. Bilal, L. O. Oyedele, J. Qadir, K. Munir, S. O. Ajayi, O. O. Akinade, H. A. Owolabi, H. A. Alaka, and M. Pasha, "Big data in the construction industry: A review of present status, opportunities, and future trends," *Adv. Eng. Informat.*, vol. 30, no. 3, pp. 500–521, Aug. 2016, doi: 10.1016/j.aei.2016.07.001.

[41] A. Oussous, F.-Z. Benjelloun, A. A. Lahcen, and S. Belfkih, "Big data technologies: A survey," *J. King Saud Univ., Comput. Inf. Sci.*, vol. 30, no. 4, pp. 431–448, Oct. 2018, doi: 10.1016/j.jksuci.2017.06.001.

[42] A. Gandomi and M. Haider, "Beyond the hype: Big data concepts, methods, and analytics," *Int. J. Inf. Manage.*, vol. 35, no. 2, pp. 137–144, Apr. 2015, doi: 10.1016/j.ijinfomgt.2014.10.007.

[43] K. Zhou, C. Fu, and S. Yang, "Big data driven smart energy management: From big data to big insights," *Renew. Sustain. Energy Rev.*, vol. 56, pp. 215–225, Apr. 2016, doi: 10.1016/j.rser.2015.11.050.

[44] I. Lee, "Big data: Dimensions, evolution, impacts, and challenges," *Bus. Horizons*, vol. 60, no. 3, pp. 293–303, May 2017, doi: 10.1016/j.bushor.2017.01.004.

[45] B. Furht and F. Villanustre, "Introduction to big data," in *Big Data Technologies and Applications*. Cham, Switzerland: Springer, 2016, pp. 3–11.

[46] S. M. Borodo, S. M. Shamsuddin, and S. Hasan, "Big data platforms and techniques," *Indonesian J. Electr. Eng. Comput. Sci.*, vol. 1, no. 1, p. 191, Jan. 2016, doi: 10.11591/ijeecs.v1.i1.pp191-200.

[47] A. Cravero, O. Saldana, R. Espinosa, and C. Antileo, "Big data architecture for water resources management: A systematic mapping study," *IEEE Latin Amer. Trans.*, vol. 16, no. 3, pp. 902–908, Mar. 2018, doi: 10.1109/TLA.2018.8358672.

[48] I. Taleb, M. A. Serhani, and R. Dssouli, "Big data quality: A survey," in *Proc. IEEE Int. Congr. Big Data (BigData Congress)*, San Francisco, CA, USA, Jul. 2018, pp. 166–173, doi: 10.1109/BigDataCongress.2018.00029.

[49] E. Y. T. Adesta and D. Agusman, "Internet of Things and big data revolution in the context of green technology," Seminar Nasional Inovasi dan Aplikasi Teknologi di Industri, Indonesia, Tech. Rep. Prosiding SENIATI 2018, 2018, p. 9.

[50] M. A.-U.-D. Khan, M. F. Uddin, and N. Gupta, "Seven V's of big data understanding big data to extract value," in *Proc. Zone 1 Conf. Amer. Soc. Eng. Educ.*, Bridgeport, CT, USA, Apr. 2014, pp. 1–5, doi: 10.1109/ASEEZone1.2014.6820689.

[51] E. A. Nuaimi, H. A. Neyadi, N. Mohamed, and J. Al-Jaroodi, "Applications of big data to smart cities," *J. Internet Services Appl.*, vol. 6, no. 1, Aug. 2015, Art. no. 25, doi: 10.1186/s13174-015-0041-5.

[52] X. Jin, B. W. Wah, X. Cheng, and Y. Wang, "Significance and challenges of big data research," *Big Data Res.*, vol. 2, no. 2, pp. 59–64, Jun. 2015, doi: 10.1016/j.bdr.2015.01.006.

[53] C. K. Emani, N. Cullot, and C. Nicolle, "Understandable big data: A survey," *Comput. Sci. Rev.*, vol. 17, pp. 70–81, Aug. 2015, doi: 10.1016/j.cosrev.2015.05.002.

[54] H. Daki, A. E. Hannani, A. Aqqal, A. Haidine, and A. Dahbi, "Big data management in smart grid: Concepts, requirements and implementation," *J. Big Data*, vol. 4, no. 1, Dec. 2017, Art. no. 13, doi: 10.1186/s40537-017-0070-y.

[55] V. C. Storey and I.-Y. Song, "Big data technologies and management: What conceptual modeling can do," *Data Knowl. Eng.*, vol. 108, pp. 50–67, Mar. 2017, doi: 10.1016/j.datak.2017.01.001.

[56] J. I. Rodríguez-Molano, L. E. Contreras-Bravo, and E. R. López-Santana, "Big data tools for smart cities," in *Data Mining and Big Data*, vol. 10943, Y. Tan, Y. Shi, and Q. Tang, Eds. Cham, Switzerland: Springer, 2018, pp. 649–658.

[57] K. N. Singh, R. K. Behera, and J. K. Mantri, "Big data ecosystem: Review on architectural evolution," in *Emerging Technologies in Data Mining and Information Security*, vol. 813, A. Abraham, P. Dutta, J. K. Mandal, A. Bhattacharya, and S. Dutta, Eds. Singapore: Springer, 2019, pp. 335–345.

[58] C. Costa and M. Y. Santos, "Big data: State-of-the-art concepts, techniques, technologies, modeling approaches and research challenges," *Int. J. Comput. Sci.*, vol. 44, no. 3, pp. 285–301, 2017.

[59] N. E. Aboudi and L. Benhlima, "Big data management for healthcare systems: Architecture, requirements, and implementation," *Adv. Bioinf.*, vol. 2018, pp. 1–10, Jun. 2018, doi: 10.1155/2018/4059018.

[60] M. Usama, M. Liu, and M. Chen, "Job schedulers for big data processing in Hadoop environment: Testing real-life schedulers using benchmark programs," *Digit. Commun. Netw.*, vol. 3, no. 4, pp. 260–273, Nov. 2017, doi: 10.1016/j.dcan.2017.07.008.

[61] F. Almeida, "Big data: Concept, potentialities and vulnerabilities," *Emerg. Sci. J.*, vol. 2, no. 1, pp. 1–10, Mar. 2018, doi: 10.28991/esj-2018-01123.

[62] A. F. C. Santos, I. P. Teles, O. M. P. Siqueira, and A. A. de Oliveira, "Big data: A systematic review," in *Information Technology—New Generations*, vol. 558, S. Latifi, Ed. Cham, Switzerland: Springer, 2018, pp. 501–506.

[63] A. M. S. Osman, "A novel big data analytics framework for smart cities," *Future Gener. Comput. Syst.*, vol. 91, pp. 620–633, Feb. 2019, doi: 10.1016/j.future.2018.06.046.

[64] V. Marinakis, H. Doukas, J. Tsapelas, S. Mouzakitis, Á. Sicilia, L. Madrazo, and S. Sgouridis, "From big data to smart energy services: An application for intelligent energy management," *Future Gener. Comput. Syst.*, vol. 110, pp. 572–586, Sep. 2020, doi: 10.1016/j.future.2018.04.062.

[65] E. H. A. Gomes and M. A. R. Dantas, "An infrastructure model for smart cities based on big data," *Int. J. Grid Utility Comput.*, vol. 9, no. 4, p. 11, 2018.

[66] P. V. Desai, "A survey on big data applications and challenges," in *Proc. 2nd Int. Conf. Inventive Commun. Comput. Technol. (ICICCT)*, Coimbatore, India, Apr. 2018, pp. 737–740, doi: 10.1109/ICICCT.2018.8472999.

[67] D. P. Acharjya and K. Ahmed, "A survey on big data analytics: Challenges, open research issues and tools," *Int. J. Adv. Comput. Sci. Appl.*, vol. 7, no. 2, pp. 511–518, 2016, doi: 10.14569/IJACSA.2016.070267.

[68] A. Fernández, S. del Río, V. López, A. Bawakid, M. J. del Jesus, J. M. Benítez, and F. Herrera, "Big data with cloud computing: An insight on the computing environment, mapreduce, and programming frameworks: Big data with cloud computing," *Wiley Interdiscipl. Rev., Data Mining Knowl. Discovery*, vol. 4, no. 5, pp. 380–409, Sep. 2014, doi: 10.1002/widm.1134.

[69] L. Wen, K. Zhou, S. Yang, and L. Li, "Compression of smart meter big data: A survey," *Renew. Sustain. Energy Rev.*, vol. 91, pp. 59–69, Aug. 2018, doi: 10.1016/j.rser.2018.03.088.

[70] K. Zhou and S. Yang, "Understanding household energy consumption behavior: The contribution of energy big data analytics," *Renew. Sustain. Energy Rev.*, vol. 56, pp. 810–819, Apr. 2016, doi: 10.1016/j.rser.2015.12.001.

[71] Y. Guo, Z. Yang, S. Feng, and J. Hu, "Complex power system status monitoring and evaluation using big data platform and machine learning algorithms: A review and a case study," *Complexity*, vol. 2018, pp. 1–21, Sep. 2018, doi: 10.1155/2018/8496187.

[72] S. Pancholi, "Solving big data challenges us electric utility industry," in *Proc. IEEE PES Gen. Meeting Presentation*, National Harbor, MD, USA, Jul. 2014, pp. 27–31.

[73] B. P. Bhattarai, S. Paudyal, Y. Luo, M. Mohanpurkar, K. Cheung, R. Tonkoski, R. Hovsapian, K. S. Myers, R. Zhang, P. Zhao, M. Manic, S. Zhang, and X. Zhang, "Big data analytics in smart grids: State-of-the-art, challenges, opportunities, and future directions," *IET Smart Grid*, vol. 2, no. 2, pp. 141–154, Jun. 2019, doi: 10.1049/iet-stg.2018.0261.

[74] H. Jaakkola and B. Thalheim, "Architecture-driven modelling methodologies," in *Proc. Inf. Modelling Knowl. Bases*, 2011, p. 21.

[75] L. Dobrica and E. Niemela, "A survey on software architecture analysis methods," *IEEE Trans. Softw. Eng.*, vol. 28, no. 7, pp. 638–653, Jul. 2002, doi: 10.1109/TSE.2002.1019479.

[76] A. Sharma, M. Kumar, and S. Agarwal, "A complete survey on software architectural styles and patterns," *Procedia Comput. Sci.*, vol. 70, pp. 16–28, Jan. 2015, doi: 10.1016/j.procs.2015.10.019.

[77] M. Dabbagh and S. P. Lee, "An approach for integrating the prioritization of functional and nonfunctional requirements," *Sci. World J.*, vol. 2014, Apr. 2014, Art. no. e737626, doi: 10.1155/2014/737626.

[78] J. Eckhardt, A. Vogelsang, and D. M. Fernández, "Are 'non-functional' requirements really non-functional?: An investigation of non-functional requirements in practice," in *Proc. 38th Int. Conf. Softw. Eng. (ICSE)*, May 2016, pp. 832–842, doi: 10.1145/2884781.2884788.

[79] D. Ameller, X. Burgués, D. Costal, C. Farré, and X. Franch, "Non-functional requirements in model-driven development of service-oriented architectures," *Sci. Comput. Program.*, vol. 168, pp. 18–37, Dec. 2018, doi: 10.1016/j.scico.2018.08.001.

[80] I. Sommerville and P. Sawyer, *Requirements Engineering: A Good Practice Guide*, 1st ed. Hoboken, NJ, USA: Wiley, 1997.

[81] H. Daki, A. E. Hannani, and H. Ouahmane, "HBase-based storage system for electrical consumption forecasting in a Moroccan engineering school," in *Proc. 4th Int. Conf. Optim. Appl. (ICOA)*, Mohammedia, Morocco, Apr. 2018, pp. 1–6, doi: 10.1109/ICOA.2018.8370520.

[82] M. Babar and F. Arif, "Smart urban planning using big data analytics to contend with the interoperability in Internet of Things," *Future Gener. Comput. Syst.*, vol. 77, pp. 65–76, Dec. 2017, doi: 10.1016/j.future.2017.07.029.

[83] E. F. Z. Santana, A. P. Chaves, M. A. Gerosa, F. Kon, and D. S. Milojicic, "Software platforms for smart cities: Concepts, requirements, challenges, and a unified reference architecture," *ACM Comput. Surv.*, vol. 50, no. 6, pp. 1–37, Jan. 2018, doi: 10.1145/3124391.

[84] S. Martin, J. Hernandez, and C. Valmaseda, "A novel middleware for smart grid data exchange towards the energy efficiency in buildings," in *Proc. Int. Conf. Workshops Netw. Syst. (NetSys)*, Cottbus, Germany, Mar. 2015, pp. 1–8, doi: 10.1109/NetSys.2015.7089063.

[85] H. U. Gökçe and K. U. Gökçe, "Holistic system architecture for energy efficient building operation," *Sustain. Cities Soc.*, vol. 6, pp. 77–84, Feb. 2013, doi: 10.1016/j.scs.2012.07.003.

[86] H. U. Gökçe and K. U. Gökçe, "Multi dimensional energy monitoring, analysis and optimization system for energy efficient building operations," *Sustain. Cities Soc.*, vol. 10, pp. 161–173, Feb. 2014, doi: 10.1016/j.scs.2013.08.004.

[87] Y. Zhang, S. Ma, H. Yang, J. Lv, and Y. Liu, "A big data driven analytical framework for energy-intensive manufacturing industries," *J. Cleaner Prod.*, vol. 197, pp. 57–72, Oct. 2018, doi: 10.1016/j.jclepro.2018.06.170.
[88] X. He, K. Wang, H. Huang, and B. Liu, "QoE-driven big data architecture for smart city," *IEEE Commun. Mag.*, vol. 56, no. 2, pp. 88–93, Feb. 2018, doi: 10.1109/MCOM.2018.1700231.
[89] D. Sembroiz, S. Ricciardi, and D. Careglio, "A novel cloud-based IoT architecture for smart building automation," in *Security and Resilience in Intelligent Data-Centric Systems and Communication Networks*. Amsterdam, The Netherlands: Elsevier, 2018, pp. 215–233.
[90] Y. Simmhan, P. Ravindra, S. Chaturvedi, M. Hegde, and R. Ballamajalu, "Towards a data-driven IoT software architecture for smart city utilities," *Softw., Pract. Exp.*, vol. 48, no. 7, pp. 1390–1416, Jul. 2018, doi: 10.1002/spe.2580.
[91] J.-S. Chou, N.-T. Ngo, W. K. Chong, and G. E. Gibson, "Big data analytics and cloud computing for sustainable building energy efficiency," in *Start-Up Creation*. Amsterdam, The Netherlands: Elsevier, 2016, pp. 397–412.
[92] H. U. Gökçe and K. U. Gökçe, "Integrated system platform for energy efficient building operations," *J. Comput. Civil Eng.*, vol. 28, no. 6, Nov. 2014, Art. no. 05014005, doi: 10.1061/(ASCE)CP.1943-5487.0000288.
[93] B. Cheng, S. Longo, F. Cirillo, M. Bauer, and E. Kovacs, "Building a big data platform for smart cities: Experience and lessons from santander," in *Proc. IEEE Int. Congr. Big Data*, New York, NY, USA, Jun. 2015, pp. 592–599, doi: 10.1109/BigDataCongress.2015.91.
[94] E. Gomes, M. A. R. Dantas, D. D. J. de Macedo, C. De Rolt, M. L. Brocardo, and L. Foschini, "Towards an infrastructure to support big data for a smart city project," in *Proc. IEEE 25th Int. Conf. Enabling Technol., Infrastruct. Collaborative Enterprises (WETICE)*, Paris, France, Jun. 2016, pp. 107–112, doi: 10.1109/WETICE.2016.31.
[95] L. Linder, D. Vionnet, J.-P. Bacher, and J. Hennebert, "Big building data—A big data platform for smart buildings," *Energy Procedia*, vol. 122, pp. 589–594, Sep. 2017, doi: 10.1016/j.egypro.2017.07.354.
[96] C. Chilipirea, A.-C. Petre, L.-M. Groza, C. Dobre, and F. Pop, "An integrated architecture for future studies in data processing for smart cities," *Microprocessors Microsyst.*, vol. 52, pp. 335–342, Jul. 2017, doi: 10.1016/j.micpro.2017.03.004.
[97] M. Malik, M. Tabone, D. P. Chassin, E. C. Kara, R. V. Guha, and S. Kiliccote, "A common data architecture for energy data analytics," in *Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm)*, Dresden, Germany, Oct. 2017, pp. 417–422, doi: 10.1109/SmartGridComm.2017.8340736.
[98] I. Khajenasiri, A. Estebsari, M. Verhelst, and G. Gielen, "A review on Internet of Things solutions for intelligent energy control in buildings for smart city applications," *Energy Procedia*, vol. 111, pp. 770–779, Mar. 2017, doi: 10.1016/j.egypro.2017.03.239.
[99] S. Lazarova-Molnar and N. Mohamed, "Collaborative data analytics for smart buildings: Opportunities and models," *Cluster Comput.*, vol. 22, no. S1, pp. 1065–1077, Jan. 2019, doi: 10.1007/s10586-017-1362-x.
[100] L. Kallab, R. Chbeir, P. Bourreau, P. Brassier, and M. Mrissa, "HIT2GAP: Towards a better building energy management," *Energy Procedia*, vol. 122, pp. 895–900, Sep. 2017, doi: 10.1016/j.egypro.2017.07.399.
[101] K. Vatanparvar and M. A. A. Faruque, "Control-as-a-service in cyber-physical energy systems over fog computing," in *Fog Computing in the Internet of Things*, A. M. Rahmani, P. Liljeberg, J.-S. Preden, and A. Jantsch, Eds. Cham, Switzerland: Springer, 2018, pp. 123–144.
[102] H. Elhoseny, M. Elhoseny, S. Abdelrazek, H. Bakry, and A. Riad, "Utilizing service oriented architecture (SOA) in smart cities," *Int. J. Adv. Comput. Technol.*, vol. 8, no. 3, pp. 77–84, 2017.
[103] N. Mohamed, J. Al-Jaroodi, and I. Jawhar, "Service-oriented big data analytics for improving buildings energy management in smart cities," in *Proc. 14th Int. Wireless Commun. Mobile Comput. Conf. (IWCMC)*, Limassol, Cyprus, Jun. 2018, pp. 1243–1248, doi: 10.1109/IWCMC.2018.8450469.
[104] J. Al-Jaroodi and N. Mohamed, "Service-oriented architecture for big data analytics in smart cities," in *Proc. 18th IEEE/ACM Int. Symp. Cluster, Cloud Grid Comput. (CCGRID)*, Washington, DC, USA, May 2018, pp. 633–640, doi: 10.1109/CCGRID.2018.00052.
[105] R. Santos and P. Carreira, "Service oriented development of building energy management systems—An architecture blueprint," in *Proc. 3rd Int. Conf. Smart Grids Green IT Syst.*, Barcelona, Spain, 2014, pp. 315–323, doi: 10.5220/0004974903150323.
[106] FIWARE. *What is Fiware?* Accessed: May 02, 2019. [Online]. Available: https://www.fiware.org/developers/
[107] M. A. A. Faruque and K. Vatanparvar, "Energy management-as-a-service over fog computing platform," *IEEE Internet Things J.*, vol. 3, no. 2, pp. 161–169, Apr. 2016, doi: 10.1109/JIOT.2015.2471260.
[108] N. Mohamed, J. Al-Jaroodi, I. Jawhar, S. Lazarova-Molnar, and S. Mahmoud, "SmartCityWare: A service-oriented middleware for cloud and fog enabled smart city services," *IEEE Access*, vol. 5, pp. 17576–17588, 2017, doi: 10.1109/ACCESS.2017.2731382.
[109] J. Minguez, M. Jakob, U. Heinkel, and B. Mitschang, "A SOA-based approach for the integration of a data propagation system," in *Proc. IEEE Int. Conf. Inf. Reuse Integr.*, Las Vegas, NV, USA, Aug. 2009, pp. 47–52, doi: 10.1109/IRI.2009.5211609.
[110] N. P. Kotsiopoulos and D. Vrakas, "Policies production system for ambient intelligence environments," in *Artificial Intelligence: Methods and Applications*, vol. 8445, A. Likas, K. Blekas, and D. Kalles, Eds. Cham, Switzerland: Springer, 2014, pp. 251–263.
[111] F. Fayaza, "Service oriented architecture in enterprise application," Dept. Inf. Technol., Univ. Moratuwa, Katubedda, Sri Lanka, Tech. Rep., 2014, doi: 10.13140/RG.2.1.3597.8087.
[112] C. Kyriazopoulou, "Architectures and requirements for the development of smart cities: A literature study," in *Smart Cities, Green Technologies, and Intelligent Transport Systems*, vol. 579, M. Helfert, K.-H. Krempels, C. Klein, B. Donellan, and O. Guiskhin, Eds. Cham, Switzerland: Springer, 2015, pp. 75–103.
[113] A. Dutta, M. S. Devi, and M. Arora, "Online census-based information sharing for delivery of e-Governance services," in *Proc. Special Collection eGovernment Innov. India (ICEGOV)*, New Delhi, India, 2017, pp. 45–51, doi: 10.1145/3055219.3055226.
[114] A. Dutta, M. S. Devi, and M. Arora, "Census Web service architecture for e-Governance applications," in *Proc. 10th Int. Conf. Theory Pract. Electron. Governance (ICEGOV)*, New Delhi, India, Mar. 2017, pp. 1–4, doi: 10.1145/3047273.3047390.
[115] T. H. Ashrafi, S. E. Arefin, K. D. J. Das, M. A. Hossain, and A. Chakrabarty, "FOG based distributed IoT infrastructure," in *Proc. 2nd Int. Conf. Internet Things, Data Cloud Comput. (ICC)*, Cambridge, U.K., Mar. 2017, pp. 1–13, doi: 10.1145/3018896.3036365.
[116] J. A. Oliveira, M. Vargas, and R. Rodrigues, "SOA reuse: Systematic literature review updating and research directions," in *Proc. XIV Brazilian Symp. Inf. Syst. (SBSI)*, Caxias do Sul, Brazil, 2018, pp. 1–8, doi: 10.1145/3229345.3229419.
[117] E. G. Nadhan. (Apr. 2004). *Service-Oriented Architecture: Implementation Challenges*. Accessed: Apr. 12, 2019. [Online]. Available: https://docs.microsoft.com/en-us/previous-versions/aa480029(v%3dmsdn.10)
[118] G. Agugiaro, J.-L. Robineau, and P. Rodrigues, "Project Ci-nergy: Towards AN integrated energy urban planning system from a data modelling and system architecture perspective," *ISPRS Ann. Photogramm., Remote Sens. Spatial Inf. Sci.*, vol. IV–4/W3, pp. 5–12, Sep. 2017, doi: 10.5194/isprs-annals-IV-4-W3-5-2017.
[119] N. M. Josuttis, *SOA in Practice: The Art of Distributed System Design*. Newton, MA, USA: O'Reilly Media, 2007.
[120] H. Zhao, Z. Nagy, D. Thomas, and A. Schlueter, "Service-oriented architecture for data exchange between a building information model and a building energy model," in *Proc. Int. Conf. CISBAT Future Buildings Districts Sustain. Nano Urban Scale*, 2015, pp. 761–766.
[121] I. Petri, Y. Rezgui, T. Beach, H. Li, M. Arnesano, and G. M. Revel, "A semantic service-oriented platform for energy efficient buildings," *Clean Technol. Environ. Policy*, vol. 17, no. 3, pp. 721–734, Mar. 2015, doi: 10.1007/s10098-014-0828-2.
[122] I. A. T. Hashem, V. Chang, N. B. Anuar, K. Adewole, I. Yaqoob, A. Gani, E. Ahmed, and H. Chiroma, "The role of big data in smart city," *Int. J. Inf. Manage.*, vol. 36, no. 5, pp. 748–758, Oct. 2016, doi: 10.1016/j.ijinfomgt.2016.05.002.
[123] H. Ahmed. (Aug. 2014). *Applying Big Data Analytics for Energy Efficiency*. Accessed: Sep. 09, 2020. [Online]. Available: https://aaltodoc.aalto.fi:443/handle/123456789/13899
[124] V. Marinakis, "Big data for energy management and energy-efficient buildings," *Energies*, vol. 13, no. 7, Mar. 2020, Art. no. 7, doi: 10.3390/en13071555.
[125] A. Ashabi, S. B. Sahibuddin, and M. S. Haghighi, "Big data: Current challenges and future scope," in *Proc. IEEE 10th Symp. Comput. Appl. Ind. Electron. (ISCAIE)*, Apr. 2020, pp. 131–134, doi: 10.1109/ISCAIE47305.2020.9108826.

[126] A. Andriyanto, R. Doss, and P. Yustianto, "Adopting SOA and microservices for inter-enterprise architecture in SME communities," in *Proc. Int. Conf. Electr., Electron. Inf. Eng. (ICEEIE)*, vol. 6, Oct. 2019, pp. 282–287, doi: 10.1109/ICEEIE47180.2019.8981437.

[127] P. Kumar, G. S. Brar, and L. Singh, "Energy efficiency evaluation in commercial and residential buildings with demand side management: A review," in *Proc. 8th Int. Conf. Power Syst. (ICPS)*, Dec. 2019, pp. 1–6, doi: 10.1109/ICPS48983.2019.9067675.

[128] A. Ozadowicz and J. Grela, "An event-driven building energy management system enabling active demand side management," in *Proc. 2nd Int. Conf. Event-Based Control, Commun., Signal Process. (EBCCSP)*, Jun. 2016, pp. 1–8, doi: 10.1109/EBCCSP.2016.7605082.

[129] Y. Li, J. De La Ree, and Y. Gong, "The smart thermostat of HVAC systems based on PMV-PPD model for energy efficiency and demand response," in *Proc. 2nd IEEE Conf. Energy Internet Energy Syst. Integr. (EI2)*, Oct. 2018, pp. 1–6, doi: 10.1109/EI2.2018.8582341.

[130] C. Chase, "Rapid demand response forecasting techniques are helping companies adapt during covid-19," *J. Bus. Forecasting*, vol. 39, no. 2, pp. 21–27, Jun. 2020.

[131] IEA. (Jun. 2020). *Energy Integration—The Covid-19 Crisis and Clean Energy Progress—Analysis*. Accessed: Aug. 27, 2020. [Online]. Available: https://www.iea.org/reports/the-covid-19-crisis-and-clean-energy-progress/energy-integration

[132] T.-Y. Chiu, S.-L. Lo, and Y.-Y. Tsai, "Establishing an integration-energy-practice model for improving energy performance indicators in ISO 50001 energy management systems," *Energies*, vol. 5, no. 12, Dec. 2012, Art. no. 12, doi: 10.3390/en5125324.

[133] *The New EN ISO 52000 Family of Standards to Assess the Energy Performance of Buildings Put in Practice—NASA/ADS*. Accessed: Aug. 27, 2020. [Online]. Available: https://ui.adsabs.harvard.edu/abs/2019E3SWC.11104047V/abstract

[134] R. J. Cole and M. J. Valdebenito, "The importation of building environmental certification systems: International usages of BREEAM and LEED," *Building Res. Inf.*, vol. 41, no. 6, pp. 662–676, Nov. 2013, doi: 10.1080/09613218.2013.802115.

[135] C. Eu. *Directive (EU) 2018/2002 of the European Parliament and of the Council—Of 11 December 2018—Amending Directive 2012/27/EU on Energy Efficiency*. European Parliament. Accessed: Aug. 27, 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2002&from=EN

[136] L. Berglund, "Mathematical models for predicting thermal comfort response of building occupants," *Ashrae J.-Amer. Soc. Heating Refrigerating Air-Conditioning Eng.*, vol. 19, no. 12, p. 38, 1977.

[137] D. Guaman, L. Yaguachi, C. C. Samanta, J. H. Danilo, and F. Soto, "Performance evaluation in the migration process from a monolithic application to microservices," in *Proc. 13th Iberian Conf. Inf. Syst. Technol. (CISTI)*, Jun. 2018, pp. 1–8, doi: 10.23919/CISTI.2018.8399148.

[138] N. Mohamed, J. Al-Jaroodi, and S. Lazarova-Molnar, "Energy cloud: Services for smart buildings," in *Sustainable Cloud and Energy Services*, W. Rivera, Ed. Cham, Switzerland: Springer, 2018, pp. 117–134.

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