Adekunle, P., Aigbavboa, C., Oke, A., Akinradewo, O., & Otasowie, O. (2023). Application of big data and internet of things in the built environment: a bibliometric review. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31),* 50–58. doi.org/10.24928/2023/0138

APPLICATION OF BIG DATA AND INTERNET OF THINGS IN THE BUILT ENVIRONMENT: A BIBLIOMETRIC REVIEW

Peter Adekunle[1], Cliton Aigbavboa[2], Ayodeji Oke[3], Opeoluwa Akinradewo[4], and Osamudiamen Otasowie[5]

ABSTRACT

Using big data and internet of things (IoT) technologies is without a doubt growing more and more important on a global basis. The two 4IR components stand out for their innovative methods that might aid organizations in developing high-performing teams and a culture that is performance-focused. Big data platforms offer methods for methodically eliminating data from data arrays that are too intricate to be used in standard data-processing applications. The Internet of Things and big data are used in every sector. The utilization of big data is significantly growing on a global scale. A staggering number of individuals, including architects, contractors, suppliers, and clients, are now involved in the building process. Large data warehouses are mined for information using big data analysis techniques, which then make the information available to all parties involved. With an overview of IoT and big data applications in the built environment, this research aims to tie current trends to them. In order to identify prior studies on IoT and big data in the construction industry, this study did a bibliometric evaluation and looked at the SCOPUS database. In addition, this probe only allowed recovery of documents from the previous 16 months. Papers based on quantitative, qualitative, and literary reviews made up the majority of the contents. The research also revealed that the bulk of articles were published in industrialized countries. Construction is under underway on phases that will largely focus on IoT research as well as an audit and assessment of the expansion of big data applications. The essay also evaluates and discusses recent advancements in the internet of things and big data industries. Data management, storage systems, automation, and retrofitting are the four main clusters of big data and IoT applications, according to the report. It has been shown that there are several potential when big data and IoT are combined. When properly implemented, such solutions provide professionals and other industry participants in the building sector an accuracy of over 90%.

KEYWORDS

Adoption, Industry 4.0, Big data, Internet of Things, Trend

INTRODUCTION

The desire to increase construction productivity is driven by the sector's well-known inefficiency in transforming raw resources into commodities and by the significance of building or infrastructure development to economic growth (Hussain & Al-Turjman, 2021).

[1] acidb Centre for Excellence & Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa, Adekunlepeter90@gmail.com
[2] University of Johannesburg, Nigeria
[3] University of Johannesburg, Nigeria
[4] University of Johannesburg, Nigeria
[5] University of Johannesburg, Nigeria

Modern building techniques make use of cutting-edge digital technologies to improve building operations. Building project planning and execution are being revolutionized by the internet of things (IoT), big data, and cyber-physical systems (Bilal et al., 2016). Evidence suggests that the construction industry's transition to Industry 4.0 will require the integration of cutting-edge technologies like Big Data and the Internet of Things in order to automate value-added jobs and data-acquisition systems (IoT). IoT refers to a network of physical objects that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet and big data is data that contains more variety, arrives in greater volumes, and moves more quickly (Yin & Kaynak, 2015; Patel & Patel, 2016). The application of big data and IoT is then a thorough procedure that removes inaccurate information from construction operations, improving quality and efficiency, lowering costs, and increasing value for the client. Many Internet of Things (IoT) devices operate on remote servers that may be accessed via the cloud, however clients occasionally employ big data processing to speed up data transit (Hassanalieragh et al., 2015). This model enables more immediate outcomes for time-sensitive procedures by retaining power to analyze some data locally. The bulk of the Internet of Things (IoT) focuses on the instant analysis and utilization of incoming data, big data tools can help with some other crucial tasks including predictive analytics. Predictive analysis takes into account machine performance and service alerts over time, and then builds the library of data required to foresee impending issues (Sayad et al., 2019). Due to this, construction businesses can maintain their equipment proactively and prevent the potentially expensive downtime that comes with equipment breakdown.

Furthermore, users may monitor vital information about their cars through the Internet of Things, often known as telematics, such as idle speed, tire pressure, and GPS tracking (Gamil et al., 2020). Additionally, it increases productivity, helps employees visualize tasks and solve problems, and may be used to provide instructions for on-the-job responsibilities. Additionally, it promotes worker and workplace safety. Funding for the design and development of new technologies will increase as more people become aware of the potential and requirements of the Internet of Things (Gbadamosi et al., 2019). When it comes to what this kind of technology is capable of, the sky is the limit. Since they are designed to use automated systems to handle things like heating, cooling, and lighting, smart buildings are becoming more and more prevalent (Chen et al., 2022). Routine maintenance might be aided by smart buildings, which can also look for potential system issues. They are lauded for having little environmental effect and for assisting in lowering energy waste (Zhao et al., 2022). The building process could be hastened while preserving worker safety when new technologies are developed (Lawal & Rafsanjani, 2022). Big data and drones are two cutting-edge technologies that might be utilized to analyze and create a building design more quickly. Despite the Internet of Things' (IoT) sluggish adoption in the construction industry, many increasingly understand that adopting cutting-edge technology into operational strategies is essential for construction businesses to remain competitive.

As technology advances, the quantity of data in the world today only gets more and more overwhelming (Bilal et al., 2016). The construction sector now manages petabytes (1015 bytes) of data. The industry makes extensive use of data from several disciplines throughout the life cycle of a facility. Building Information Modelling (BIM) is a process for methodically collecting three-dimensional CAD data to promote multidisciplinary collaboration among stakeholders (Munawar et al., 2022). BIM data is frequently networked in a variety of distinct formats; it is typically geometrically stored in three dimensions, computationally expensive (using graphics and Boolean operations), and compressed. This scattered data is merged to produce federated BIM models, which are continuously produced and kept long after a facility has reached the end of its useful life (Teisserenc & Sepasgozar, 2021). The design data for a five-story building model may eventually be 80GB in size, demonstrating how rapidly BIM files may grow (Lin et al., 2016). No matter how they are presented, it is clear that the success of the industry is greatly influenced by these facts. The spectrum of Big BIM Data sources has expanded due to the introduction of embedded devices and sensors, which have caused facilities to start producing vast volumes of data both during and after construction. Due to the extensive collection of BIM data, the construction industry has entered the "Big Data age" (Su et al., 2021). Due to its enormous size (terabytes, petabytes, and beyond) and diversity (a wide range of heterogeneous formats, including text, sensors, audio, video, graphs, and more), big data stands out (rapid streams of the data). The generation of data serves as an example for all three aspects of big data. A huge, fascinating, and dynamic collection of construction data is usual. Due to the massive volumes of design data and timelines, construction data is vast (Moeini et al., 2017). The use of big data and the Internet of Things to improve building practices and lessen negative impacts has been covered thus far in this article. The connection between big data applications and IoT in the context of the built environment has not been extensively studied. The major goal of the study is to understand how big data and IoT applications connect to recent advancements in the built environment.

IOT AND BIG DATA APPLICATION

When construction companies effectively use technology to solve typical workplace difficulties and improve operations, they benefit from improved productivity and better response to the industry's growing requirements (Arai & Morimoto, 2021). Construction companies are exploring integrating IoT and big data for a number of reasons, including sluggish productivity, declining margins, increasing schedule overruns, and rising competition (D'Amico et al., 2020). The categories stated in Table 1 are what are driving the use of IoT and big data in the construction industry.

Table 1: Application of IoT and Big data

IoT and Big data application areas	Motivation	Reference
Productivity	The construction sector is governed by deadlines and goals. Because they force budget increases, backlogs must be prevented at all costs. IoT can increase readiness and efficiency, which will increase output.	(Opoku et al., 2021); (Aghimien et al., 2020); (Adekunle, Aigbavboa, Akinradewo, et al., 2022)
Maintenance	Real-time data is now available, making it feasible to arrange maintenance breaks or refueling as well as turn off idle equipment and determine the status of any asset.	(Zhang, 2020); (Dave et al., 2016)
Safety and Security	Any material or item theft may be easily prevented with IoT connected tags since these sensors will inform you of the whereabouts of the materials or item at all times. Sending a human worker to undertake a comprehensive check is no longer necessary.	(Awolusi et al., 2019); (Demirkesen & Tezel, 2022)
Unmanned aerial vehicles and Autonomous vehicles	Key construction equipment has to be manually tracked since it takes time and is prone to mistake. The installation and usage of unmanned aerial vehicles and autonomous vehicle on these significant assets has many advantages for the construction/project management. These vehicles can perform operation autonomously in areas where human interventions can be risky and dangerous.	(Gao et al., 2020); (Hacker, 2017)

BIM optimization and Digital twins	In addition to providing an ever-growing dataset that can be integrated with machine learning to perform predictive analytics, to monitor active job sites, a combination of historical data from prior jobs and the ongoing stream of real-time data from IoT sensors may be employed. This will make construction even smarter.	(Hmidah et al., 2022); (Jiang et al., 2021)
Data Mining	Waste management, BIM-based quality control in construction engineering, and other significant areas of the construction industry have all made use of data mining. For the purpose of making decisions on construction management projects, data mining finds relevant patterns and information. As it combines and analyzes various construction items into homogeneous groups, cluster analysis is a crucial data mining technique for the construction industry.	(Sacks et al., 2009); (Munawar et al., 2022)
Sensors	There are several types of sensors that may operate in a certain environment and be applied to improve management effectiveness by setting up and sending out alarms. They can be employed to find a number of alarming circumstances that demand rapid response. Humidity, temperature, and pressure calculations may be tracked by linked and monitored equipment utilizing IoT software and processes. This will notify management to any possible risk that needs rapid care.	(Heiskanen, 2017); (Andújar-Montoya et al., 2017)
Real-Time Site Map	Employers may use this technology to both identify workers on the job and prevent them from entering dangerous areas. Using this, a real-time map of the building site could be created so that everyone could see who is working where and when. If the situation is actually dire, some danger zones and managers' only zones can be highlighted on the map, and other individuals may be persuaded to stay away from such areas if they are not absolutely necessary. All of this data may be gathered by IoT devices on the internet and used for projects.	(Sharma et al., 2020); (Abu Ghazaleh & Zabadi, 2020)

RESEARCH METHODOLOGY

An exhaustive and thorough audit of big data and IoT in construction was achieved using a descriptive research method and bibliometric evaluation of the literature. According to Hallinger & Kovaevi (2019), a quantitative analysis of bibliographic data that categorizes research articles, authors, and themes provides a comprehensive view of a study field. The bibliometric review employs a variety of qualitative indicators to evaluate the current level of study on a certain subject utilizing a wealth of bibliographical data (Baas et al., 2020). Since content analysis enables one to generate logical conclusions from literature obtained from a database, the bibliometric evaluation was deemed appropriate for the study project that it was implemented into (Garrigos-Simon et al., 2019). The database to be utilized for the research study was chosen in the first phase to ensure that a sizable amount of literature could be acquired. Due of the popularity and effectiveness of Web of Science (WoS), ScienceDirect, and SCOPUS, we originally looked at these sources (Singh et al., 2021; Charoenthammachoke et al., 2020; Martn-Martn et al., 2018). The software utilized for this study can only examine data from one database at a time, even if it is possible that all three databases were used. SCOPUS was chosen following a preliminary search of all databases since it had a greater number of articles published and was found to have more comprehensive coverage, with the majority of publications on WoS and ScienceDirect also being indexed on SCOPUS. The search was limited to works published in 2019 and 2022 using words that includes “Big data”, “Applications”, “Internet of Things”, and “Building Sector” or “Construction sectors”. Table 1.0 contains papers from the top ten journals in order to achieve the study's objectives, the top 10 journals was derived based on the numbers of article published. Journal articles were preferred to book chapters and conference papers because the judgments and analyses that go into them are typically more thorough and in-depth. When these keywords were used to search through the title, abstract, and keywords of published articles, only 81 of the 104 items discovered were relevant to the study's objectives. Journal articles, conference papers, and book chapters make up the 145 items. The bibliometric network visualization tool VOSviewer was used to analyze these texts (Yu et al., 2020). Content analysis was utilized to describe the investigation's findings in order to achieve the study's objectives.

Table 2: Top ten journals explored

Journal	Number of documents
Automation in construction	13
Journal of Building Engineering	9
Material and Structures	8
Journal of Construction Engineering and Management	6
Journal of Industrial Information Integration	6
Sustainability	5
Advanced Engineering Informatics	5
Engineering, Construction and Architectural Management	3
Future Generation Computer Systems	3
Engineering structures	3

FINDINGS AND DISCUSSION

This study attempts to summarize the current research goals for internet of things and big data in the construction industry, as was already stated. A quantitative content analysis of the 145 recovered documents was used to achieve this. To do this, a co-occurrence network of terms was created using bibliographic data acquired from retrieved articles. The creator of VOSviewer claims that a minimum of three keywords should be used for keyword co-occurrence analysis (Anna & Mannan, 2020). Thus, among the indexed and author's keywords, our investigation used a minimum of three co-occurrences. Only 78 out of 960 keywords met the co-occurrence criterion; their frequency of recurrence and general strength were confirmed. The internet of things occurred the most in the documents that were retrieved, with a total link strength of 602, showing the magnitude of its involvement in the co-occurrence map (146 times). Given that this survey is focused on the construction sector, the building industry came in second (81 occurrences and 396 total link strength). Big data is the word for the many applications and components of the internet of things and big data, and it is placed seventh out of the remaining 76 terms used in the construction business. The network visualization map of the 78 co-occurring key phrases and their four different clusters is shown in Figure 1.

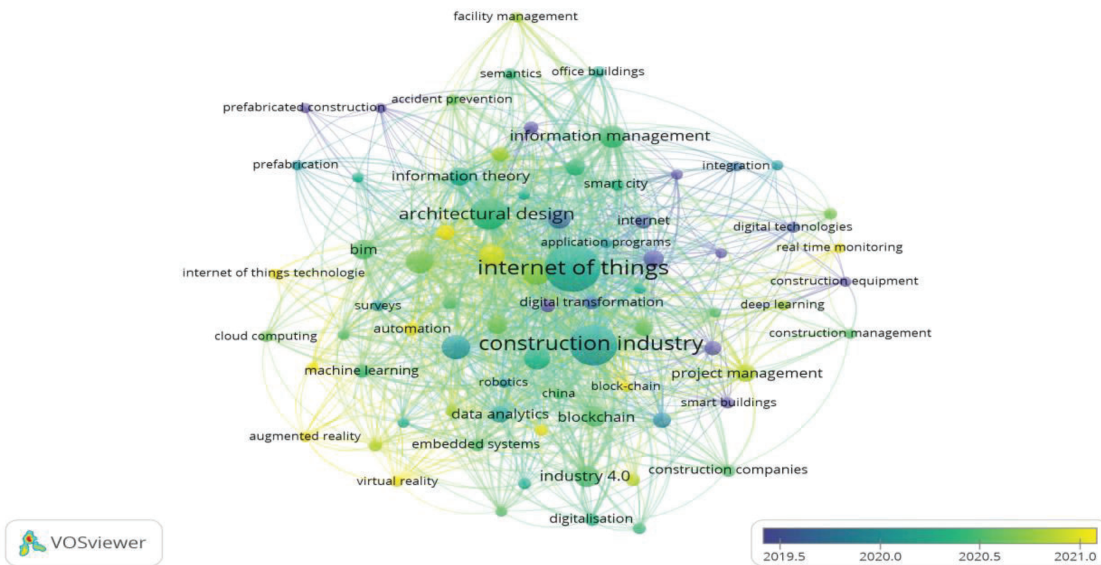

Figure 1: Publication keyword trend overlay visualization map.

Cluster 1 – Storage Systems: On the map, the deep green region with 25 co-occurring phrases represents the Internet of Things area. Construction projects, digital storage, industry 4.0, blockchain, artificial intelligence, embedded systems, and industry 4.0 are notable examples having connections to the core idea ("Internet of things and big data"). Because of this, this cluster may be thought of as a collection of key words for applications connected to the Internet of Things and big data storage. Opoku et al. (2021) claim that IoT technologies may be used to almost any device that can offer important data on its own operation, the success of an endeavor, or even the environmental conditions that we need to remotely monitor and regulate. As a result, they are said to have a wide range of applications.

Cluster 2 – Automating: is the area of light green on the map that has 20 related keywords. Important essential terms include "application programs," "automation," "sensor," "smart city," "digital twins," and others. The utilization of IoT and bid data for the automation of different activities inside the built environment is therefore thought to be the cluster's primary focus. It demonstrates that big data will be able to evaluate massive volumes of data at breakneck speeds, enabling construction companies to focus on the jobsite rather than IT problems (Dave et al., 2016).

Cluster 3 – The purple region on the map with 17 co-occurring terms is Retrofitting. Notable essential concepts include "construction equipment," "deep learning," "integration," "energy usage," "life cycle," and other connotations. Therefore, it is assumed that this cluster is interested in topics pertaining to retrofitting. According to a report by Demirkesen & Tezel (2022), IoT and big data technologies are more useful than ever for the construction industry because of their decreased prices and increased levels of reliability. The digital transition has enhanced productivity across many industries, but the construction industry has been slower to adapt. Building complexity makes things more challenging, but IoT and big data may be able to aid with many issues connected to energy consumption reduction. These strategies might provide businesses a competitive edge despite rising costs.

Cluster 4 – Data management: is the yellow region on the map which has 16 co-occurring keywords. Understanding the underlying concepts of augmented reality, data collection, cloud computing, machine learning, and other related topics is crucial. Therefore, it is expected that this cluster is working on data management issues. Data management's importance has been emphasized in earlier publications. The findings are in line with those of Jiang et al. (2021) and (Adekunle et al., 2022), who explain how the recent expansion of construction big data and the creation of computational tools in the area of information technology enable construction specialists and practitioners to extract and visualize big data for a variety of new applications.

CONCLUSION

Using bibliometric techniques, this study pinpoints areas of construction-related research that prioritize IoT and big data. The study was able to identify the major area of focus in research related to big data and IoT applications inside the built environment based on extracted articles published in the recent sixteen months and indexed in the Scopus database. The results show a rise in the amount of IoT and big data research papers published, with 2021 recording the most papers. This is useful because it highlights the need of having a solid understanding of big data and IoT applications in the built environment as well as the advantages of their adoption for the construction industry. When correctly considered, such technologies provide information to stakeholders and building industry experts that is up to 90% accurate. The paper examines current big data and IoT applications in the construction industry. Big data and IoT have a significant relationship that will only intensify as technology progresses. Construction firms that want to use data effectively should be very selective about the devices used and the data obtained. The process of analytics will be made considerably simpler by making an effort up front to collect only relevant, usable data and by creating internal systems to handle the data in industry-specific ways.

REFERENCES

Abu Ghazaleh, M., & Zabadi, A. M. (2020). Promoting a revamped CRM through Internet of Things and Big Data: an AHP-based evaluation. *International Journal of Organizational Analysis*, *28*(1), 66–91. https://doi.org/10.1108/IJOA-12-2018-1602

Adekunle, P., Aigbavboa, C., Akinradewo, O., Oke, A., & Aghimien, D. (2022). Construction Information Management: Benefits to the Construction Industry. *Sustainability*, *14*(18), 11366. https://doi.org/10.3390/su141811366

Adekunle, P., Aigbavboa, C., Thwala, D., Oke, A., & Akinradewo, O. (2022). Construction Information Management: The role of Fourth Industrial Revolution Tools. *Human Factors in Architecture, Sustainable Urban Planning and Infrastructure*, *58*(Cim), 254–261. https://doi.org/10.54941/ahfe1002359

Aghimien, D. O., Aigbavboa, C. O., Oke, A. E., & Thwala, W. D. (2020). Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. *Journal of Engineering, Design and Technology*, *18*(5), 1063–1079. https://doi.org/10.1108/JEDT-09-2019-0237

Andújar-Montoya, M. D., Marcos-Jorquera, D., García-Botella, F. M., & Gilart-Iglesias, V. (2017). A context-driven model for the flat roofs construction process through sensing systems, internet-of-things and last planner system. *Sensors (Switzerland)*, *17*(7). https://doi.org/10.3390/s17071691

Awolusi, I., Nnaji, C., Marks, E., & Hallowell, M. (2019). Enhancing Construction Safety Monitoring through the Application of Internet of Things and Wearable Sensing Devices: A Review. *Computing in Civil Engineering 2019: Data, Sensing, and Analytics*

- *Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2019*, *June*, 530–538. https://doi.org/10.1061/9780784482438.067

Dave, B., Kubler, S., Främling, K., & Koskela, L. (2016). Opportunities for enhanced lean construction management using Internet of Things standards. *Automation in Construction*, *61*, 86–97. https://doi.org/10.1016/j.autcon.2015.10.009

Demirkesen, S., & Tezel, A. (2022). Investigating major challenges for industry 4.0 adoption among construction companies. *Engineering, Construction and Architectural Management*, *29*(3), 1470–1503. https://doi.org/10.1108/ECAM-12-2020-1059

Gao, D., Sun, Q., Hu, B., & Zhang, S. (2020). A framework for agricultural pest and disease monitoring based on internet-of-things and unmanned aerial vehicles. *Sensors (Switzerland)*, *20*(5). https://doi.org/10.3390/s20051487

Hacker, P. (2017). Personal data, exploitative contracts, and algorithmic fairness: Autonomous vehicles meet the internet of things. *International Data Privacy Law*, *7*(4), 266–286. https://doi.org/10.1093/idpl/ipx014

Hassanalieragh, M., Page, A., Soyata, T., Sharma, G., Aktas, M., Mateos, G., Kantarci, B., & Andreescu, S. (2015). Health Monitoring and Management Using Internet-of-Things (IoT) Sensing with Cloud-Based Processing: Opportunities and Challenges. *Proceedings - 2015 IEEE International Conference on Services Computing, SCC 2015*, 285–292. https://doi.org/10.1109/SCC.2015.47

Heiskanen, A. (2017). The technology of trust: How the Internet of Things and blockchain could usher in a new era of construction productivity. *Construction Research and Innovation*, *8*(2), 66–70. https://doi.org/10.1080/20450249.2017.1337349

Hmidah, N. A., Haron, N. A., Alias, A. H., Law, T. H., Altohami, A. B. A., & Effendi, R. A. A. R. A. (2022). The Role of the Interface and Interface Management in the Optimization of BIM Multi-Model Applications: A Review. *Sustainability (Switzerland)*, *14*(3). https://doi.org/10.3390/su14031869

Jiang, Z., Guo, Y., & Wang, Z. (2021). Digital twin to improve the virtual-real integration of industrial IoT. *Journal of Industrial Information Integration*, *22*(August 2020), 100196. https://doi.org/10.1016/j.jii.2020.100196

Munawar, H. S., Ullah, F., Qayyum, S., & Shahzad, D. (2022). Big Data in Construction: Current Applications and Future Opportunities. *Big Data and Cognitive Computing*, *6*(1). https://doi.org/10.3390/bdcc6010018

Opoku, D. G. J., Perera, S., Osei-Kyei, R., & Rashidi, M. (2021). Digital twin application in the construction industry: A literature review. *Journal of Building Engineering*, *40*(May), 102726. https://doi.org/10.1016/j.jobe.2021.102726

Patel, K. K., & Patel, S. M. (2016). Internet of Things-IOT: Definition, Characteristics, Architecture, Enabling Technologies, Application & Future Challenges. *International Journal of Engineering Science and Computing*, *6*(5), 6122–6131. http://www.opjstamnar.com/download/Worksheet/Day-110/IP-XI.pdf

Sacks, R., Koskela, L., Dave, B. A., & Owen, R. (2009). Interaction of Lean and Building Information Modeling in Construction. *Journal of Construction Engineering and Management*, *136*(9), 968–980.

Sayad, Y. O., Mousannif, H., & Al Moatassime, H. (2019). Predictive modeling of wildfires: A new dataset and machine learning approach. *Fire Safety Journal*, *104*(September 2018), 130–146. https://doi.org/10.1016/j.firesaf.2019.01.006

Sharma, R., Agarwal, P., & Mahapatra, R. P. (2020). Evolution in Big Data Analytics on Internet of Things: Applications and Future Plan. In S. Tanwar, S. Tyagi, & N. Kumar (Eds.), *Multimedia Big Data Computing for IoT Applications* (3rd ed., pp. 453–477). Springer, Singapore. https://doi.org/https://doi.org/10.1007/978-981-13-8759-3_18

Yin, S., & Kaynak, O. (2015). Big Data for Modern Industry: Challenges and Trends. *Proceedings of the IEEE*, *103*(2), 143–146. https://doi.org/10.1109/JPROC.2015.2388958

Zhang, C. (2020). Design and application of fog computing and Internet of Things service platform for smart city. *Future Generation Computer Systems*, *112*, 630–640. https://doi.org/10.1016/j.future.2020.06.016