A Scientometric Review of Present and Future Trends of Embedded Systems in the Built Environment

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Abstract. This study presents a scientometric review conducted to define and delineate utilization of embedded systems in construction project delivery. This was done with the view of providing directions for future studies as well as stimulating a wider debate among construction stakeholders on the use of embedded systems in the industry. The study adopted an interpretivist philosophical view using an inductive approach and a grounded theory strategy. The data used were secondary in nature and were gathered from the Scopus database using specific related keywords. Co-occurrence maps were further created based on the bibliographic data gathered using the VOSviewer text mining software. Three clusters of co-occurring keywords were formed from the analysis, and these are labelled as sensor network systems and models, real-time systems and designs, and construction process automation. The study opens a new vista in the deliberations of the studies on technological innovations in the built environment.

Keywords: Built environment · Embedded systems · Real-time systems · Scientometric review · VosViewer

1 Introduction

The importance of the construction industry to the economy and development of any nation cannot be overemphasized. The industry is considered to be key for its influence in the provision of jobs as well as the multiplier of the GDP growth of any country [1]. It serves as a multiplicand to other industries with the provision of infrastructure at the center of other developmental needs of the society. With the glaring importance of the industry, it faces its own fair share of challenges hindering it from harnessing its optimum potentials to yield optimized benefits. One of the major challenges facing the construction industry is its slow pace of adoption of innovations in information technology and digitization [2]. This has placed the industry behind other industries that are early adopters of digital technologies and hence has limited its capacity to attain competitive

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gains and optimization of processes. Halim [3] opined that no industry, organization or profession can successfully solve developmental problems except their strategies, visions and aspirations are grounded in the creation of knowledge and systematically propelled by digital technology. In abating the challenges posed to the industry's full realization of its untapped benefits, there must be a strong drive in leveraging emerging information and communication technologies.

Businesses and industries have made frantic efforts to optimize efficiency, and this has increasingly brought about advancement in their methods and operations. The last century experienced the deployment of various operational methods for increased efficiency of processes; however, only a handful attained the heights of dominance. As earlier stated, the construction industry is still inefficient. According to Hampson *et al.*, [4], the construction industry in the last 50 years has only attained approximately half of the efficiency developments when compared with other industries. To a large extent, these results from time and cost overruns, issues pertaining to quality, safety issues, inefficient processes, outdated methods and repetition of processes [5–7]. These shortcomings could have been surmounted if the industry had grown with the advancement of other industries in the last 50 years. The daunting challenges plaguing the industry are usually a derivative of inherent industry features such as building processes and its fragmented nature, models for business based on objectives set out in the short term, ineffective flow of information among economic actors and ineffective procurement routes [8, 9]. Furthermore, Ballard [10] stated that the challenges facing the construction industry emanate from the fact that the engaging process of construction production is seemingly different from monotonous manufacturing process due to the nature of the product. The distinguishing attributes of the construction industry are cogent reasons for the survival strategies as adopted by actors in the construction landscape.

Over the years, advancement in information technology and computing has garnered a significant increase in attention as well as its slow adoption in the construction process. This offers good opportunities for improving and automating the process delivery and performance of the construction industry in comparison with other industries [11, 12]. One of the distinguishing technological advancement adopted for construction is the utilization of embedded systems, which serves a combination of computer processors, devices involving input/output and the computer memory. They are usually a part of a whole device which includes hardware in the form of electronics as well as mechanical parts. According to Jahromi and Kundur [13], the term embedded systems refer to devices that comprise of a synergized cyber (software and processor) and physical (electrical and/or mechanical) constituents for the delivery of a defined task.

Due to the nature of construction activities, embedded systems such as wireless sensors and networks are mostly deployed. According to Jang and Skibniewsky [12], this aids in the methodologies for the acquisition of data. The gathering of field data through wireless means improves the management of construction activities by gaining access to real-time information systems. The application of embedded systems in construction activities, processes and management have been investigated by many studies [14, 15]. A large pool of these studies highlighted the inherent benefits of the adoption of embedded systems in the delivery of construction processes, these spans from monitoring of equipment [16], use of radio frequency identification (RFID) for material tracking [12], tracking progress of work on site [17]. With the clear benefits and advantages brought about with the utilization of embedded systems in construction activities and management, this study reviews the studies on embedded systems in the built environment with a view to understanding what has been accomplished and identifying future research directions.

2 Methodology

Adopting the post-constructivist philosophical thinking, using an inductive approach, this study assesses the trends of published works using the searched keywords "embedded systems" AND "construction industry" OR "built environment" in relation to studies pertaining to construction and its allied fields. Text mining was used to construct meaning and understanding of the research footprint of embedded systems in construction/buildings. Scopus database was chosen for mining researches in this area, as it has been adjudged to have a wide coverage of science-related research [18]. With the adoption of a bibliometric approach, the identification and mining of published intellectual works in the area of embedded systems for construction related fields was carried out. Furthermore, the mapping out of chronological flow and trend pattern of the study area was outlined. The time limitation for the extracted studies was 15 years (2007–2022); and there was a limitation to language type, as all the documents were in English language except for four documents in Spanish and two documents in Chinese which were expunged. There was no filtering of the output with respect to Access type, Subject area, Document type, Publication stage, Source title, Keyword, Affiliation, Funding sponsor, Country/territory and Source type. This is due to the fact that studies in this domain are still in their nascent stage, especially in developing countries, and to provide a better view of the current trends. A total of one hundred and sixty-four (164) documents were extracted after the refinement of the output. The extracted documents were analysed using VOSviewer (version 1.6.17); a software that is easy to use and its approach for visualization is distance-based rather than graph-based [19]. Also, it gives a bibliometric network outlay in nodes that are depicted in a graphic interface that is user friendly.

3 Results and Discussion

3.1 Publication on Yearly Basis

With an extraction of 164 documents which spanned from 2007 to 2022, an analysis was carried out to show the trend of publications within this time frame. As shown in Fig. 1, there is a rise in the number of publications from 1 to 8 within the time frame of 2007 to 2009. This coincides with the introduction of the term "cyber-physical systems" in 2007 by Helen Gill at the National Science Foundation in USA. The next significant rise in the number of publications was in 2012 (6 publications) which connotes the period the concept of Industry 4.0 was initiated in Hannover, Germany. This ushered in a new drive towards innovative applications in system processes and production. In a similar move to that of Industry 4.0 conceptualized in Germany, the introduction of 'Made in China' in 2015 which aimed at attaining similar feats as that of Industry 4.0, spurred on more publications which culminated in the attainment of the number of publications in 2020 (20 publications). The trajectory followed up till 2021 experiencing a total number of 36 publications. The study was done in August 2022, which explains why 13 publications are presented for 2022.

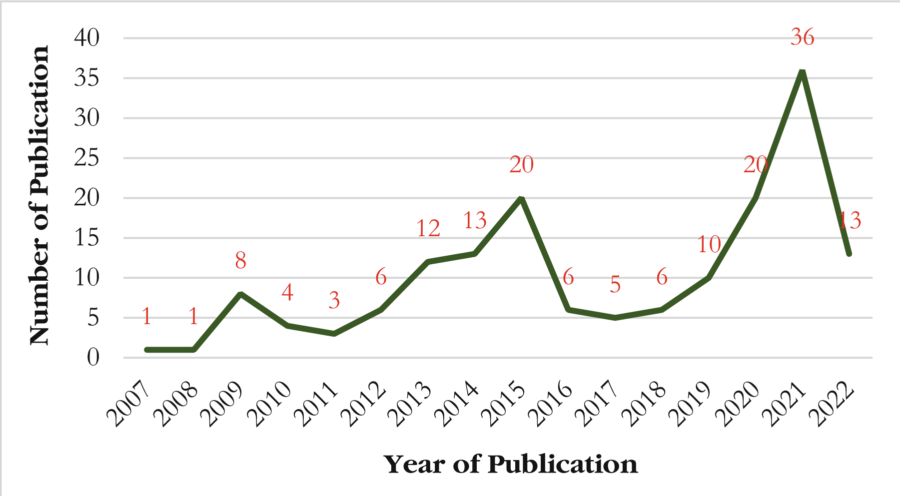

Fig. 1. Publication on yearly basis

3.2 Publication From Countries

Analysis was carried out on the publications emanating from various countries using a threshold of a minimum of 2 publications. However, it was observed that some of the extracted publications had overlap with respect to country of publication (affiliation of authors). Table 1 shows an outline of the various countries having publications including the number of documents and also their citations. The countries with the most published documents are the United States (48 papers, 531 citations), China (41 papers, 209 citations), Germany (14 papers, 154 citations), France (12 papers, 133 citations) and Russia Federation (12 papers, 14 citations). Others are United Kingdom (11 papers, 200 citations), Netherlands (10 papers, 9 citations), Italy (9 papers, 44 citations), Brazil (8 papers, 42 citations), Canada (8 papers, 46 citations), and India (8 papers, 42 citations).

3.3 Citation Rating of Publications

An assessment of the most cited documents was carried out after the extraction of the total documents. With the adoption of the threshold of a minimum of 8 cited documents, a total of 44 documents scaled through the sieving process. Table 2 shows the top 10 extracted documents portraying the author(s) of the documents, the titles, number of citations, and the area of focus. As shown in the table, the most cited document is the

Table 1. Table captions should be placed above the tables

Country	Documents	Citations	Country	Documents	Citations
United States	48	531	Portugal	5	12
China	41	209	Spain	5	54
Germany	14	154	Austria	4	195
France	12	133	Czech Republic	4	34
Russian Federation	12	14	Ireland	4	30
United Kingdom	11	200	Poland	4	43
Netherlands	10	19	Hong Kong	3	7
Italy	9	44	Mexico	3	5
Brazil	8	42	Sweden	3	15
Canada	8	46	Denmark	2	24
India	8	42	Finland	2	7
South Korea	8	38	Hungary	2	10
Taiwan	8	44	Malaysia	2	119
Australia	6	46	Norway	2	2
Switzerland	6	38	Serbia	2	7
Greece	5	23	Turkey	2	66
Japan	5	42	Ukraine	2	3

study of Adam and Markiewiez [20] with 209 citations, this is followed by Motawa and Almarshad [21] having 201 citations. The third and fourth most cited documents are the studies of Zhuang *et al.*, [22] having 200 citations and Göçer *et al.*, [23] having 97 citations.

3.4 Catchment Based on Co-occurring Keywords

Using co-occurring keywords from the extracted documents, the bibliographic data was deployed in the production of a co-occurrence map. A threshold of a minimum of 10 number of occurrence was set, Aghimien *et al.*, [26] used a threshold of a minimum of 4 while the default threshold of VOSviewer is 5. Thus the implication of this is that the choice of the extraction of a particular keyword is dependent on the minimum of 10 occurrences. As shown Fig. 2, findings from the analysis indicated that a total number of 33 keywords were extracted using the adopted threshold of a minimum of 10 occurrences, and 3 clusters were formed. The most frequent keywords are 'embedded systems' occurring 235 times, 'cyber-physical systems' occurring 59 times, 'intelligent buildings' occurring 30 times, 'construction industry' occurring 27 times, architectural design occurring 22 times and 'building information model' occurring 17 times. Figure 2 portrays the map for the co-occurring keywords network visualization of the extracted 33 keywords, and also giving an outlay of the 3 formed clusters.

Table 2. The top 10 extracted documents

Authors	Title	Citations	Area of Focus
Adam and Markiewicz [20]	Energy from earth-coupled structures, foundations, tunnels and sewers	209	Environmental Engineering; Foundations
Motawa and Almarshad [21]	A knowledge-based BIM system for building maintenance	201	BIM, Case-Based Reasoning
Zhuang *et al.*, [22]	Digital twin-based smart production management and control framework for the complex product assembly shop-floor	200	Assembly shop-floor; Big data
Göçer *et al.*, [23]	Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance	97	BIM; Building performance
Pereira and Pereira [24]	Embedded image processing systems for automatic recognition of cracks using UAVs	46	Cracks detection; Image processing; Unmanned Aerial Vehicle
Bhattacharya *et al.*, [25]	Automated metadata construction to support portable building applications	41	Portable building applications; Sensor metadata

Cluster 1 (Sensor Network Systems and Models). This cluster has key words such as sensor networks, radio frequency identification (RFID), network security, robotics, mathematical models and embedded software. It has a purple coloration and labelled as *Sensor network systems and models*. The cluster emphasizes the significance of the use of sensor network systems in embedded systems. Shaikh and Pathan [27] noted that sensor network systems are characterized by the capability of effective communication coupled with well-defined networking capabilities. This forms an important aspect of embedded systems. This has led to research in this area being extended to military, commercial and scientific applications which further includes the monitoring of industrial processes, agriculture and biological habitats. Heidemann and Govindan [28] assessed the application of sensor networks in embedded systems and highlighted the important services to include the development of code tools and operating systems, node localization, time synchronization, resource discovery, storage services and databases, remote programming and security. Furthermore, Domdouzis *et al.*, [29] highlighted the prospects

of wireless sensor networking in construction industry, and affirmed the innovativeness brought about with the inculcation of the system in the delivery of construction activities.

Cluster 2 (Real Time Systems and Designs). This cluster has a pictorial of green coloration and having keywords such as real time systems, computer software, energy efficiency, decision making, hardware, design and buildings; and labelled as *Real time systems and designs*. This cluster gives credence to the recent drive for the adoption of innovative systems such as cyber-physical systems and internet of things in construction processes and management. Raj *et al.*, [30] noted that the processing of real time complex events is a core functionality of embedded systems in the analysis of building construction and management.

Cluster 3 (Construction Process Automation). This cluster has a yellow pictorial representation with keywords as big data, structural design, information theory, construction industry, project management, building information modeling, internet of things, automation, and semantics, and labelled as *Construction process automation*. The automation of processes involved in construction activities has been highly encouraged as a result of the immense benefits from such adoption. The overwhelming advantages attained from the automation of construction process spans from pre-construction to post-construction phases.

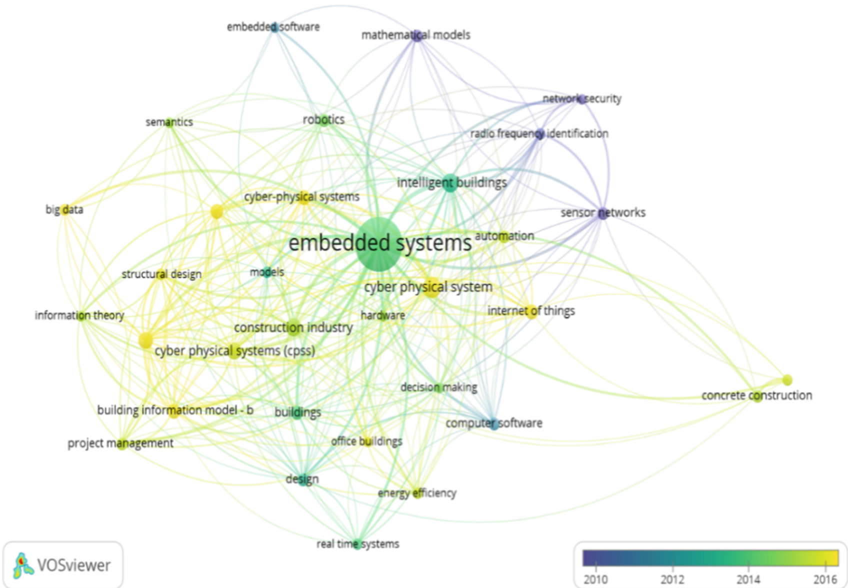

Fig. 2. Overlay visualization of co-occurring keywords

3.5 Past Trends and Future Applications

The visual outlay map of the co-occurring keywords in Fig. 2 also depicts the publication trends of these keywords over the years. As shown in the map, Cluster 1 (Sensor networks systems and models) appeared as the most keywords from 2010 to 2012. The keywords are sensor networks, radio frequency identification (RFID), network security, robotics, mathematical models and embedded software. From the period of 2012 to 2014, Cluster 2 (Real time systems and designs) formed the most occurring keywords within that time frame and includes words such as real time systems, computer software, energy efficiency, decision making, hardware, design and buildings. The third cluster (Construction process automation) makes up the last cluster which spans from 2014 to 2016. The keywords making up this era are big data, structural design, information theory, construction industry, project management, building information modeling, internet of things, automation and semantics.

The construction industry has much to gain from future applications of the different types of embedded systems for construction project execution and management. As mentioned earlier, there is a gradual espousal of systems such as sensor networks, radio frequency identification (RFID), cyber-physical systems and building information modeling. However, future applications should include not just the aforementioned systems but also embedded software technologies, system of systems integration platforms for digitalization, artificial intelligence, edge computing and high-performance computing among others. The execution of construction projects and the management of built facilities tend to experience a revolutionary drive with the adoption of these systems, thus serving as a shift from the conventional and contemporary approaches which would eventually lead to better performance and enhanced delivery.

4 Conclusion

This study has examined the trend of publications pertaining to embedded systems within the built environment. Adopting a bibliometric method and extracting documents published in a span of 15 years, documents were extracted from Scopus database and were subjected to analysis with the aid of VOSviewer. Findings from the study revealed that research publications on embedded systems in the construction industry and the built environment has a fluctuating trend within the time under review with 2007 and 2008 having the least number of publications with 1; while 2021 have the highest number of publication with 36. In between these years, the number of publications is surprisingly inconsistent.

Furthermore, it is shown in this study that the countries with the highest number of publications are USA, China, Germany, France, Russia Federation and the United Kingdom. It is noteworthy that there is no representation of any published work from the African continent. This ultimately showcases a gulf in the research focus between developed countries and Africa, thereby highlighting a potential future direction of research needed in Africa. This is important in bridging the knowledge gap and Africa and developed countries, and enhancing construction processes and the effective management of built facilities. This study revealed three clusters which make up the research direction of the extracted publications; these are sensor network systems and models, real time systems and designs, and construction process automation. The trend shows that research in this domain has evolved from studies on radio frequency identification (RFID), sensor networks and mathematical models, and is currently focusing on cyber-physical systems, building information modeling and big data.

The contribution made by this study to the body of knowledge centres on its unraveling of the research area and focus with respect to embedded systems in the built environment. The evolution of the research focus shows how the various publications have navigated through the different facets making up embedded systems. Moreover, a clear distinction has been made on the strengths of the various countries involved in this area; this includes countries from North America, Europe and Asia. Also, it showcases the dearth in research studies in most developing countries with particular reference to Africa. This reflects the current state of construction project delivery in the continent which is still hugely characterized with outdated systems thereby contributing to the stagnant posture of the construction industry. It is without doubt that as researches of this stature are engaged in, the inherent features of the construction industry peculiar to Africa would be addressed which in turn would aid in abating the perennial challenges in the delivery of construction projects. It is important to state that the study was limited to the use of Scopus database. Future studies can explore the other databases for a comparative analysis.

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