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INFORMATION AND COMMUNICATION TECHNOLOGY APPLICATIONS IN CONSTRUCTION ORGANIZATIONS: A SCIENTOMETRIC REVIEW

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SUMMARY: *The application and research of Information and Communication Technology has exponentially grown in construction and is of a multidiscipline nature. However, there is a lack of investigation into progression of ICT research topics within the construction disciplines and the knowledge domain has not been deeply explored. This research fills this gap using a scientometric review of construction ICT research. Relevant literature from reputable sources are reviewed and classified to create a comprehensive framework for ICT application in construction. Accordingly, a manual review of research titles, as well as abstracts, was conducted. Accordingly, five analysis steps were performed including "Journals Selection, Publication Type and Name" "Citation Analysis", "Keywords Co-Occurrence Network", "Cluster Analysis", and "Keyword time analysis". A total of 376 research selected for burst detection, co-citation analysis, cluster analysis, keyword co-releases, and ICT application analysis in order to provide a comprehensive knowledge summary of the ICT application in the construction industry. Automation in Construction and Journal of Management in Engineering were identified as the major journals associated with research on the ICT application in the construction industry. Based on the research method, the articles used for scientometric analysis were only selected from Scopus and Web of Science database. Moreover, the study mainly concentrated on the quantitative analysis in regard to articles emerging frequently the knowledge domain, and were used to indicate the trends, timelines and hot topics. This research explores the construction industry body of knowledge by classifying the existing ICT related research, evolutionary trend, providing current status, a comprehensive knowledge framework, and future directions.*

KEYWORDS: *Information and Communication Technology (ICT) Applications, Construction Organization, Literature Review, Construction Management*

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1. INTRODUCTION AND BACKGROUND

Based on studies, the construction and engineering field has lagged other industries in technology implementation and adoption (MBIE, 2010; Negahban et al., 2012; Amusan et al., 2018). Nevertheless, there is rising momentum to implement and introduce modern technologies into the construction and engineering industry during the last two decades which were driven by the potential to reduce costs, improve productivity, improve safety and increase sustainability (Lee et al., 2013; Oliveira and Martins, 2011; Eliwa et al., 2020). Oliveira and Martins (2011) expected that we are moving towards a "machine-dominated" construction sector (Oliveira and Martins, 2011). However, it is recognised that the construction industry is considered to be irresolute in adopting advanced technology (Pekericli et al., 2004; Peansupap and Walker, 2005; Perkinson and Ahmad, 2006; Jung and Joo, 2011; Eliwa et al., 2020). Lu et al. (2014) presented two main factors that cause the reluctance to utilise innovative technologies: the lack of information regarding technologies and corresponding benefits as well as the uncertainty in using new technologies (Lu et al., 2014). With the development of various technologies, a significant number of researchers have realised that technology utilisation could be an effective solution to the construction process issues (Jung and Joo, 2011; Eliwa et al., 2020).

The implementation of the information and communication technologies (ICT) in construction industry organisations results in formidable opportunities for improving the construction works productivity as well as the projects' internal communications to enhance the effectiveness of construction processes and for creating business innovation (Pekericli et al., 2004; Peansupap and Walker, 2005; Amusan et al., 2018; DG Azevêdo, 2020).

The influence of the ICT has been developed from the improvement of the conventional construction work to an innovative process that necessarily simplifies recent and creative alternatives to organising and operating construction organisations (Amusan et al., 2018; Gunasekaran et al., 2017; Xiong et al., 2015). Moreover, according to global reports, ICT in different type of application has assist most of the construction organisation during COVI-19 restrictions as a mean of reducing indirect cost and enhancing project productivity (MBIE-COVID-19, 2020; DG Azevêdo, 2020).

During the last thirty years, information technology and especially ICT has attracted researcher's attention in the construction field seeking to address a vision of managerial and operational affairs within the construction organisation (Abdirad and Dossick, 2016; Ghaffarianhoseini et al., 2017; Lu et al., 2014). However, in the enormous body of current studies, a comprehensive and an accurate review of information technology and ICT application in the construction organisations is missing (Mutesi and Kyakula, 2011; Liu et al., 2021).

Moreover, Various authors have specified an enormous domain of organisational, cultural and institutional obstacles to technology utilisation (Guo et al., 2017; Peansupap and Walker, 2005). Many of these studies show that a consciousness of modern technologies alone will not ensure that technology utilisation will happen and indicate the key to the technology utilisation is the performance by which modern technology is incorporated into an organisation's cultures, processes and systems, instead of the technology itself (Orlikowski, 2000; Pekericli et al., 2004). A deep and meaningful understanding questions general research trend in organisational ICT for construction firms has not been achieved. In addition, methods of aligning resources to organisational structure, ICT diffusion patterns in construction organisations, the popularity of the technologies, and taxonomy of ICT effects on construction organisational outcomes are still unclear (Son et al., 2015; Liu et al., 2021).

ICT application in construction organisation literature involves multiple disciplines, which has made navigating the field very difficult and complex. The research trends and timeline of these trends are often difficult to identify. In addition, there has been no proper investigation into the progression of ICT research topics in construction and little attention is paid to characterising the whole field through in-depth systematic and scientometric review of literature. To address this problem, this paper provides a comprehensive and scientometric review of ICT application within the construction organisations context based on high impact studies performed in the last two decades. Therefore, the aim of this study is to presents a critical literature review on the application of ICT in construction organisations. This study presents an overview of the available and trending ICT in the construction organisations and their adaptions to different work and project process. This research adopts the quantitative and qualitative method of analysis to explicate the current studies in an effective way from a holistic viewpoint.

2. RESEARCH METHODOLOGY: SCIENTOMETRIC ANALYSIS

The Web of Science (WoS) and Scopus are core global database for covering critical journals and studying literature in many fields and knowledge areas (Gingras and Khelfaoui, 2018; Martín-Martín et al., 2018) (Mongeon and Paul-Hus, 2016). Both the Web of Science (WOS) core database and Scopus were selected as primary sources for this investigation since they contain the most reputable publications on information technology and digitisation and other advanced technology applications in construction research (Harzing and Alakangas, 2016). Although these studies exist in the construction domain, they have not been classified based on ICT application in construction organisational theories, requirements and structure which is the aim of the current research.

Manual analysis of literature tends is limited and restricted by the amount of publications which being reviewed and the relationship between publications cannot be analysed (Peansupap and Walker, 2005; Surulinathi et al., 2013). Scientometrics analysis method considers an implementation of statistical and mathematical processes for quantitative analysis of domain knowledge for a specific research subject with a large number of articles and outputs (Kaliyaperumal, 2015). Others have defined the scientometric method based on application quantitative analysis techniques to bibliometric data associated with academic publications (Chong et al., 2017). This method of analysis is applied widely in construction, management and architecture research to study the hot topics, structure, characteristics and research trend (Aswathy and Gopikuttan, 2013; Coccia et al., 2015; Hosseini et al., 2018). Although the final analysis results and presentation of the scientometric analysis has qualitative features, the method of analysis itself is quantitative (Hosseini et al., 2018; Chang et al., 2020).

There are many scientometric analysis software tools developed and considered to be used for research review purpose such as Ucinet, VOSviewer, CiteSpace and SCIMAT. Some of these software tools such as Ucinet, focus on data collection and processing which required a third-party visualisation software such as Gephi on NetBeans platform to use the processed data results for the network map presentation (He et al., 2017; Pollack and Adler, 2015). VOSviewer, CiteSpace and SCIMAT software are able to do the full scientometric analysis mission including data processing and results visualisation (Hosseini et al., 2018). The general network analysis and framework require a combination and integration of the manual review and classifications with the software results. Moreover, the quality and the depth of the classifications are affected by the researchers' academic background and field experience (Hosseini et al., 2018).

Based on that, VOSviewer software has been selected in this research for scientometric analysis, and mapping visualisation (Heilig and Voß, 2014; Chang et al., 2020). VOSviewer software provides several types of functions, including the co-occurrence analysis for the research keywords, analysing the collaboration network, deep analysis of researcher co-citation, and by integration, with CiteSpace it can provide document co-citation analysis (Hosseini et al., 2018).

The bibliographic data which export from WOS contains multiple domains, including research title, cited year, keywords, researchers name, abstract, journal identification, addresses and references. The higher number of citations mainly is perceived as an indication of higher impact, in addition to the subject discussed in the research receives comprehensive awareness. The research title, research keywords, and the research abstract can provide indications of the article content. Accordingly, three levels of scientometric analysis procedure have been considered in this research via VOSviewer. Starting by co-citation analysis of the research papers which filtering the top cited research and therefore recognise the domain of knowledge. Keywords analysis level has been used secondly to present and identify the trending subjects arranged by processing domains resulted from co-releases in topic titles, topic keywords, and the research summary or abstracts (Valderrama-Zurián et al., 2015). Finally, assemblage analysis has been proceeded to identify the primary cluster of the construction ICT knowledge domain (Valderrama-Zurián et al., 2015).

3. DATA COLLECTION

In this study, two stages have been followed to develop a comprehensive analysis. The first stage, a general literature search was conducted on the topic of ICT applications in construction organisations to explore the knowledge area for terminology and identify appropriate keywords for this investigation. In the second stage, an integration of the top frequently clarifying search phrases about construction ICT was selected after introductory studies reviewed. Papers including these search phrases in the research keywords, research summary or abstract and research title has been selected. Based on that, the concluded search phrases or terms was "TS = ("information

and communication technology *" OR "construction organisations *" OR "construction and information technology *" OR "construction ICT" OR "construction&ICT") AND TS = ("information and communication technology" OR "ICT applications" OR "technology applications" OR "innovation")". The document type was limited to articles, the research main language was limited to the English language, and the time span was set to the previous two decades. As a result, 512 bibliographic records were retrieved.

Therefore, a manual review of research titles and abstracts conducted to assess the relevance to ICT research in construction engineering and management domain. Finally, a total of 376 articles were selected from the above pool of 512 research extracted from top journals of WOS and Scopus.

Fig. 1 displayed the time-trend analysis of 376 ICT associated research in constructions research. The number of publications relating to ICT in construction increased significantly from 2009 to 2021. This is because after 2009 many researchers started to compare the impact of using technologies in other industries with the construction industry (Zhong et al., 2019).

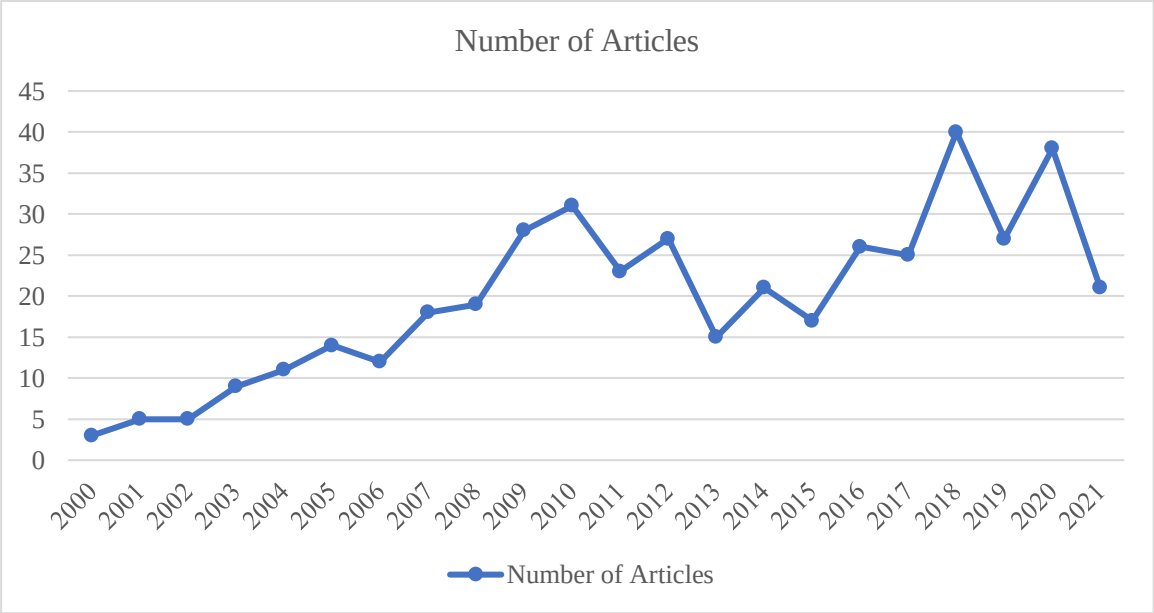

FIG. 1: Number of studies on ICT in construction organisation during two decades period

4. RESEARCH RESULTS

In this section, the results are presented based on "Journals Selection, Publication Type and Name", "Citation Analysis", "Keywords Co-Occurrence Network", "Cluster Analysis", "Keyword time analysis", and tools and software identification.

4.1 Journals Selection, Publication Type and Name

The 405 articles which have been extracted are published in 51 journals. Table 1 presents the achievement of the top 12 productive journals that published at least four articles on ICT Application in construction from 2009 to 2021. The top 12 journals account for 77% of the 405 articles indicting that these journals have a high density of articles on ICT Application in construction.

Moreover, the top five journals account for 73% of the total articles (228 articles), which indicates that these five journals are the significant disseminators of research in sophisticated technologies and ICT in construction engineering and management field. Automation in construction published the highest quantity of articles with 68 (21.8%), followed by Journal of Construction Engineering and Management 51 (16.3%), Journal of Computing in Civil Engineering 47 (15.0%), journal of management in engineering 33 (10.6%) and Journal of Information Technology in Construction (ITcon) 29 (9.3%).

It is also interesting to report that among the top 12 journals of Communications in Computer and Information Science and ACSR Advances in Computer Science Research have the highest impact factor. These journals are not in the field of construction engineering and management, which perhaps is an indication that in construction field technology and ICT research receive less attention among researchers. Lu and Wang (2014) also discovered 10 types of target journals related to ICT Application in construction through ScienceDirect, the WoS, EI Compendex and other databases (Lu et al., 2014).

TABLE 1: The top 12 papers' performance from 2009 to 2021

No.	Journal Name	No. of Articles	Percentage from total	Journal Impact Factor
1	Automation In Construction	68	21.8%	4.032
2	Journal Of Construction Engineering and Management	51	16.3%	3.711
3	Journal Of Computing in Civil Engineering	47	15.0%	1.798
4	Journal Of Management in Engineering	33	10.6%	2.282
5	Journal of Information Technology in Construction (ITcon)	29	9.3	1.94
6	Journal Of Civil Engineering and Management	28	9.0%	1.66
7	Advances In Economics Business and Management Research	17	5.4%	0.428
8	Communications In Computer and Information Science	14	4.5%	1.996
9	Advanced Engineering Informatics	9	2.9%	3.358
10	Advanced Materials Research	6	1.9%	1.95
11	Communications In Computer and Information Science	6	1.9%	4.616
12	Advances In Education Research	4	1.3%	1.163

4.2 Co-Citation Analysis

The papers co-citation network and density of the ICT application in the construction industry research are presented in Fig. 2 generated by VOSviewer and "Publish or Perish" tools with 381 nodes and 1311 edge. The time range of the data is set to the previous two decades and the time range is set to two years as shown in Fig. 2. Thus, 40 documents as the topmost cited are picked for producing of the posterior network map. The lines or nodes refer to the cited sources and bubbles between two lines – also called edges - present co-citation relationships Fig. 2.

The nodes represent a publication by an author. The width of the bubbles is commensurate with the consensual of the resource's relationship, and the density of each node is commensurate with the amount of citations. X Wang et al. (2013) owned the top citations count, presenting the research trend for the IT and ICT application in the construction industry. The second cited article was by Y Zhang et al. (2012); who presented a model for the critical success factors of construction projects. As such, X Wang et al. (2013) estimated the volume of Building Information Modeling (BIM) application in construction projects and organisation from 2005 to 2013. Unlike Y Zhang et al. (2012), X Wang et al. (2013) further discussed the proposed benefits of implementing new technologies in construction organisations based on the volume of technology application in the construction industry.

The top ten researches were published from 2012 to 2021 and can be organised into four types, including literature review (Guo et al., 2017; Rezgui, 2001; Vidogah and Ndekugri, 1998; Zhou et al., 2013), information technology and ICT utilisation in the construction industry (Lu et al., 2014; Shen et al., 2010; Tam and Tam, 2006; Valero et al., 2015), barriers and strategy to technology application (Stewart et al., 2004; Yan and Demian, 2008) and technology and methods of innovation in the construction industry (Blayse and Manley, 2004). The highly citation

of the review research is logically understanding as they present the trends based on systematic and comprehensive analysis assisting readers earn an in-depth understanding of the study field. Understanding the application and infrastructure of ICT in the construction industry is necessary for the productive management and improvement.

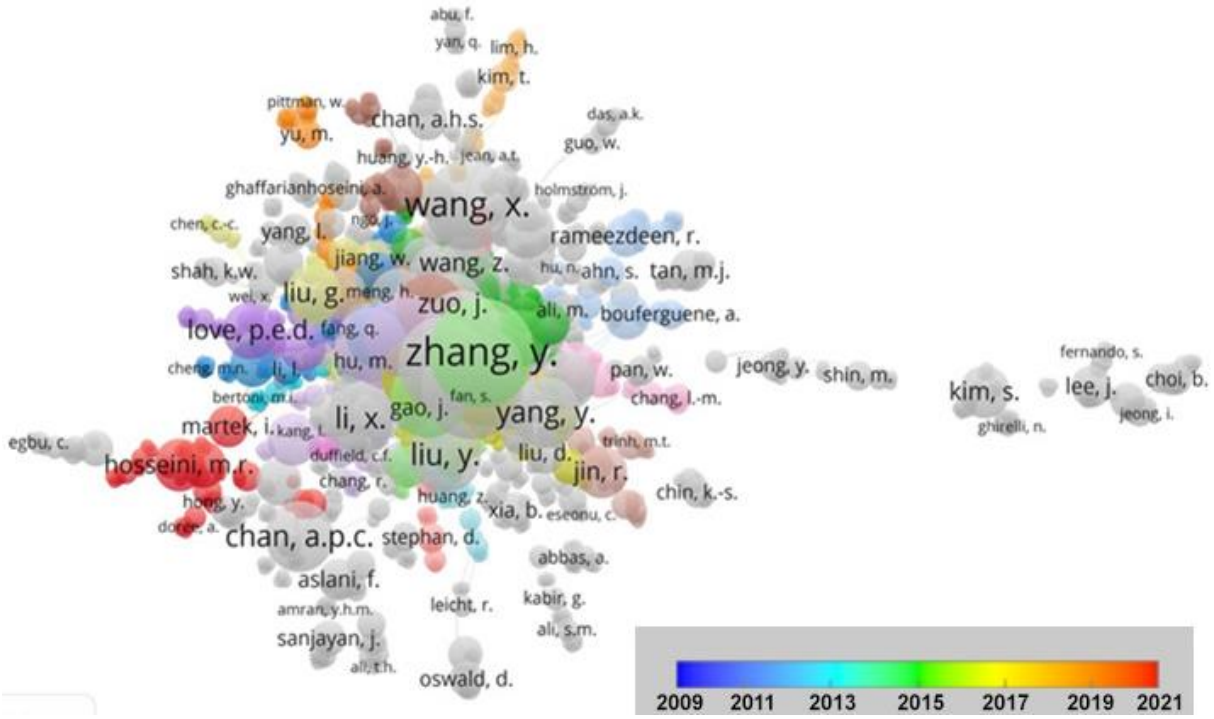

FIG. 2: Researches co-citation network for the ICT in Construction Industry: 2009–2021

Therefore, researchers aim to evaluate the size of construction technology generation either at the project level (Porwal and Hewage, 2013), an organisation level (Berente et al., 2010) or at a regional level (Becerik-Gerber et al., 2011). Critical factors and barriers for ICT implementation in construction are analysed to help decision-makers to develop productive construction management strategies.

4.3 Keywords Co-releases Network

In general, keywords reflect the core of the main content in research and reflect the development of study themes. In regards, the keyword co-releases network for the identified literature is shown in Fig. 3 which has 214 lines and 618 bubbles. The time range of the study data is 2009 to 2021 and based on the density of the data a time slice two years was generated and set by the software. In the previous network presentation (Fig. 3), nodes present keywords that trend more than two times in the 376-research selected in this study. The connection between the bubbles or the edges reflects the number of times that keywords have been combined in different studies. The size of these edges or keywords bubble represents the number of times these keywords have been used. It has to be indicated that, "construction information and communication technology", "construction organisation", "construction industry", and "construction technology application" are treated as stop-words. These stop word function as a filter for the search data after processing and refers to the most common keywords in the specific search processing (Merschbrock et al., 2016; Chang et al., 2020). As they are the fundamental concepts of ICT in the construction industry, and they do not add essential value to the current analysis. Alternatively, the recurrence of these keywords is more than other keywords, which will impact on the meaning of significant and topic core keywords in Fig. 3 considering that the volume of the keyword bubble is relative to its recurrence.

The top repeated co-releases keywords are "Construction Industry", "Information Technology", ICT, and "Application" appearing 81, 64, and 59 times, respectively (Fig. 3). "Application" is the third-top-ranking term, which is meet the study performed by many researchers such as Sanders et al. (Sanders and Premus, 2002), which predicted a raising number of research utilise these technologies (i.e., BIM, programme management tools and decision-support tools) to address complicated issues in the construction management, unlike other traditional researches which focusing on statistical analysis methods.

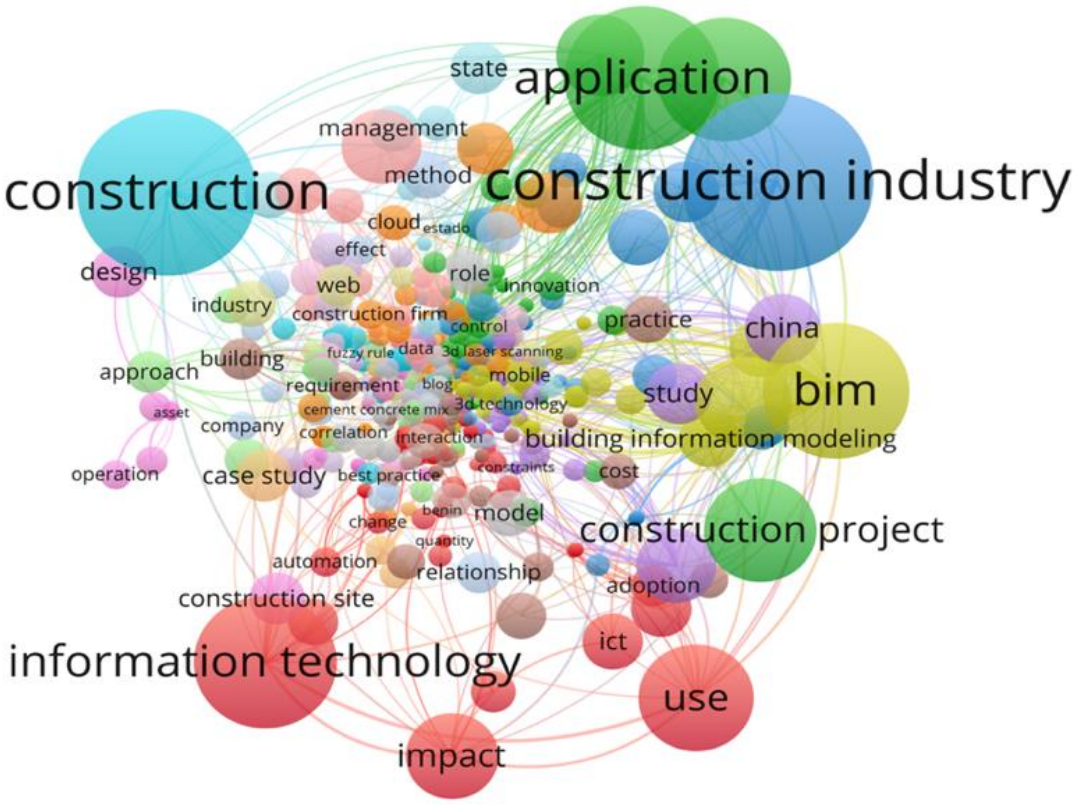

FIG. 3. Keywords Co-occurrence Network in the ICT-in Construction

The following high-frequent keywords "BIM" (frequency = 56), "impact" (53), "ICT" (49), “case study” (47), “management” (36), “use” (25), and “adoption” (19) represent the hot topics in construction associated with information and communication technologies research. These keywords also represent the following well-established areas of research in construction engineering and management: (a) Building information modelling in construction, (b) The impact of technology on construction, (c) Information and communication technology in construction, (d) implementation of technology in construction, (e) Construction Management, (f) The use of information technology and ICT in construction, and (g) ICT adoption in construction. As a widely accepted strategy for ICT in construction impact, adoption, management, and use are jointly included as one category.

4.5 Assemblage Analysis

The co-releases analysis of the studies keywords has enabled us to understand the trending subjects in the field of information technology in construction research and specifically provide some insight on ICT application. However, word frequency alone is not enough in terms of the knowledge structure and the classification of the area of study. Assemblage analysis using VOSViewer tool employs a set of algorithms to translate the collected data into multiple structured assemblages (ZHANG, X., 2016; Chang et al., 2020). In this paper, cluster labels are generated automatically by VOSViewer, which picks the top-ranked keywords happening in each cluster and labels. Four clusters are identified based on research keywords, such as BIM, analysis, construction enterprise, application, case study, impact, building information modelling, and challenge as presented on the left side of Fig. 4 and Fig. 5. The modularity of the clusters is 0.4116 (modularity is greater than 0.3), and the silhouette is 0.6092 (silhouette is greater than 0.4), identifying the structure gained by clustering is important, and the result is credible and robust. Modularity in the clusters analysis compares the number of keywords or edges inside a specific cluster with the planned number of keywords or edges that one would find in the cluster (Gao and Yan, 2013; Gries and Stefanowitsch, 2010; Li-ming and Heng-heng, 2011; Ng et al., 2011).

Further detailed information of these four research clusters including the number of keywords inside each cluster and representative keywords is displayed in Fig. 6 and Fig. 7 in rank order. Cluster ordered based on its size which identifies the number of research in each cluster from the total of 376 articles, and silhouette indicates the identity

of a certain cluster. The value range of the silhouette is from number zero to number one which is the highest, thus the higher number of the silhouette represent higher the uniformity of clustering domains (Heidarinejad et al., 2014; Miriello et al., 2010; Ren et al., 2010).

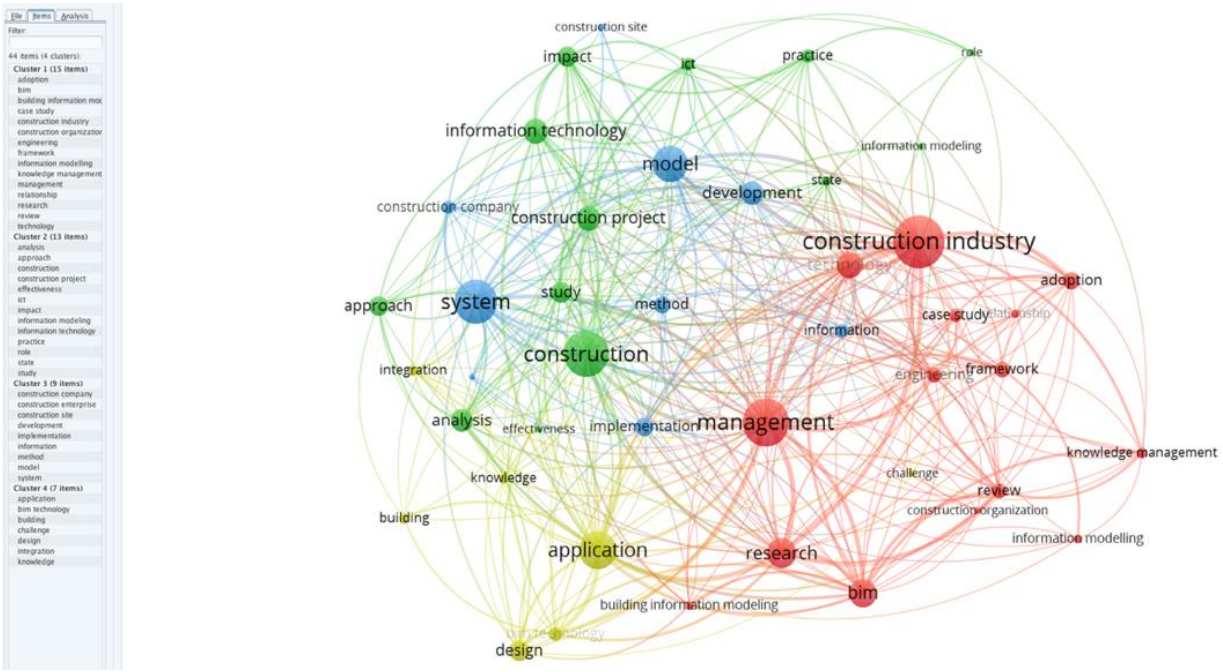

FIG. 4: Cluster analysis network and density in the Construction ICT: 2009–2021

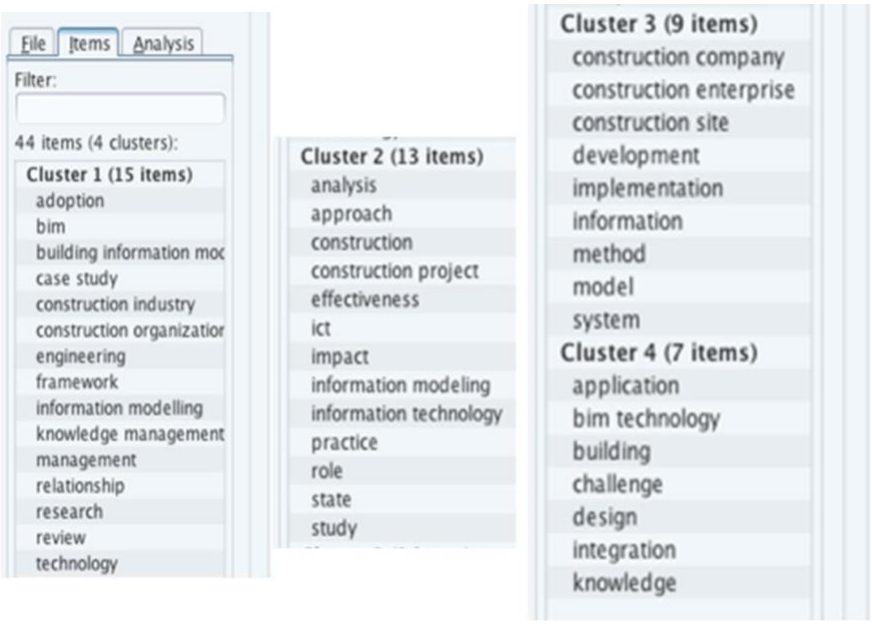

FIG. 5: Cluster grouping analysis density in the Construction ICT: 2009–2021

The most significant cluster is cluster #1 which including keywords related to new technology adoption and implementation, including 15 keywords or topics inside (Fig. 5). The publications inside this cluster refer to the ICT application and utilisation in the construction industry and organisation. Cluster #2 is related to the analysis of the impact of these technologies on construction project or industry. Cluster #3 talking more on the management of this technology and providing a system or model such as strategic alignment model which provide a method to assess the technology implementation in construction companies or enterprises. Cluster #4 which related more on

the technology implementation and case study conclusion and the final thought regarding the integration of ICT in construction projects or organisations. In general, cluster #4 includes the issues of research methodology and practice in ICT utilisation.

An overlap between the results from the assemblage analysis and the co-releases analysis results cleared after comparing the subjects from these method of analysis such as building information modelling, adoption and case study. Moreover, differences between the two methods of analysis have been declared; for instance, assemblage analysis identifies some methods applied in the construction ICT implementation and analysis, including approach, relationship, review, case study, whereas co-releases analysis presents the trending subjects, such as BIM in construction, and the impact of the ICT on construction industry. These results integrate in each other and benefit the understanding of the construction information technology and ICT implementation (Aier et al., 2011; Bennett and Cialone, 2014; Deb and Lee, 2018; Yi-ling, 2011).

4.6 Keywords Time Analysis

The keyword co-releases analysis as well as the assemblage assessment help us to define and better understand the domain of knowledge of the ICT application in the construction amongst the general trends of technology application. However, differences in keyword frequencies over time have not been presented. To discover the significance and frequency diversities of particular keywords in a limited range of time, Burst Detection tool has been used. A keyword can be considered as an effective sub-field, if there is a dramatic increase during a short time range in the recurrence of a keyword. VOSViewer has an option with a keyword burst tool that useful to identify significant swings over time in addition to high trends in a knowledge domain (Hosseini et al., 2018). Fig. 6 presents the trending keywords with the most powerful citation bursts in the construction ICT field from 2009 to 2021 in time zone order.

Papers' keywords from 2009 to 2012 have a burst time of more than three years, which mean a considerable amount of data for these keywords presented during this period comparing with other periods and the typical keywords in this period are "system", "value", and "performance" (Fig. 6). In this period, these studies focus on the value of using new technologies in construction (Goodrum et al., 2010), barriers or factors impact the technology utilisation in construction (Ametepey et al., 2015; Shi et al., 2013), the economic feasibility of using technology in construction (Ganesan, 2019), system or model using in implementation of technology, and impact evaluation of using the technologies on construction performance (Ding et al., 2012).

The frequency of the term "information and communication technology" and "application" experienced a considerable ascension from 2013 to 2016, that is probably related to the application and the utilisation of the ICT, ICT in the construction and the strategy around that. After 2016, a varied group of subjects presented by authors and each subject lasted between 2 to 3 years. From 2014 to 2017, the ICT became a trending subject, especially through project management and construction performance. Likewise, quantify business performance and construction enterprises were also trending subjects from 2014 to 2017 (Agwu, 2012; L. Oyewobi et al., 2013; L. O. Oyewobi et al., 2016). On the other hand, the keywords related to BIM technology clarified in 2016 to 2021 with comparatively low recurrence if been compared to others. However, the BIM technology has been considered to be used as a reinforcing tool of the construction performance management with an integration of the information and communication tools in the construction, design, procurement, and commissioning phase (Panuwatwanich and Nguyen, 2017).

The keyword time analysis also provided some insight into the type of construction economy and the application of technological tools (Antuchevičiene et al., 2010; Brauers and Zavadskas, 2010). The analysis demonstrates that more recently; the projected attitude theory is utilised to investigate construction performance behaviour and the behaviour of the engineers, contractor employees' practitioners, designers, project managers and particularly contractors (Altheide, 2018; Li et al., 2018). As new technologies and innovations gained worldwide attention, building information modelling, 3D printing technology and ICT applications from gained more popularity from 2017 to 2021. Therefore, many research engaged in "business performance" and "strategy", including simulation of the potential impact of new technologies on construction management approaches (i.e. BIM, information modelling, cloud computing and e-risk) (Takim et al., 2013; Wong et al., 2014).

In order to monitor the studies major trends of the last decade, a visual network view was developed to highlight the keywords co-releases from 2009 to 2021 (Fig. 6). The integration of burst detection using VOSViewer and the network view can present the analysed trend of a study area (X. ZHANG, 2016).

The lines which connect the nodes refers to the co-releases connections between keywords. Moreover, the level of the colours of these lines are presenting the time zone relationship between the two keywords. The volume of node bubble (keywords) is symmetrical to the occurring frequency of keywords.

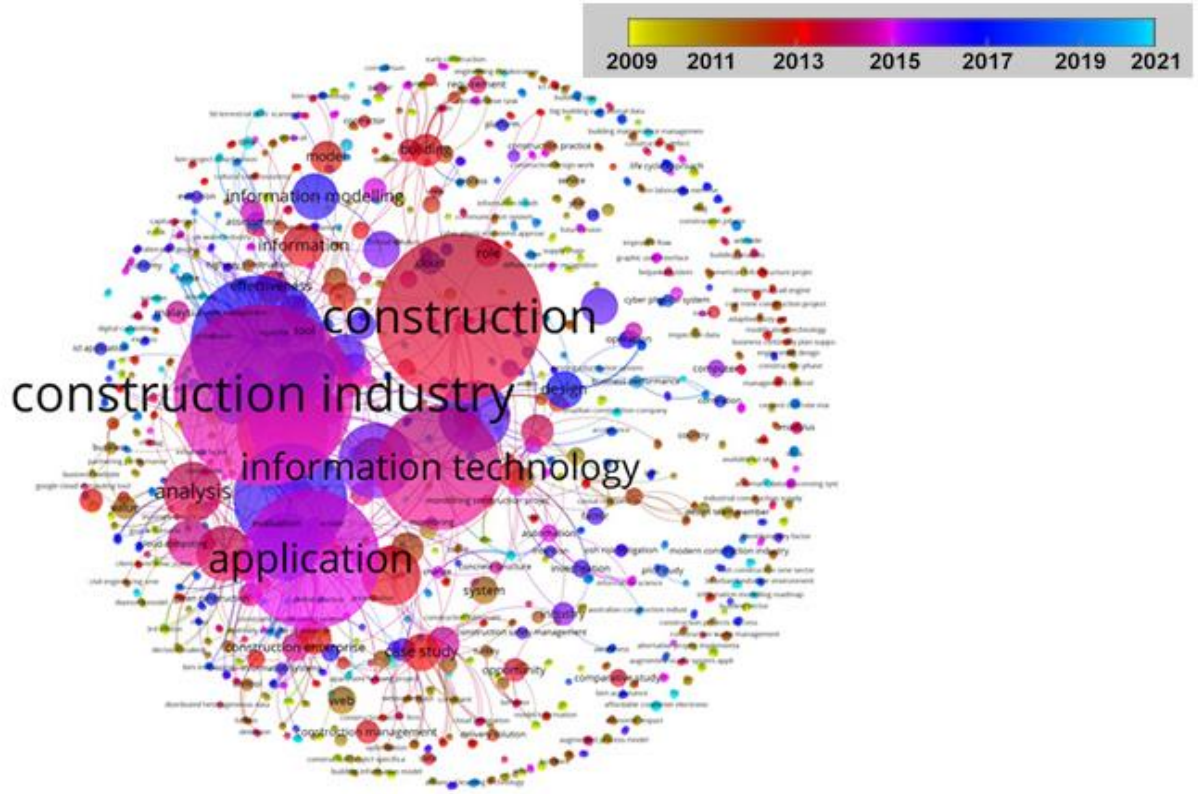

FIG. 6: Top keywords with the strongest citation bursts from 2009 - 2021

4.7 Tools and Software Usage Analysis

The final analysis has been considered in this research was to identify and analyse the ICT tools usage in the previous technical research. Ezcan, V., Goulding, J. S., & Arif, M. (2020) have identified five main ICT applications groups which can cover most of the ICT products in construction as the following:

- Planning and Project Management: This group covers software or tools that allow managing complicated business processes with planning, organizing, and managing the various resource pools available (Li et al., 2018).
- Job Site Data Collection & Reporting: This group covers the most common usage of software or tools in any project size which involving the daily reporting support tools and can be used by non-professional construction teams (Pidgeon A et al., 2021).
- Computer-aided drafting (CAD): CAD systems provide drawing entities with powerful construction, editing, and database techniques to produce drawings and models of what buildings will look like when finished (Li et al., 2018).
- Cloud Storage, Sharing, and Web Conferencing: this group includes the communication technology tools which facilitate the organization or project communication and information sharing system (Li et al., 2018).
- Building information modelling (BIM): BIM software can directly and interactively present concepts of design in a form which represent physical and real images of the building to allow designers to identify clients' needs, and to promptly and effectively provide solutions to these needs (Chang et al., 2020).

Based on the above groups of ICT tools, a general search on The Web of Science (WoS) and Scopus has been conducted considering the ICT groups as search keywords and the timeframe from 2009 to 2021. Finally, the result data has been summarized in Table 2. The average citation score in Table 2 represents the mean citation score of

the target research which have been selected to calculate the popularity of the ICT group. Based on this table, the Building Information Modelling ICT group are the most popular ICT research area considering the number of studies related to this ICT groups compared with the total number of the ICT studies. On the other hand, the studies related to the computer-aided drafting (CAD) ICT group have scored more citation popularity comparing with other ICT research areas.

TABLE 2: ICT applications groups' performance from 2009 to 2021

ICT Groups	Application examples	%age of usage in researches	Avg. Citation score
Planning and Project Management	*Primavera, Microsoft Project, Syncro 4D Planning, Deltek Acumen, Planswift*	12%	41
Job Site Data Collection & Reporting	*Microsoft Office Package, NoteVault*	6%	14
Computer-aided drafting (CAD)	*AutoCad, Navisworks, Tekla*	31%	79
Cloud Storage, Sharing, and Web Conferencing	*Dropbox, Adobe Acrobat, Aconex, StoneX*	8%	12
Building information modeling (BIM)	*Navisworks, Tekla, Syncro 4D Planning*	43%	64

5. DISCUSSION

The scientometric systematic analysis can provide the main components to draw an integrated framework for ICT in the construction industry (Darko et al., 2019; He et al., 2017; Zhong et al., 2019). The comprehensive framework in Fig. 7 contains three main parts: the knowledge domains which is the top section, knowledge evolution which is the middle part and at the bottom the directions for future studies (Chen, 2017; Ivancheva, 2008). Based on the burst detection which has been described above, the knowledge development in ICT in the construction industry has been presented in the above "Keywords Time Analysis" section. In this section, the main identified knowledge domains for ICT in the construction research are discussed based on the outcomes of the keywords co-releases analysis and assemblage analysis.

5.1 Knowledge Domains

Considering the outcomes of keywords co-releases network and assemblage assessment, the domains of knowledge in ICT in the construction industry are declared and further illustrated in four columns within Fig. 7. These knowledge areas are categorised as the following (Fig. 7):

- Technologies and Methods
- Assessment and Comparison
- Composition and Quantification
- Factors and Challenges

The combination of high-frequency keywords from cluster #1, Cluster #3 and cluster #4 has been developed using SciMAT mapping analysis tool and create an indication of different knowledge domains. This is performed based on the trend of each keyword in research categories and the identified in the previously identified clusters.

Accordingly, the first column in Fig. 7 demonstrates a knowledge domain involving the keywords related to the factors and barriers that disturb the management of ICT in the construction industry. Therefore, this column is critical for an effective implementation of ICT in construction by demonstrate the implementations challenges as well as the process to pass these utilisation barriers (Darko et al., 2019; Zhong et al., 2019; DG Azevêdo, 2020).

In the second domain, related keywords from cluster number one to cluster number four have been organised in this column which concern estimation and quantification of the construction industry, construction organisations and building research. Within this domain construction quantification methodology involves the classification of

the study field, research scope, variables modelling method, and other particular methods (Oliveira and Martins, 2011; Pekericli et al., 2004).

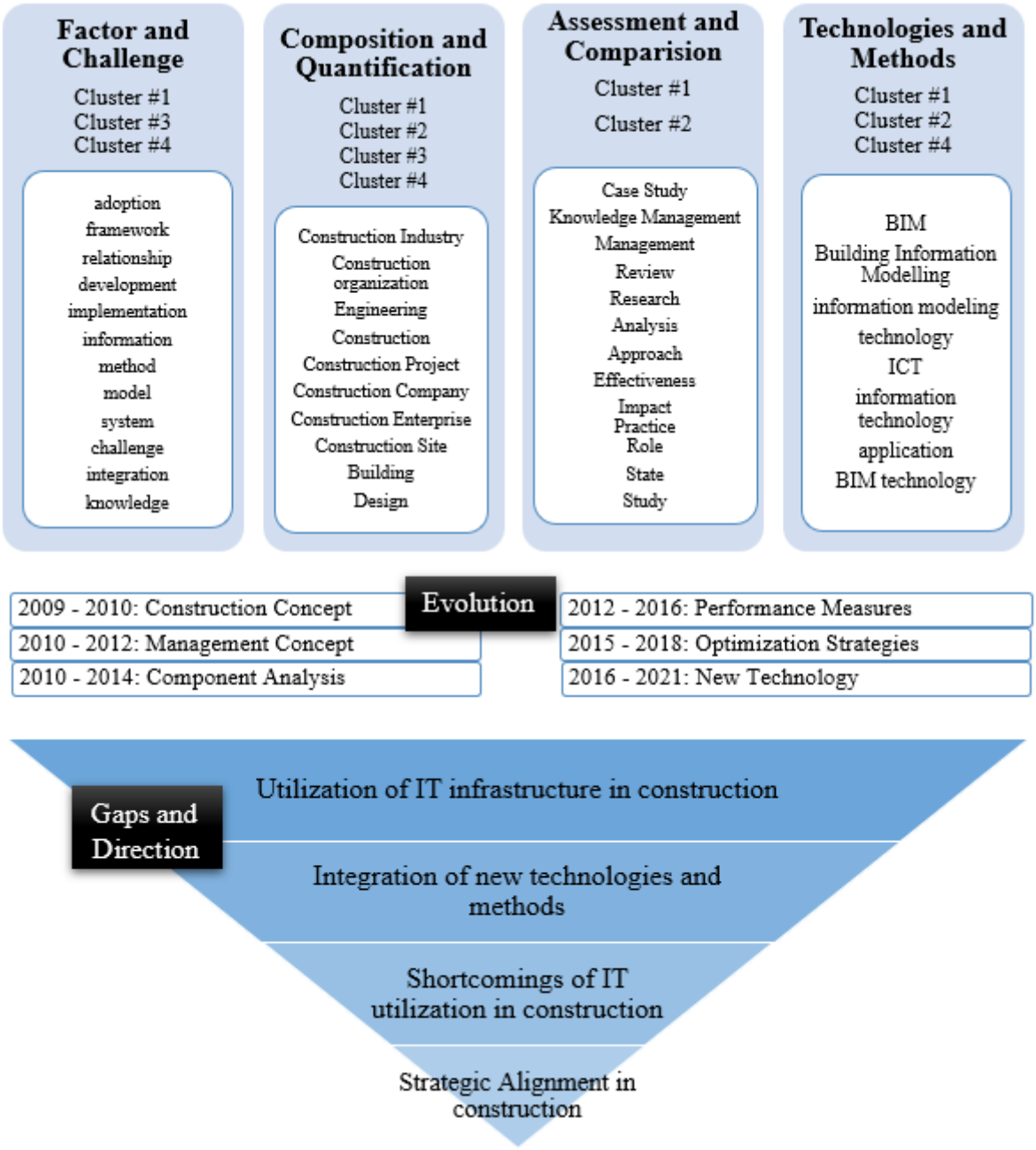

FIG. 7: The comprehensive framework for ICT in Construction 2009 - 2021

The next domain categorised related to the ICT implementation assessment which can further characterised into two types starting with the feasibility analysis and process to the impact analysis for each utilisation simulations. This domain includes the related keywords from cluster #1 and cluster #2.

Finally, the fourth domain is technology and method; including correlative high-frequency keywords from Cluster #1, Cluster #2, and cluster #4 such as BIM, information modelling, cloud computing, big data, CAD and ICT.

The existing construction information technology ICT applications and tools have the problems related to insufficient data quality which is most researchers concentrated more on solving the issues related to it. However,

there is a lack of studies related to the second problem which is the shortage to integrate with the various construction process (Orlikowski, 2000; Perkinson and Ahmad, 2006; Oliveira and Martins, 2011; Lu et al., 2014; Gunasekaran et al., 2017; Guo et al., 2017). The top keyword in this list is related to the building information modelling (BIM). This is one of the most effective areas of study in term of the integration of ICT in the construction industry and by integrating the data monitoring ICT with a visual related technology like BIM to improve project monitoring system, location-based management, and remote data collection (Abdirad and Dossick, 2016; Bui et al., 2016; Ghaffarianhoseini et al., 2017; Lee et al., 2013; Rogers et al., 2015).

5.2 Knowledge Evolution and ICT Application

Considering the keyword detection results using the time-range view which discussed during "Keywords Time Analysis" Section, the evolution of ICT research and knowledge in the construction industry can be tracked. Based on this keyword detection results, the trending research subjects from 2009 to 2010 were only related to primary concepts, for instance the topics related to "value", "construction", and "project management". Since 2011, the concepts have been changing from primary to advanced management such as the topics related to "performance" and "system". On the other hand, considering the research focus in the same range period, the concept itself has been diverted from the topics related to the basic ICT implementation challenges to more advanced and internal component analysis (i.e., productivity improvement). Research from 2013 to 2016 focused on construction "analysis", especially through "design" and "construction" measures (Amusan et al., 2018; Gunasekaran et al., 2017). From 2017 to 2018, "strategy" became the new concerns to improve performance and outcomes in both organisation size and project size (Altheide, 2018; Amusan et al., 2018; Zhong et al., 2019). From the time range of 2016 to 2021, new ICT and methods such as "big data" and "BIM" became trending topics. The evolutionary trend of ICT in the construction industry from 2009 to 2021 can be summarised as a transformation from traditional management concepts to an external and internal challenge analysis to innovative management practices and organisational strategy (Darko et al., 2019; Ganesan, 2019). Regarding the ICT application studies, building information modelling (BIM) applications have been identified as the most studied ICT construction application compared with other ICT application groups which can be because of the natural of BIM technology and how it is involving and can be integrated into other type of ICT group. On the other hand, the computer-aided drafting (CAD) application groups have scored the top citation rate which can be due to the history of the CAD applications and how it involves the integration with other ICT application groups.

5.3 Directions for Future Studies

The directions for future studies section have also been captured in Fig. 7. The first knowledge gap is to study the utilisation of ICT infrastructure in the construction industry. According to studies by researchers which have been considered in this investigation, it is necessary to analyse the connection between the information technology and ICT strategy and construction organisation or construction project strategy before the implementation of these technologies in the construction organisations (Amusan et al., 2018; Guo et al., 2017; Kanapeckiene et al., 2010; Lu et al., 2014; Mutesi and Kyakula, 2011; Oliveira and Martins, 2011; Son et al., 2015). However, most of the previous researchers concluded that the common problem of the construction organisations is the soft link between the organisation infrastructure and ICT infrastructure which affect the efficiency of information technology and ICT implementation (Jelodar et al., 2022; Amusan et al., 2018; Panuwatwanich and Nguyen, 2017; Rezgui, 2001).

The second research gap is to explore the utilisation of new ICT in the construction industry; analyse the results of this integration and also discuss methods of integration. Many research have investigated in the first research gap which is related to ICT utilisation in construction industry without discussing and analysing the strategy behind the utilisation methods (Ghaffarianhoseini et al., 2017; Oliveira and Martins, 2011). For instance, Zhang et al. proposed a BIM-based method that assists in construction safety management in an early construction stage (S. Zhang et al., 2015). Akinade et al. developed a comprehensive model based on BIM technology to determine the demolish capacity in the design stage of the project and before the construction stage start (Akinade et al., 2015). Accordingly, future studies can improve and expand the application of ICT from the early construction stage such as design, procurement and manufacturing stage to the stage of construction and commissioning and accordingly to the end of the project life stage (He et al., 2017; Wong et al., 2014; Zhong et al., 2019). Moreover, integrating further data processing technologies and data collection such as RFID and GIS into BIM is also becoming a necessity of modern construction practices (Darko et al., 2019; Hosseini et al., 2018; Panuwatwanich and Nguyen, 2017; Sun et al., 2017).

The third and fourth knowledge gaps are related to the shortcoming of ICT utilisation and having strategic alignment of resources in the construction sector. Based on reviewed research from 2009 to 2021, it is essential to conduct in-depth investigations of the relationship between ICT strategy and the existing business strategy (Henderson and Ruikar, 2010; Khosrowshahi and Arayici, 2012; Woo et al., 2016). It is still required to fill the gap of knowledge in strategic alignment of construction ICT and business and identify the issues behind the underperformance of ICT implementation in construction organisations. The mixed results across various studies appealed for more empirical research to investigate the link between strategic alignment and organisational performance (Eliwa et al., 2022; Eliwa et al., 2018; Acur et al., 2012; Johnson and Lederer, 2010; Morrison et al., 2011).

In addition, there is a lack of research and empirical evidence on the issue of the strategic alignment for information technologies and ICT in the construction organisations and the challenges in the adoption of these technologies. Thus, in-depth studies are required to present empirical evidence which can benefit the construction industry practice in the future and contribute to the body of knowledge (Budayan et al., 2015; Coltman et al., 2015; Doumi et al., 2013; Dutot et al., 2014; Morrison et al., 2011). The important of the ICT in construction industry has been highlighted out during the COVID-19 and post COVID period and how this type of study will benefit the construction organisation to implement to ICT in productive manner considering the strategic alignment between the business and ICT (MBIE-COVID-19, 2020; DG Azevêdo, 2020).

As new technologies and concepts are introduced this research can be replicated through similar methodology to further understand future trends. There is also a need for further in-depth research to understand ICT application and integration with major trending technologies and concepts in construction. This could include ICT integration with BIM; digital tools such virtual reality and augmented reality; application of sensor, Internet of Things and etc. Furthermore, the relationship of ICT with digital twins which is a high-fidelity representation of the real-world that connected and behaves like the real world, should be explored to improve understanding of the project life-cycle requirements and enhance decision making processes (Jones et al., 2020).

6. CONCLUSION

This study systematically reviewed publications related to ICT in the construction industry from 2009 to 2021 by using the scientometric analysis method. A total of 376 research selected for burst detection, co-citation analysis, cluster analysis, and keyword co-releases, in order to provide a comprehensive knowledge summary of the ICT application in the construction industry. Automation in Construction, Journal of Management in Engineering, Advanced Engineering Informatics, and Journal of Intelligent & Robotic Systems were identified as the four major journals associated with research on the ICT application in the construction industry. X Wang et al. (2013), Y Zhang et al. (2012), Albert P.C. Chan (2018), Y Yang et al. (2013), Peter E.D. Love et al. (2015) identified as the top five critical papers. By determining the high-frequent co-releases keywords, the trending research subjects in this area were identified as; “Building information modelling in construction”, “The impact of technology on construction”, “Information and communication technology in construction”, “Case study on the implementation of technology in construction”, “Construction Management”, “The use of ICT in construction”, and “ICT adoption in construction”. Building information modelling (BIM) and the computer-aided drafting (CAD) group of application have been identified the most studied tools in the field of construction information technology.

Using the scientometric review analysis method, this study has presented a comprehensive framework for ICT application in the construction industry. The overall trends of ICT application in the construction industry from 2009 to 2021 were summarised as a transformation from traditional management concepts to an external and internal challenge analysis to innovative management practices and organisational strategy. The main knowledge domains of ICT application in the construction industry were identified and further classified into four columns (Fig. 7) or domains and future studies directions were eventually discussed.

This study contributes to the construction industry body of knowledge by classifying the existing ICT related research, evolutionary trend, providing current status and lending to a comprehensive knowledge framework, and future directions. The research findings can provide hindsight; helping researchers and practitioners better understand the current research related to ICT applications in the construction sector. The evolutionary trend and knowledge domains can offer a clear and in-depth cognition of construction ICT research.

As mentioned above, the knowledge gap related to summarising and reviewing the depth and breadth of the technology application studies, especially the ICT applications and its effect on construction organisations has been identified. Also, a large amount of research has been devoted to the technology application in different industries ICT is still unclassified within the construction sector and organisational research. This identified knowledge gap provides specific needs and research directions for construction ICT research.

Finally, considering the research method, there are three limitations in this study. The first limitation is that the articles used for scientometric analysis collected only from the Scopus and WOS database only. Moreover, the study is mainly concentrated on the quantitative analysis in regards to the articles merging frequently in the ICT applications in the construction industry, which were used to indicate the hot topics. Finally, results may change at different with the updating databases.

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