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Research Methods in Construction Robotics and Human-Robot Teams: - A Scientometric and Systematic Review

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Abstract

In the emerging studies on construction robotics, discussions on methodological approaches are lacking. Despite the potential of robotics adoption in construction to enhance productivity and improve safety, debates regarding research methods have been identified as an underlying factor in limited output in the area. With limited studies and publication in the domain, a methodology review is needed to further develop knowledge in this area. Using a two-phased literature review adopting scientometric review and systematic literature review, the study reviews 112 Journal articles on the Construction robotics research domain and identified insights from the analysed publications. An overview of publications between 1987 and 2021 is presented, examining the topics and approaches researchers adopt most in construction robotics and human-robot teams. The findings offer insight into the popular methods and the need to adopt comprehensive methods specific to the nature of the research problem. The study's findings are vital to guiding subsequent studies in construction robotics on available methods, those frequently used and emerging approaches.

Keywords

Collaborative robots, Construction Robotics, Human-Robot teams, Research Methods, Scientiometric, Systematic Review

1. Introduction

Rate of fatalities and incidents occurring on Construction sites, inhibited productivity in the face of increasing infrastructure demands, ageing population of workers and shortage of skilled workers are challenges advancing the need to adopt innovative technologies in the built environment. Primary amongst these emerging technologies is the potential in the use of robotics and collaborative human-robot teams to improve dangerous aspects of construction in high-risk areas, enhance productivity, avail prompt and sustainable infrastructure delivery even during shock events such as pandemics and improve overall construction resilience, responsiveness, health and safety (Huang and Mao, 2021; Atkinson and Clark, 2014). This is further reiterated by Cai et al. (2020), stating that research and techniques in construction automation and robots have emerged to cut costs while also improving productivity, quality, and safety. Therefore, the argument for their favourable adoption is inevitable because traditional building methods have reached their limits in serving the construction industry's rising needs. A future technology disruption of construction automation and robotics' ubiquity has been projected (Bock 2015). Ergo, the use of robots has been promoted as one of the most promising methods for industry change (Pan et al., 2020a)

However, despite the gains of widely adopting these technologies, the advancement of research and development in construction robotics and the human-robot teams' domain is constrained by varying factors (Edwards et al., 2021). Among these factors is the dearth of studies on research methods in construction robotics and human-robot teams able to provide pathways and clarity on the approaches researchers adopt in solving construction robotics challenges. According to Agyekum-Mensah et al. (2020), there has been a current debate about the inappropriateness

and dominance of quantitative data collection, regardless of the type and form of knowledge research, with academics disputing that the sampling procedure and mechanism is frequently inappropriate. This is further exacerbated with restriction of construction robotics research to selected approaches identified as resulting from lack of knowledge on the methods available and experimented by previous robotics researchers in the field of construction robotics and human-robot teams in the Architectural Engineering and Construction (AEC) sector. With construction research central to improving the effectiveness and efficiency necessary for practice, construction robotics research must be relevant and beneficial. A failure to adequately highlight research methods to advance research in informing development that resonates with workplace practices is unbeneficial to the built sector. Ergo, this study presents a review of research methods in construction robotics and human-robot teams vital to furthering research studies in this area through the integration of a Scientometric analysis and a systematic literature review

2. Methods

The current paper was developed using a four-research method, with the first stage involving the scientific search for publications, the second stage adopted the definition and application of exclusion criteria, the third stage integrated the development of a Scientometric analysis, and the fourth stage is the execution of a systematic literature review. The Scopus database was used as it is the largest database for scientific articles containing comprehensive publications (Abdullahi B. Saka & Chan, 2019). The keywords "Robotics" AND "Construction" were used to gather the most relevant publications associated with Construction Robotics. The document types were limited to Journal articles as they are considered more comprehensive, and all documents published in English only were selected(Cardoso et al., 2020). The initial query revealed 9971 documents which were further refined to 2082 documents related to the Construction domain. With the exclusion of other document types and refining of abstracts to remove redundant outputs, 112 publications were reviewed for this study as presented in Fig 1. The Scientometric analysis was limited to analytical queries related to the overarching objectives of the research. Thus, only the document citation and keyword co-occurrence network were highlighted from the study (Zabidin et al., 2020). The metric data was transferred from CSV to VOSViewer, which allows you to create bibliometric networks and execute analyses like this. The final and fourth phases involved identifying the primary themes and categories of information and dividing them into key subject categories, thus allowing the data to be presented systematically.

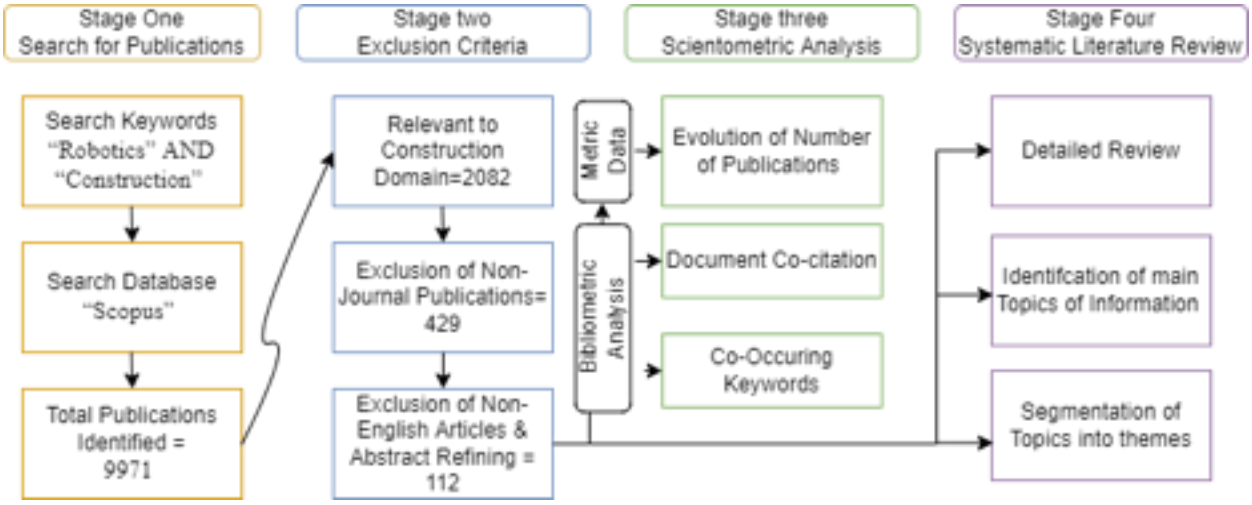

Fig 1. Research Method incorporating Scientometric Analysis and Systematic Literature Review

3. Results

3. 1 Evolution of Publications

The evolution of the number of publications on construction robotics was examined in the timeframe between the year 1987 and the year 2021 to comprehensively have a visual timeline of the inception of research in construction robotics till the present. The result reveals a steady increase in publications between 2016 and 2021, while the trend between 1987 and 2015 had been unsteady with intermittent highs and lows. The maximum number of publications was

identified in 2021 with 43 publications. This corroborates the existing hypothesis that interest in construction robotics and collaborative robots is increasing. The high number of publications rising sharply between 2020 and 2021 could, amongst other factors, be due to shock events such as the COVID-19 pandemic necessitating alternative means of construction requiring minimal human interaction for sustainable infrastructure delivery in future shock events that might need humans to be off-site.

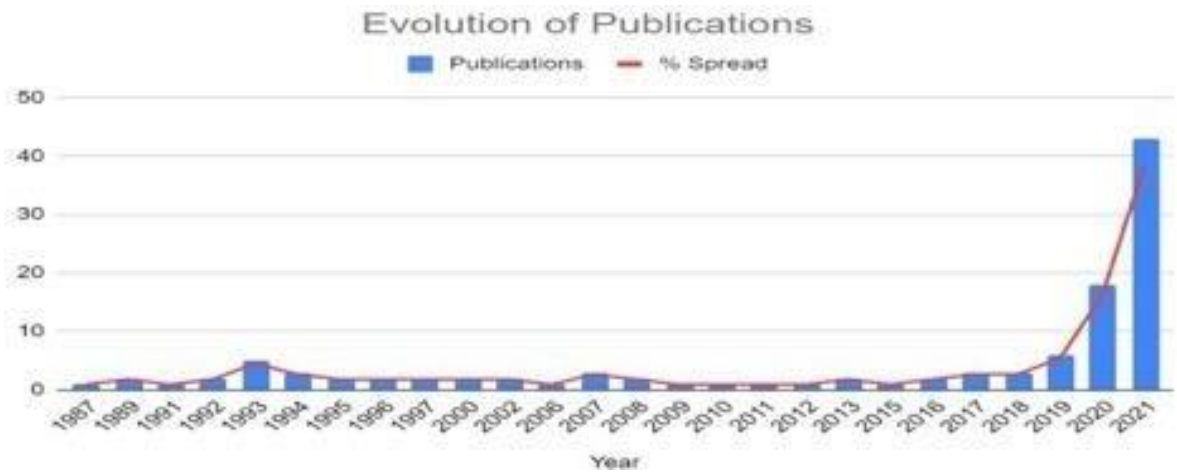

Fig 2. Evolution of Publications

3.2 Publication Outlets & Sources

The Publication sources revealed that Automation in Construction has the highest outcome in publishing articles on Construction robotics with 50 out of the 112 articles reviewed. Followed is the Journal of Construction Engineering and Management with 6 articles, the Journal of Building Engineering with 4 articles.

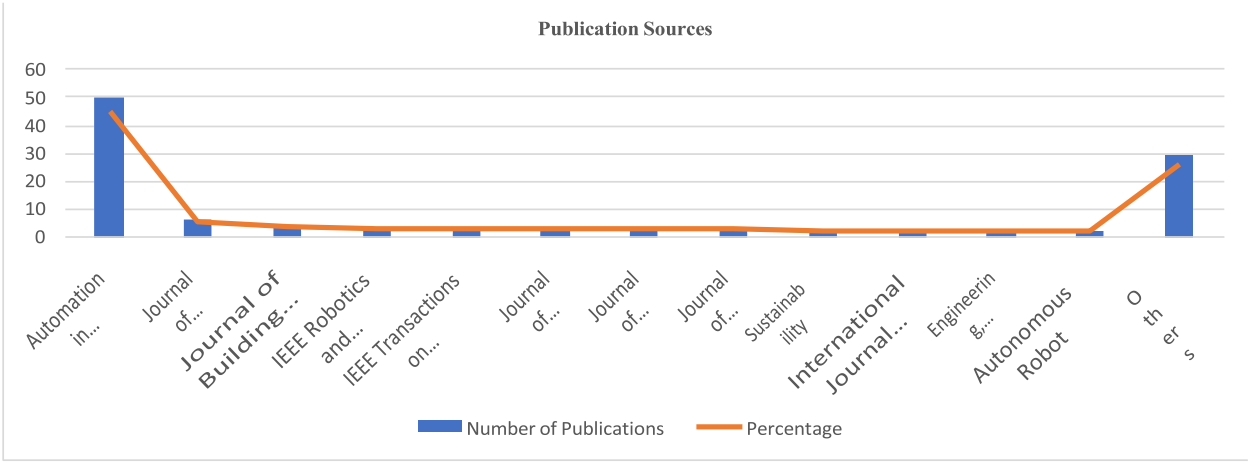

Fig 3. Publications Sources

The low amount of publications in all other Journals could be attributed to low turnout of Special Issues on Construction Robotics and Human-Robot Teams compared to more trendy topics such as "Building Information modelling" and "Sustainable development" The Journal with 3 articles were; Journal of Architectural Engineering, Journal of Information Technology in Construction, Journal of Management in Engineering, IEEE Robotics and Automation Letters, IEEE Transactions on Automation Science and Engineering. The Journals classified as others were those with single articles.

3.3 Most Cited Publications

The number of citations was also analysed and presented in Fig 4 below, Bock (2015) is the most cited publication, followed by Pan et al. (2020), Bogue, (2018) and Manuel et al. (2019), amongst other publications. Knowledge of the methods adopted by the most cited publications is essential to measuring the impact of the different approaches. While the most cited document, Bock (2015) adopted a review approach, an analysis of other most cited publications indicated the prominence of experimental and case study approaches. This is further validated by (Aghimien et al., 2020)

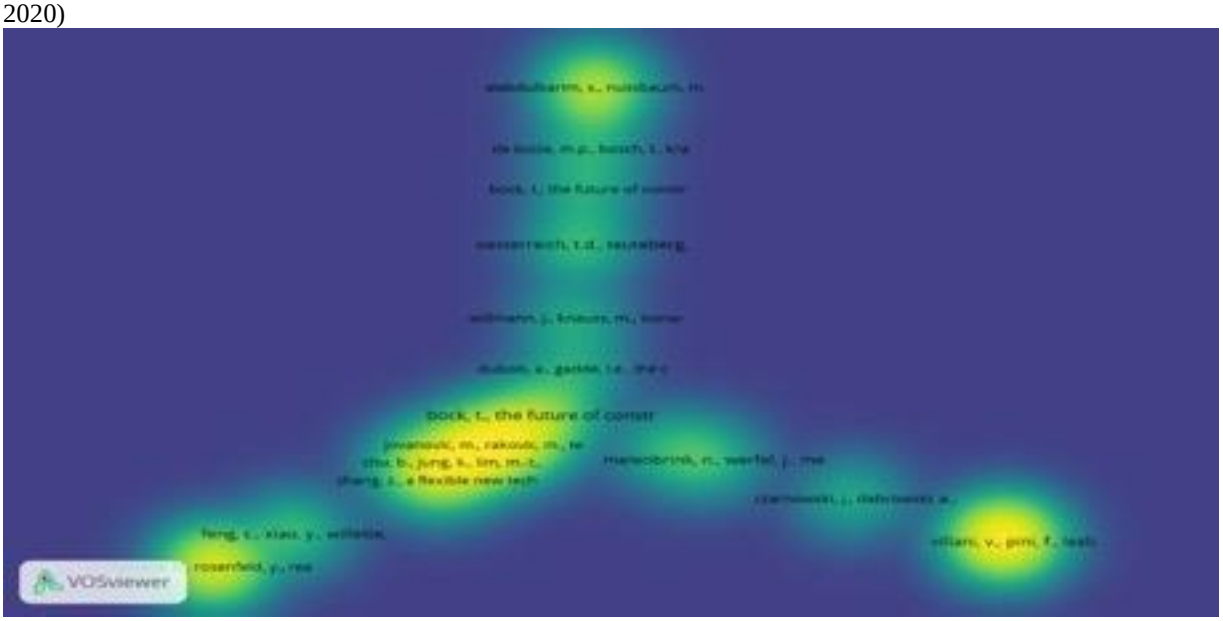

Fig 4. Most Cited publications

3.4 Co-Occurring Keywords

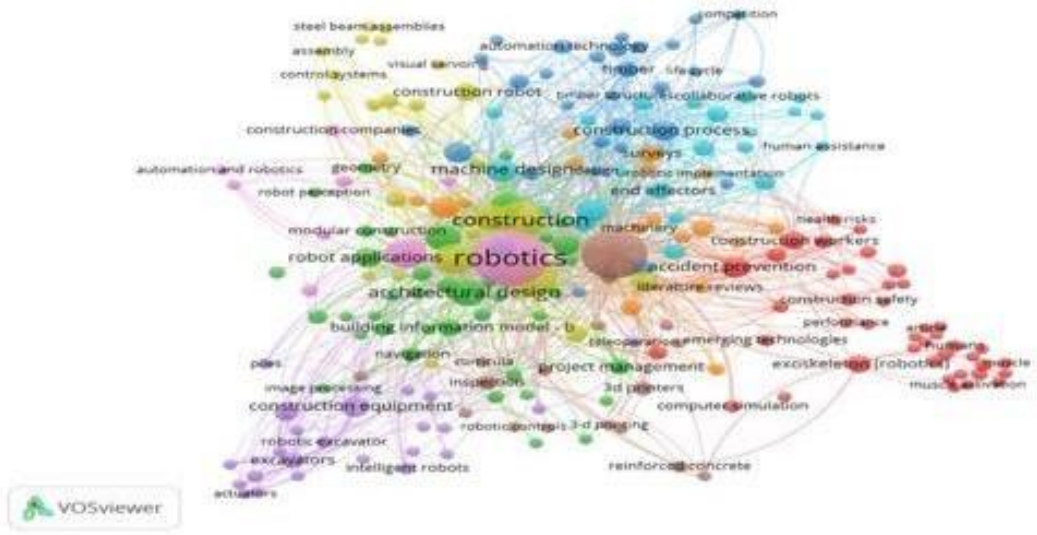

Fig 5. Co-occurring keywords

The map illustrates those keywords that occur frequently in the publications reviewed. The word robotics is the most commonly used author keyword in journals. The other keywords shown are; architectural design, accident and prevention, construction workers, collaborative robotics, intelligent robots, construction equipment, automation, computer simulation, etc. The appearance of construction workers, human assistance, collaborative robots reveals emerging discussion on the need to consider human factors research imperative to robotics adoptions in the AEC sector.

3.5 Comparison of Research Methods and No of Publications

In this section, key research methods were cross-tabulated with publications to identify the trends. The analysis reveals that quantitative methods were the most used research data approach in Construction robotics. Furthermore, most Journal publications also published articles with quantitative research methods. This is followed by review-based studies using systematic and Scientometric techniques to answer research questions and occurs more than the use of qualitative methods in the construction robotics research domain. The least considered research methods involve the use of mixed methods.

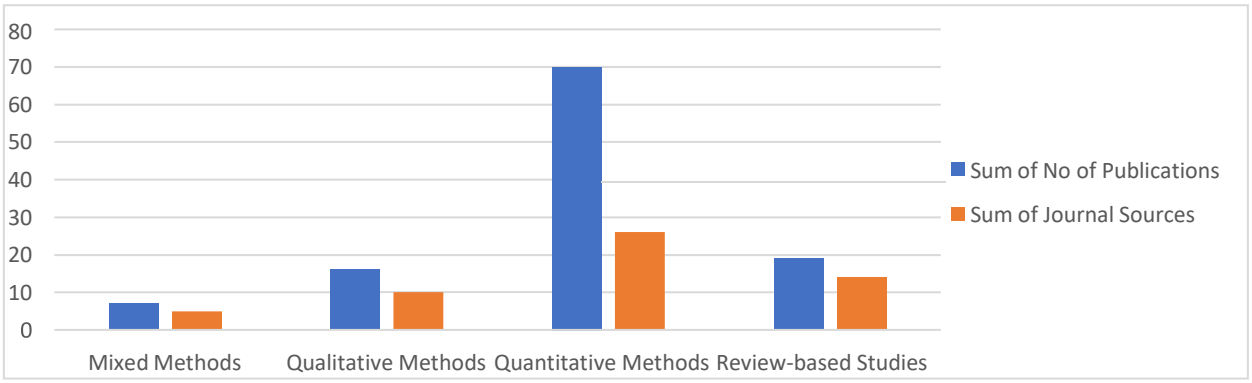

Fig 6. Pivot Chart cross tabulating research methods and number of publications.

3.6 Research Methods Adopted and Sub-Categories

This section brings together the methods associated with Construction robotics in the literature reviewed. While analysing this section, the key research approaches were grouped together and further discussed. The research methods were classified into four categories based on previous studies recommendations. The four categories were quantitative, qualitative, mixed, and review-based studies. The Quantitative methods had 63% of total publications with Surveys taking 4%, Experimental approaches taking 46%, Analytical techniques taking 13%, while qualitative methods took 14% of the total publications reviewed with Case studies having 8%, Interviews having 3%, Delphi Survey with 6%, focus group, and observations also with 6%. These were followed by Mixed Methods research taking 6% of total articles reviewed, while the review-based studies accounted for 17% of the 112 articles adopted for the two-phase reviews.

Table 22. Research Methods Adopted and Sub-Categories

Quantitative Methods	No of Publications	Percentage		Qualitative Methods	No of Publications	Percentage		Mixed Methods	No of Publications	Percentage		Review-based Studies	No of Publications	Percentage	
		α	β			α	β			α	β			α	β
Survey	4	6%	4 %	Case Studies	10	63 %	8 %	Mixed Methods	7	100%	6 %	Systematic /Scientometric	19	100%	17 %
Experimental	52	74 %	46 %	Interviews	3	19 %	3 %								

Analytical	14	20%	13%	Delphi Survey	1	6%	1%							
				Focus Group	1	6%	1%							
				Observations	1	6%	1%							
Total	70	100%	63%		16	100%	14%	7	100%	6%	19	100%	17%	

Note: **α represents the percentage spread of sub-groups under each research method. β represents the percentage spread of sub-groups to overall publication reviews**

4. Discussion

The study reviewed the research methods adopted in construction robotics using a two-phase literature review approach. The findings reveal the increasing interest in robotics research and its development, as highlighted in Fig 2. This is consistent with studies by (Bademosi & Issa, 2021; Aghimien et al., 2019; Bock, 2015). Also, as showcased in the study, automation in construction has the highest number of publications which was also revealed in (Aghimienet al., 2019). The decrease in publication across the other Journals has been attributed to a low commitment to advancing thematic research on robotics in the built environment. Bock (2015) is identified as the most cited researcheras also identified in Aghimien et al. (2019) while the keywords indicating most researched topics which also discussesthe nature of the problem being examined are; architectural design, accident and prevention, construction workers, collaborative robotics, intelligent robots, construction equipment, automation, computer simulation etc

Categorising research methods was based on previous classifications validated by (Dainty, 2007) and (Agyekum-mensah et al., 2018) as Quantitative, Qualitative, Inductive and deductive research methodologies combined in mixed methods research and Review – based studies (literature reviews/Systematic/Bibliometric/Scientometric).

In comparing research methods and the number of publications, the study revealed that quantitative methods were the most used research data approach and most published by Journals, followed by the use of systematic and Scientometric ways to address research questions taking larger proportions than the use of qualitative methods in the construction robotics research domain. Mixed methods research is one of the least adopted research approaches.

Many domains have established techniques, especially pure sciences), but construction research draws from both natural and social sciences; therefore, many diverse paradigms struggle for methodological dominance, as stated by (Agyekum-mensah et al., 2018). The qualitative and quantitative techniques to data collection are the two basic extremes, though both can be used simultaneously. By examining the knowledge claims, tactics, and methods, researchers can determine whether they use a qualitative, quantitative, or mixed methodologies approach (Creswell, 2014). To advance practical and industry applicable solutions to robotics challenges, construction robotics researchers must begin to diversify their approach by not employing a single methodology to derive solutions but rather by replicating numerous research approaches based on the nature of the problem being examined. As revealed by the study, Quantitative methods had 63% of total publications, with Surveys taking 4%, experimental approaches taking 46%, and analytical approaches taking 13%, which validates the studies of Agyekum-mensah et al. (2020) and Dainty (2007) that quantitative approach was the most frequently used method. Virtual immersive environments are also increasingly helpful in human-robotics research as they can evoke psychological responses typical of case studies using robotics in practical usage on the construction site (Atkinson & Clark, 2014). As stated by Bernold & Lee (2010), the most effective way for examining the impact of any intervention on human performance is through group experiments. Experiments involving representative survey participants are necessary to provide generalisable conclusions. Furthermore, there are many advantages to testing in a controlled setting with large standardised equipment, but their relevance to reality in construction is lacking most of the time. (Bernold & Lee, 2010).

The use of VR and AR in built environment robotics research is valuable. It offers characteristics in which physical robot features and behaviour of interest interaction between robot and humans can be simulated to measure participants perception, disposition and attitudinal measures to the usage and adoption of robotics. A challenge to this method is inherent in skills and competencies to simulate and model the scenarios and the cost of procuring AR and VR systems for learning institutions, especially in developing economies. Also, qualitative methods took 14% of the total publications reviewed, with Case studies having 8%. Case studies are the driving force for robotics research in the built environment. They provide appropriate test cases to demonstrate the viability and feasibility of adopting

robotics and ensure safety before interaction with humans on site. Atkinson & Clark (2014) stated that real-life scenarios of dangerous work tasks are imperative to providing a safe and effective performance of robots collaboration with humans, especially in unstructured environments such as construction sites. Furthermore, real-life scenarios offer an excellent opportunity to evaluate engineered robot capability and the possibility to provide needed aid during construction (Atkinson & Clark, 2014).

Interviews had 3% usage from the study, Delphi Survey with 6%, focus group, and observations also with 6%. User experience in the design of Human-Robot Interaction, as conducted by Prati et al. (2021), adopted user observation, focus groups, and interviews which are qualitative approaches and were demonstrated as the most common UX methodologies used to understand users perception. Because it allows users to be observed in their natural environment without impacting their usual behaviour and performance, user observations are frequently used for context analysis and preliminary user analysis. Focus groups and interviews, for example, allow users to participatemore actively in gathering qualitative data about their needs, expectations, and fears in a variety of ways. Despite thelow usage of Mixed Methods research taking 6% of total articles reviewed, mixed research methods are effective instruments for investigating complicated processes and systems in various fields. This technique can be beneficial to construction robotics research since qualitative results can help to support and guide the collection and analysis of quantitative data (Johnson & Onwuegbuzie 2004; Abowitz & Toole 2010). Brosque et al. (2020) is the first solution that uses physically correct simulations and real task data to allow robots to interact with construction site elements. This method was used to investigate the use of haptic interfaces for construction jobs and contribute to developing human-robot collaboration robots that can relieve workers of difficult and repetitive manual labour.

The review-based studies accounted for 17% of the 112 articles adopted for the two-phase review. Aghimien et al. (2019) adopted the bibliometric approach to map out the research focus of robotics in the built sector using the Scopus database, which has been identified as one of the major academic databases that cover scientific fields is frequently adopted by researchers. Tools adapted for bibliometric studies are VOS Viewers Gephi Survey (Golizadeh et al., 2019); while using other tools such as BibExcel, CiteSpace, CoPalRed, Sci2, VantagePoint is rare but has usage potentials for future studies depending on the objectives of the studies. VOS viewer has a high adoption rate in built environment research due to its strength in being freely sourced, ease of use, easily comprehensible results, while Gephi is also open source and Java-based has lesser usage compared to VOSviewer (Zabidin et al., 2020; Golizadeh et al., 2019; Abdullahi Babatunde Saka & Chan, 2019;)

In the built environment, research naturally attracts diverse disciplinary and methodological perspectives to solve problems. As Knight and Ruddock (2008) explain, this variety can at times necessitate the adoption of methods from the arts, sciences, and other disciplines to solve problems. Similarly, other studies have urged the use of different approaches; for example, Hallowell and Gambatese (2010) advocated for the use of Delphi, while Azhar et al. (2010) addresses 'action research,' both of which have not been widely used in construction robotics research. For bridging the gap between research and practice in construction safety, Zou et al. (2014) advocated for a mixed methodologies study design, while AlSehaimi et al. (2012) identified the 'need for different research approaches in construction management. Ergo, for Construction robotics research and collaborative teams, some scholars are beginning to consider the use of photos and videos elicitation for surveys, which shifts the locus of meaning away from empirically objective representations of objects or interactions, gaining significance from the way that participants engage the questions in the surveys. Therefore, studies on research methods are important in utilising a bridge between methodological perspectives and research. This is imperative in guiding further studies on approaches available for Construction robotics research which is essential in advancing research in construction robotics and human-robot teams

5. Conclusions

The study was conducted due to a lack of a two-phased review to deeply examine research methods in construction robotics as an emerging field in the AEC sector. It reveals the evolutions of publications, the components of research methods adopted, and the prominent approaches vital to construction robotics research. The findings offer insights into the adopted trendy approaches, the need to balance methods with the nature of problems addressed, and the novelty in adopting research methods from allied fields. Future research should be directed towards studying the

limitations of these approaches, considering novel options to improve human-robot teams' research, and improving challenging areas to enhance robotics usage and collaboration in the built environment.

Acknowledgement

This work is supported by the National Research Foundation, NRF (Grant Number-129953). Opinions and conclusions are those of the authors and are not necessarily attributable to the NRF. The work is part of collaborative research at the Centre of Applied Research and Innovation in the Built Environment (CARINBE).

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