

Digital Transformation and The Construction Industry Research Landscape: Exploring the evolving research methods

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Abstract

The construction industry has experienced a lot of digital transformation during the present industrial revolution. This transformation has disrupted every aspect of the construction industry. However, little attention has been paid to the impact of this technology driven disruption on the research landscape. This study aims to identify the present research methods and approaches to check for a commensurate transformation in the research landscape. To achieve this, a bibliometric review was carried out. The data for the study was extracted using keywords from the Scopus database, and the analysis was done using VosViewer. It was observed that researchers are moving more towards the adoption of mixed methods research. Also, researchers are adopting technology-driven research methods (data collection and analysis).

Keywords- construction research 4.0, research methodology, research focus

1. INTRODUCTION

The construction industry is no longer the same as it used to be in previous industrial revolutions. In recent times, the construction industry has witnessed a lot of transformation due to the present technological revolutions (Adekunle *et al.*, 2021). These emerging technologies in the fourth industrial revolution (e.g blockchain, artificial intelligence, Building information modelling among others) have greatly impacted every facet of the industry (Ejohwomu *et al.*, 2021). These studies point to the impact of the many emerging technologies, benefits, and other dynamics regarding the adoption of several emerging technologies and innovations. Another good thing observed is that, unlike previous industrial revolutions, the construction industry is more responsive to technology adoption.

These revolutions and transformations have not only impacted practical or industry practitioners but have also seen increased research interests from built environment researchers. As the technology adoption landscape continuously changes, there are commensurate efforts to achieve its widespread diffusion through research. Efforts have been made to capture the trend, albeit for specific technologies. For instance so Olawumi, Chan and Wong, (2017) researched the evolution of BIM knowledge via a review of existing work. However, there is a dearth of holistic attention on the evolving research landscape in the digital transformation era and the method adopted. Heretofore, the research methodology and approach adopted by researchers are primarily formulated based on conventional approaches; hence, most standpoints are taken and done based on existing methods from previous industrial revolutions.

The research method deals with how a research aims and objectives are achieved, specifically focusing on the data collection and analysis procedure. It is a critical aspect of the “how” of the research. MacDonald, & Headlam, (2014) divides this into two aspects: qualitative and quantitative. The study opines that every researcher is either to count things, talk to people, or do both while conducting research. Creswell, (2014) describe these two as “*using words (qualitative) rather than numbers (quantitative) or using closed-ended questions (quantitative hypotheses) rather than open-ended questions (qualitative interview questions)*”. Although the quantitative approach has been identified to be more prevalent over the centuries, qualitative research only became popular during the second half of the 20th century, thereby reducing the popularity of quantitative research (Sotirios Sarantakos, 2013).

However, it should be noted that there is a clear distinction between research method and research methodology. Research methodology dwells on the theoretical analysis of the methods applied in the study. Furthermore, it encompasses the process of the research, including the principles, theories, and values underpinning the choice and use of research methods. Research methodology is better understood and applied using the research onions (Saunders, Lewis and Thornhill, 2019). It is, therefore, to be noted that Research methods are a subset of research methodology.

A second look at the popularity and adoption dynamics between quantitative and qualitative research over the centuries, therefore, calls for a look into the present methods adopted due to the catalytic disruption introduced by the present digital transformation, especially in the construction industry. Thus, this study identified the various research methods adopted vis a vis the research areas in the digital transformation era. This was done to identify if there is a commensurate transformation in the research landscape, such like in the industry.

This study identifies the transformation in research methodologies within the construction industry; thus, it offers valuable insights into how academic and practical research approaches have shifted. Thus, highlighting the need for continuous methodological adaptation to stay abreast of the technological disruptions that the industry faces. It offers a foundation for understanding the trajectory of research methodologies.

2. Method

To achieve the study objectives, the study adopted a bibliometric approach. The data from the study was extracted from the Scopus database using keywords. These search keywords pull out all studies related to the keywords used in searching through publication titles, abstracts and keywords. To achieve specificity, the keywords adopted for the study and the Boolean connectors are "research" AND "method*" AND "AEC" OR "construction industry" OR "built environment". The returned results are based on the keywords searched for in abstracts, titles and keywords of the publications. The choice of the Scopus database is due to its observed completeness, and thus, it has been adopted in several existing studies (Aghimien *et al.*, 2019; Saka, Olawumi and Chan, 2019; Adekunle, Ejohwomu and Aigbavboa, 2021). Also, the study focused on the post covid 19 pandemic era, i.e. from 2020 to mid-2024. This is due to the observation that the COVID pandemic was a major disruptor for technology adoption, especially in the construction industry (Adekunle *et al.*, 2023). The study wants to identify the research methods in this era. The search provided over 11,000 results however, after the application of exclusion and inclusion criteria to ensure the data was tailored to the research aim, the following exclusion criteria were applied – Engineering as the subject area, only journal articles were selected, and the language of publication was limited to English language which produces 3088 documents adopted for the study. The choice of considering is because the study

considers articles to be more detailed and comprehensive. The collected data was analysed using the Vos viewer visualisation software (van Eck and Waltman, 2019). Other information about the collected data are

Average citation per document – 8.822

Total references – 168880

Authors – 7848

Authors of single-authored docs – 194

Single-authored docs – 207

Co-Authors per Doc – 3.68

Sources of documents – 432

For inclusion in the analysis, the threshold of 5, which is the default threshold, was adopted for the cooccurrence of keywords using the all keywords option.

3. Findings

The findings of the study are presented in Figure 1 and Table 1. Figure 1 represents a visualization of a co-occurrence network of terms from a body of research. The clusters are color-coded and represent different thematic areas. Table one presents the clusters showing the research focus areas and the research methodology based on the clusters in Figure 1.



Figure 1: Network visulaisation

Table 1: Clusters of the research focus and research methodology

| Area | Methodology | Area | Methodology |
|----------------------------|---|------------------------------|--|
| 1 | | 2 | |
| 3D printing | forecasting linear regressing machine learning multi-objective optimisation neural networks numerical methods optimisation algorithm predictive modelling random forest | adaptive management | agent-based model behavioural research comparative analysis complex networks computational fluid dynamics numerical model qualitative assessment system theory |
| Additive manufacturing | | autonomous agents | |
| building lifecycle | | building design and energy | |
| building materials | | business models | |
| carbon footprint | | climate models | |
| digital fabrication | | decarbonisation | |
| embodied carbon | | decision support system | |
| intelligent building | | disaster mgt | |
| lifecycle analysis | | energy savings | |
| modular buildings | | energy conservation | |
| recycling | | green building | |
| robotics | | green economy | |
| shape optimisation | | IAQ | |
| structural design | | IEQ | |
| structural optimisation | | occupant model | |
| sustainability performance | | performance assessment | |
| timber construction | | | |
| 3 | | sensor | |
| cloud computing | computation theory CFA correlation methods descriptive stats EFA least square approximation mixed method multivariate analysis PLS | smart city | |
| Construction 4.0 | | solar buildings | |
| construction business | | spatial analysis | |
| construction education | | sustainable cities | |
| Construction enterprise | | travel behaviour | |
| Construction innovation | | thermal comfort | |
| Construction labours | | urban development and design | |
| construction performance | | urban design/transport | |

| | | | |
|-----------------------------|---|---------------------------------|--|
| construction practice | PCA Quantitative research questionnaire surveys reliability analysis statistical mechanics | user experience | ANN Bayesian network Controlled study grounded theory fuzzy logic discrete event simulation interview meta analysis mixed method research online questionnaire Qualitative approach /research questionnaire surveys SEM systems thinking |
| construction stakeholders | | zero carbon | |
| construction technology | | 4 | |
| construction waste | | accident prevention | |
| construction workforce | | AR | |
| CSR | | Communication | |
| digital construction | | Construction accidents | |
| economic analysis | | construction equipment | |
| emerging technologies | | Construction operations | |
| innovative approaches | | Construction Safety | |
| IoT | | Construction site safety | |
| laws and legislation | | Construction work/worker | |
| natural resource management | | curricula | |
| Project performance | | e-learning | |
| project success | | engineering education | |
| resource allocation | | exoskeleton | |
| Quantity Surveying | | hazard identification | |
| value management | | human engineering | |
| work life balance | | human experiment | |
| decision making process | | human resource management | |
| | | education computing | |
| | | environmental regulation | |
| | | education and learning | |
| 5 | | Immersive VR | |
| BIM | case based reasoning case study comparative studies design science research ISM multiple case study theoretical modelling | job satisfaction | |
| Blockchain technology | | leadership | |
| construction contract | | machinery | |
| construction engineering | | mental health | |
| construction management | | Mixed reality | |
| Productivity | | musculoskeletal disorder/system | |
| | | | |

| | | | |
|------------------------------------|------------------------------|-------------------------------|--|
| construction supply chain | | occupational safety and risks | |
| industrialised construction | | organisational culture | |
| information dissemination | | organisational learning | |
| Knowledge management | | performance evaluation | |
| knowledge transfer | | personnel training | |
| lean construction | | PPE | |
| logistics | | information analysis | |
| maturity model | | risk factors/perceptions | |
| mega projects | | safety engineering | |
| modular construction | | safety management | |
| modern methods of construction | | social sustainability | |
| offsite construction | | technology adoption | |
| policy making | | transformational leadership | |
| prefabrication | | wearable technology | |
| project management | | unsafe behaviours | |
| project delivery | | wages | |
| PPP | | 6 | |
| Quality mgt | | adoption barriers | AHP Delphi method DEMATEL fuzzy AHP Game theory Multi Criteria decision making multicriteria analysis Relative importance index |
| Small and medium sized enterprises | | cost analysis | |
| smart contract | | cost overrun | |
| stakeholder mgt | | Green construction | |
| value engineering | | Lifecycle costing | |
| 7 | | project delays | |
| AI | cluster analysis | project risk mgt | |
| automation | convolutional neural network | scheduling | 8 |
| Big data | deep neural networks | sustainability assessment | |
| building codes | k means clustering | uncertainty analysis | |
| compliance control | learning algorithms | | |
| construction engineering | natural language processing | construction markets | monte Carlo methods questionnaire survey |
| cost engineering | object detection | cost-benefit analysis | |
| | natural language processing | | |

| | | | |
|-------------------------------|--|----------------------------|---------------------------|
| CPS | | cost estimating | semi-structured interview |
| Data acquisition | | highway engineering | stochastic systems |
| Data handling | | intelligent systems | text mining |
| Data mining | | international construction | |
| Deep learning | | International trade | |
| Digital twins | | strategic management | |
| embedded systems | | social implication | |
| Facilities management | | | |
| Industrial foundation classes | | | |
| IoT | | | |
| interoperability | | | |
| real-time systems | | | |
| regulatory compliance | | | |
| Unmanned aerial vehicle | | | |
| transfer learning | | | |

A quick look at the clusters shows that they are majorly a nexus of emerging technologies and other aspects of innovation and various construction industry practices. Below is each cluster with the theme name ascribed based on the constituent keywords and the research methodology approaches adopted.

- Cluster one (emerging technologies and sustainable construction)

This cluster primarily focuses on predictive analytics and optimization techniques. It utilizes linear regression, machine learning (including neural networks and random forests), numerical forecasting and predictive modelling methods. Multi-objective optimization and optimization algorithms are used to optimize various parameters within models.

- Cluster two (nexus of Smart technologies, Sustainable urban development and management models)

This cluster involves a mix of methodologies focused on understanding complex systems and behaviours. Agent-based modelling, comparative analysis, and computational fluid dynamics are used to simulate and analyze systems with multiple interacting agents/components. Qualitative assessment and system theory are employed to understand the behaviour of these systems on a conceptual level.

- Cluster three (digital transformation and construction industry product and processes).

This cluster revolves around quantitative research methods and statistical analysis techniques. It includes methods such as computation theory, multivariate analysis (including PCA and PLS), and correlation methods for analyzing relationships and patterns in data. Descriptive statistics, reliability analysis, and questionnaire surveys are used to gather and analyze quantitative data.

- Cluster 4 (Technology, education and well-being).

This cluster encompasses a range of methodologies, including both quantitative and qualitative approaches. It includes techniques such as artificial neural networks (ANN), Bayesian networks, and fuzzy logic for modelling complex systems and decision-making processes. Grounded theory, interviews, and qualitative approaches are employed for in-depth understanding, collection and interpretation of data.

- Cluster 5 (Construction efficiency and management)

This cluster is centred around case-based research methodologies. It includes methods such as case studies, comparative studies, and multiple case studies for analyzing specific instances within a broader context. Design science research and theoretical modelling are used to develop and test theories.

- Cluster 6 (Enhancing sustainability)

This cluster focuses on decision-making methodologies and techniques for evaluating alternatives. Analytic Hierarchy Process (AHP), Delphi method, and multicriteria analysis are used for decision-making, forecasting and prioritization. Fuzzy AHP and fuzzy logic are employed to handle uncertain data.

- Cluster 7 (Efficient data management and exchange)

This cluster involves methodologies related to data analysis and pattern recognition. It includes techniques such as cluster analysis, convolutional neural networks (CNN), and deep neural networks

for identifying patterns and clusters within data. Natural language processing (NLP) is used for analysing textual data and object detection for identifying objects within images.

- Cluster 8 (international construction business)

This cluster primarily utilizes probabilistic and stochastic methods for modelling and analysis. Monte Carlo methods are employed for simulating complex systems with uncertainty, while stochastic systems are used to model systems with random behaviour. Text mining and questionnaire surveys are utilized to gather and analyze textual and survey data.

A critical look at these clusters shows that diverse methodologies have been employed. Some are solely quantitative, while some are qualitative, and some are mixed. However, it will be interesting to see researchers applying other types of methodology that are currently not being adopted in each area. Be that as it may, the researcher is still under the obligation to adopt the right methodology which is appropriate for the study based on the study context (Kumar, 2011). It is also worth noting that the research landscape is changing and undergoing a disruptive transformation, as is the case with industry. Most applied data collection and analysis methods are adopting emerging technologies, e.g. AI, ML, etc.

4. Implications

The digital revolution has substantially changed research methods, particularly in the construction industry. Traditional research, which often focused on either qualitative or quantitative methods, is increasingly being replaced or complemented by mixed methods approaches. This change is primarily driven by the need for more robust and data-driven insights, which digital tools and technologies can better facilitate. As observed in the findings, researchers are increasingly adopting technology-driven methodologies, including artificial intelligence (AI), machine learning (ML), and predictive modelling, which offer the ability to process large datasets and generate previously unattainable insights using conventional methods.

The bibliometric review conducted in this study reflects a broader trend across industries, where digital tools enable more sophisticated data collection and analysis methods. For example, the use of visualization software like VOSviewer helps researchers to analyze vast amounts of data, identify trends, and establish correlations between different variables. This represents a significant departure from traditional approaches, which often relied on manual analysis and simpler statistical tools.

The digital revolution has also led to a democratization of data. With greater access to databases and real-time data analysis tools, researchers are no longer confined to isolated case studies or small data samples. Instead, they can analyze global trends, incorporate large datasets, and apply sophisticated modeling techniques to predict outcomes or optimize processes. This shift has enhanced the precision and relevance of research findings, making them more applicable to real-world scenarios.

5. Conclusion

The study focused on identifying the research methodologies being adopted by researchers in the present technological revolution and how digital transformation in the construction industry has catalyzed a shift in research methodologies. It was observed that researchers are moving more towards adopting mixed methods research. Also, researchers are adopting technology-driven research methods (data collection and analysis). The move towards mixed methods, with an increasing emphasis on technology-driven approaches like machine learning, neural networks, and predictive analytics,

signals that the research landscape is not only evolving but also adapting to the complexities introduced by modern technologies. This shift implies that future research will likely focus on more comprehensive data integration and real-time analysis, fostering innovation and improved decision-making processes in construction practices. However, it is important to research the adequacy of existing philosophies, theories, and approaches to emerging research trends. This is important as the disruption caused by technology significantly impacts existing approaches, even in the construction industry and other sectors. Furthermore, researchers should explore the impact of the emerging data analysis methods on the research outcomes and impact. A comparative analysis can be done on the traditional and emerging research methods to identify the depth of data interpretation they offer.

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