A Systematic Review of the Utilisation of Digital Technology in Infrastructure Sustainability Assessment

Hongyu Jin[1], Shen Zhan[2], Yang Zou[3] and Melissa Chan[4]

[1]Lecturer, The University of Auckland, Auckland, New Zealand
[2] PhD student, University of Melbourne, Melbourne, Australia
[3]Senior Lecturer, The University of Auckland, Auckland, New Zealand
[4]Senior Lecturer, Victoria University, Melbourne, Australia

Corresponding author's E-mail: hongyu.jin@auckland.ac.nz

Abstract

A comprehensive sustainability assessment is paramount for enhancing the sustainable outcomes of infrastructure projects. In New Zealand, all projects with a capital value of over $100 million are obliged to complete a sustainability assessment. However, the traditional human-intensive assessment process often proves to be time-consuming and costly, particularly when evaluating the sustainability of large-scale infrastructure projects. While emerging digital technologies have the potential to enhance sustainability outcomes, there is a lack of clarity on how digital technology can be effectively utilised to expedite the sustainability assessment process. This systematic study aims to address this gap by investigating the utilisation of digital technologies, including building information modelling, digital twins, drones, Internet of Things, or a combination thereof, in evaluating the sustainability performance of infrastructure projects. By conducting a thorough systematic review of academic literature, this research discusses the existing practice of integrating digital technology into infrastructure sustainability assessment. Additionally, through an in-depth scientometric analysis of global scientific research, this research provides insights into emerging trends and areas of focus in the fields of construction informatics and infrastructure sustainability assessment.

Keywords: Digital Technology, Construction Informatics, Sustainable Infrastructure, Sustainability Assessment

1. INTRODUCTION

Sustainability assessment (SA) contributes greatly to improving infrastructures' sustainability and promoting balanced development and responsible stewardship of resources. Hence, different research institutions worldwide developed SA frameworks to measure the sustainability performance of infrastructure projects over their lifecycle. The most widely adopted SA frameworks for infrastructure projects include the Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL), Green Leadership in Transportation Environmental Sustainability (GreenLITES), Greenroads, Envision and the IS rating scheme (Chan et al., 2022). The multidimensional nature of these rating frameworks often requires a comprehensive evaluation of a wide variety of sustainability criteria. As a result, the SA consumes excessive time and expenses for large-scale infrastructures, exacerbated by a human-intensive and non-automated process (Shamshirgaran et al., 2022).

Advanced digital technologies in construction, such as BIM and digital twin, can potentially be utilised to automate the assessment process of certain criteria in the abovementioned rating frameworks. However, there is a lack of research exploring how these digital technologies are applied to facilitate an automated SA for infrastructures, thereby reducing the time and effort required for SA. This research contributes to the body of knowledge by a systematic review of the existing utilisation of digital technology in assessing infrastructure sustainability, exploring the most commonly used digital technologies and their roles in improving the efficiency of SA. A scientometric analysis of the relevant literature is also conducted to identify current research focuses in the field of digital technology-aided infrastructure sustainability assessment.

2. LITERATURE REVIEW

A systematic review approach was adopted to investigate the role of construction informatics tools in evaluating the sustainability performance of infrastructure projects. The systematic review method was first introduced in the medical profession (Tranfield et al., 2003). It has been adopted in many other disciplines due to its clear guidance in identifying, analysing, and interpreting relevant literature to a chosen research topic. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol was selected as the guidance for this systematic review. PRISMA provides a clear and transparent search of the literature and complete reporting of systematic reviews and meta-analyses (Salameh et al., 2020). Following the PRISMA protocol guideline, this systematic review is composed of four steps, as shown in the following sections.

2.1. Identification of Articles

This step aims to identify all articles from the available literature relevant to the topic of this review. Scopus and Web of Science (WoS) were chosen as the literature databases due to their suitability for evidence synthesis in the form of systematic reviews (Gusenbauer and Haddaway, 2020; Martín-Martín et al., 2018). The WoS citation indices that were included in the bibliometric search are the Science Citation Index Expanded, the Social Sciences Citation Index, and the Emerging Sources Citation Index. As presented in Table 1, the search strings were derived by combining four groups of keywords related to sustainability, assessment, infrastructure, and technology, respectively. The search strings were then used to search within the article title and author keywords separately in all selected databases. The 'document type' was limited to 'article', and 'English' was chosen as the 'document language'.

Table 1. Keywords used for retrieving relevant literature

Sustainability	Infrastructure	Assessment	Digital Technology
sustainab* green environment*	infrastructure* road* bridge* railway* highway* tunnel*	assess* rating measur* optimi* evaluat*	technolog* techni* informat* digital* BIM GIS internet of thing*/ IoT* drone* virtual reality/VR unmanned aerial vehicle*/UAV* sens*

The initial search of the articles across all chosen databases was conducted on 4 June 2024. After completing the identification process, 392 academic articles were retrieved.

2.2. Screening

The title and abstract of the retrieved articles were screened to determine their relevance to the research questions of this review. First, articles not related to the utilisation of digital technologies to improve infrastructure sustainability were removed at this stage. A total of 67 articles remained after the screening process, comprising 37 from WoS and 30 from Scopus. The 'Find Duplicate' function in Endnote is then utilised to remove duplicate references between WoS and Scopus databases. A total of

12 duplicates were found, which reduces the number of references to 55. Next, the authors proceeded with an additional review of the remaining 55 articles, excluding those that did not specifically investigate the impact of digital technologies on infrastructure sustainability assessment. Ultimately, 25 articles met the validation criteria. The small number of retrieved references indicates a lack of research focusing on applying digital technology in infrastructure SA.

2.3. Eligibility and Quality Assessment

At this stage, the full text of the remaining articles is reviewed and rated based on their relevance to the research question. Articles that only mentioned the potential utilisation of digital technologies in SA without further discussion or explanation were rated as having 'low' relevance to the research objectives. Articles discussed the utilisation of digital technologies, but with no empirical data or case studies presented, were rated as 'medium' relevance. Articles that explained the utilisation of the mentioned technologies with empirical data or case studies were rated as having 'high' relevance. Only the articles rated as 'high' relevance remained for the next stage of the review.

2.4. Inclusion

Table 2 shows the list of academic articles included for a detailed analysis and review, the targeted assessment criteria and the corresponding digital technologies adopted.

Table 2. List of academic articles for detailed analysis and review

Targeted Assessment Criteria	Adopted Technology	Reference
Energy consumption, CO_2 emissions, life cycle costing	Digital Twin	Borjigin et al. (2022)
Time and cost schedule with carbon emissions calculation	Digital Twin	Kaewunruen and Xu (2018)
Four Envision scoring system: wetland and surface water buffers; preserve prime farmland; reduce net embodied carbon; reduce greenhouse gas emissions	GIS and BIM	Laali et al. (2022)
Society, environmental noise, air pollution and ecology	GIS	Li et al. (1999)
Cost, time, emissions , resources, social, safety	BIM	Lozano et al. (2023)
Environmental, economic and social indicators available in Life cycle Sustainability Assessment databases	BIM	Petel and Ruparathna (2023)
Noise and exhaust emissions	IoT and AI	Rauniyar et al. (2023)
Wetland and surface water buffers	Remote Sensing and Machine Learning	Shamshirgaran et al. (2022)
Ecological assessment – land cover	Remote Sensing and GIS	Treweek and Veitch (1996)
Environmental impact assessment	BIM	van Eldik et al. (2020)
Greenness, warmth, wetness	Remote Sensing	Wang et al. (2024)

3. SCIENTOMETRIC ANALYSIS

A scientometric analysis was conducted to reveal the current research effort in integrating digital technology and infrastructure sustainability assessment. Scientometric analysis can objectively map the scientific knowledge area (Zhong et al., 2019), and various software has been developed for performing the analysis. In this research, the retrieved bibliographic records in Section 2.2 were imported into Citespace software for scientometric analysis. Figure 1 shows the outcome of the co-citation analysis. By utilising the clustering function, Citespace generates a network with nine major clusters. Citation bursts highlight keywords that have been frequently cited within the literature during specific time periods, indicating rapidly growing topics or those experiencing significant increases in citations (Darko et al., 2020). As shown in Figure 2, 'environmental impact assessment', 'construction', 'sustainability assessment', 'life cycle assessment' and 'building information modeling' are the top five keywords.

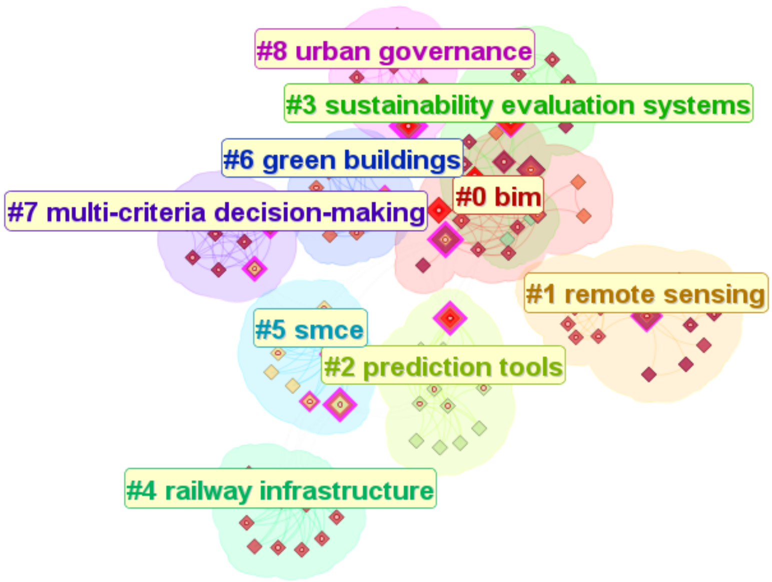

Figure 1. Clustering structure for research on digital technology-aided infrastructure sustainability assessment

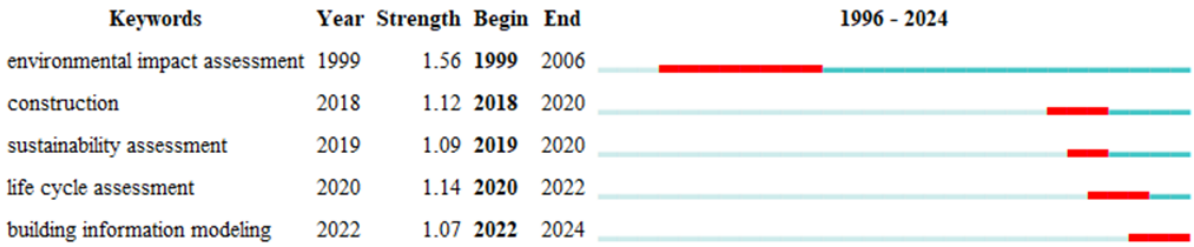

Figure 2. Top five keywords with the strongest citation bursts

4. DISCUSSION

According to the systematic literature review and scientometric analysis outcomes, key findings are summarised as follows. First, an in-depth review of the 'high' relevance literature shown in Table 2 reveals that the majority of the targeted assessment criteria can be classified into the environmental sustainability category. This is largely due to environmental SA criteria being relatively easy to quantify in comparison to social and economic sustainability. For example, environmental SA criteria such as CO_2 emissions and noise pollution can be easily monitored by IoT sensors. However, some social SA criteria like 'views and local character' often involve qualitative subjective judgement.

Second, the most commonly used digital technologies in SA of infrastructure projects include Building Information Modeling (BIM), Geographic Information System (GIS) and remote sensing. BIM software can monitor the cost and project schedule as well as simulate and analyse the energy performance of infrastructure projects. BIM can also be used to incorporate sustainability requirements, criteria and value functions for quantifying overall sustainability performance (Lozano et al., 2023). Some of existing SA frameworks, such as BREEAM Infrastructure and IS Rating Scheme, cover the SA at different project stages. The comprehensive application of BIM throughout the entire lifecycle makes it well-suited to provide the necessary data for assessing sustainability at different project stages (Carvalho et al., 2019). In addition, GIS and remote sensing work compatibly to perform large-scale assessments for SA criteria such as wetlands, water buffers, green coverage, etc.

Third, BIM and remote sensing are also two clusters in the co-citation network, which further justifies their importance in infrastructure sustainability assessment. It is worth noting that multi-criteria decision-making is one of the critical clusters. A number of research works focused on developing the objective function for optimising multiple SA criteria to achieve optimal sustainable outcomes. Laali et al. (2022) used the scripting console of the BIM tool to run the optimisation algorithm for sustainability.

Fourth, citation burst analysis shows that the early research focuses on utilising digital technology in environmental impact analysis. Around 2019, 'sustainability assessment' became a keyword with a surge in citations, indicating the shift of research focus from a single environmental analysis to a holistic environmental, economic and social assessment. 'Life cycle assessment' became a hot topic in 2020, highlighting the importance of SA over the whole lifecycle of the project. Ahmad and Thaheem (2017) stated that social and environmental externalities are challenging to evaluate using methods that overlook the project's lifecycle impacts. BIM is the latest hot topic emerging from 2022, demonstrating an ongoing research effort in applying BIM in infrastructure SA. However, as can be observed in both the systematic review and scientometric analysis outcomes, the existing research seems overly focused on BIM with a limited investigation into other emerging digital technologies such as virtual reality and drones.

5. CONCLUSION

By recognising the potential of digital technology in improving infrastructure SA efficiency, this research conducted a systematic review and scientometric analysis to investigate the existing research efforts in digital technology-aided SA for infrastructure projects. The research outcomes reveal that most existing practices focus on assessing the environmental sustainability criteria using BIM, GIS or remote sensing. In other words, there is a lack of effort made to automate the assessment process for social and economic sustainability. Future research may identify the financial proxies to translate social and economic benefits into quantifiable monetary values and then automate the process with the aid of digital technology for improved efficiency. Future research may also explore the use of other emerging technologies in SA for infrastructure projects.

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