



**A METICULOUS INVESTIGATION INTO THE APPLICATION OF
METAVERSE IN CONSTRUCTION INDUSTRY: A SYSTEMATIC
LITERATURE REVIEW**

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ABSTRACT

Purpose

The construction industry is increasingly exploring the metaverse as a transformative digital paradigm to enhance collaboration, efficiency and project delivery. However, the current body of knowledge remains fragmented, lacking a comprehensive synthesis of adoption barriers, research trends and implementation pathways. This study aims to systematically investigate (1) the evolution and trends of metaverse-related research in construction, (2) key barriers to its adoption, and (3) strategic pathways for its effective implementation. By integrating these dimensions, the study seeks to provide a holistic understanding of the metaverse ecosystem within the construction industry.

Design/methodology/approach

A systematic literature review (SLR) was conducted following the PRISMA protocol to identify relevant studies from the Scopus database. A total of 34 records were selected through rigorous screening and snowballing. Scientometric analysis was employed to examine publication trends, collaboration networks and research hotspots. A novel hybrid multi-criteria decision-making (MCDM) framework, combining Evaluation based on Distance from Average Solution (EDAS) and Criteria Importance Through Intercriteria Correlation (CRITIC), was developed to assess the quality and impact of the selected studies. Furthermore, barriers were extracted and analysed, and a conceptual framework for metaverse adoption was proposed.

Findings

The findings reveal a rapidly growing research interest in metaverse applications in construction, particularly after 2020. Key adoption barriers are categorised into political, economic, social, technological and cultural dimensions, with major challenges including high initial costs, lack of standardisation, regulatory uncertainty, technological immaturity and resistance to change. Interoperability issues, immature business models and limited awareness emerged as the most interconnected barriers. The proposed framework outlines a structured pathway from stakeholder awareness to industry-wide adoption, emphasising policy support, infrastructure development and technological integration.

Originality/value

This study contributes to the literature by integrating scientometric analysis, barrier identification, quality assessment and framework development within a unified analytical approach. Unlike prior studies that focus on isolated aspects, this research provides a comprehensive and systematic evaluation of metaverse adoption in construction. The findings offer actionable insights for policymakers, industry practitioners and researchers to facilitate strategic decision-making and accelerate digital transformation in the construction sector.

KEYWORDS

Construction; Metaverse; Barrier; Multiple Criteria Decision-Making; Digitalisation; Systematic Literature Review.

1.0 INTRODUCTION

The metaverse (and its myriad applications in different areas) continues to attract significant research attention from scholars and industry experts and is defined as a collection of immersive virtual worlds that enable people to participate in various activities using avatars (Faraji *et al.*, 2025; Hadavi and Alizadehsalehi, 2024a). Also known as “internet in 3D” and “internet plus” (Japar and Anshari, 2023), the metaverse was initially used in the novel Snow Crash in 1992 but has been used in different businesses since then (Bansal *et al.*, 2022). Several technological advancements fuel the metaverse’s evolution and include: fifth-generation mobile networks (Mendoza *et al.*, 2021); blockchain (Bayramova *et al.*, 2021); virtual reality (VR) (Johansson and Roupé, 2024); and augmented reality (AR) (Abdeen *et al.*, 2024). When combined with the metaverse, augmented VR and AR combined is known as mixed reality (MR). Artificial intelligence (AI) can also be embedded within the metaverse and is paramount to enhancing the user experience, e.g. character creation, rendering of 3D objects and personalise metaverse services (Chen *et al.*, 2024). Utilising advanced machine learning (ML) algorithms is another role of AI in metaverse, as suggested by Huynh-The *et al.* (Huynh-The *et al.*, 2023). The metaverse’s key characteristics include: scalability (Wang *et al.*, 2023); identity (Xu *et al.*, 2023); heterogeneity (Son and Jeong, 2025); interoperability (Chengoden *et al.*, 2023); immersiveness (Giang Barrera and Shah, 2023); interactivity (Park and Yoo, 2020); hyper spatiotemporality (Hadavi and Alizadehsalehi, 2024a); persistence (Lee *et al.*, 2021); and customisability (Akour *et al.*, 2022). Each of these characteristics are explained further as follows. Scalability refers to the ability to accommodate additional users and VR

regions as required; where each user has their unique identity and can get involved in different social communities and groups (Wang *et al.*, 2023). Heterogeneity encapsulates usability for varied users with different cultures, languages and accessibility needs (Son and Jeong, 2025). Users can interact with metaverse through numerous devices, platforms and virtual environments to obtain a cohesive experience (interoperability) (Chengoden *et al.*, 2023). Immersiveness allows users to have real-time and responsive interactions with each other (interactivity). Because the metaverse is not bounded by real world constraints (e.g. time and distance), it provides a hyper spatial and temporal environment where users can gain new experiences such as travel in time (hyper spatiotemporality) (Hadavi and Alizadehsalehi, 2024a). Other characteristics such as customising virtual environments (customisability), as well as existence users (even when they are offline (persistence)), further empowers the utilisation of metaverse (Lee *et al.*, 2021).

In the context of construction, the metaverse can be understood as an integrated, persistent and interactive digital environment in which physical assets, project information, stakeholders and construction processes are virtually represented and connected. Unlike standalone VR or AR applications, the metaverse combines immersive visualisation, real-time data exchange, digital twins, BIM, AI, IoT and blockchain-enabled information management to create a shared virtual project environment (Oyeyipo *et al.*, 2025). This environment can support users in interacting with design models, construction sequences, site conditions, resources and project decisions in ways that are difficult to achieve through conventional two-dimensional documentation or fragmented digital platforms. Therefore, the metaverse should not be viewed merely as a visualisation tool, but as a broader socio-technical ecosystem capable of linking people, processes and digital assets across the project lifecycle (Lucchi, 2023).

Metaverse has been adopted in various industrial sectors including: agriculture (Almessabi and Al-kfairy, 2024; Büyükkakin and Soylu, 2023); manufacturing (Amaizu *et al.*, 2024; Hosseini *et al.*, 2024); healthcare (Letafati and Otoum, 2024; Wu *et al.*, 2024); finance (Ariful Islam Mozumder *et al.*, 2023; Banaeian Far *et al.*, 2023); transportation (Anjum *et al.*, 2024; Kuo and Choi, 2024a); energy (Liu *et al.*, 2024; Luong *et al.*, 2024); hospitality and tourism (Petr and Caudan, 2024; Triviño-Tarradas *et al.*, 2024); education (Alsamh *et al.*, 2024; Singh and Singh, 2024); and telecommunication (Noisri *et al.*, 2024). However, in the construction industry adoption has been sluggish and indeed, the sector is regarded as one of slowest adapters to technological innovations (Diaz Schery *et al.*, 2026; Hadavi and Alizadehsalehi, 2024a). Sector

pioneers include An et al. (An *et al.*, 2025) who developed a framework for using the metaverse in participatory building design in Hong Kong and applied the prototype to five pilot studies. Tran et al. (Tran *et al.*, 2024) developed a common data environment digital platform to enhance the cooperation among stakeholders within the architecture, engineering, construction and operations (AECO) industry. Zaman et al. (Zaman *et al.*, 2023) investigated the potential applications and benefits of BIM-enabled facility management in construction industry to engender greater connectivity between facility managers and field workers thus, managing tasks more effectively through a commonly shared virtual environment. Al-Sabbag et al. (Al-Sabbag *et al.*, 2024) proposed a real-time distributed collaborative system to aid on- and off-site inspectors to perform synchronous structural inspections. Adami et al. (Adami *et al.*, 2021) assessed the effectiveness of VR-based training on improving the knowledge, skills and safety behaviour of the US construction workers, using qualitative and quantitative approaches.

The need to explore the metaverse in the construction industry is particularly important because construction projects are characterised by fragmented supply chains, temporary multi-organisational teams, geographically dispersed stakeholders, complex design information, safety-critical site operations and frequent coordination problems (Hosseini *et al.*, 2025). These characteristics directly affect project execution, where delays, rework, information loss, design clashes, poor communication and safety incidents can undermine productivity and performance. Metaverse-enabled environments can potentially facilitate project execution by allowing stakeholders to rehearse construction sequences before site implementation, visualise and resolve design or constructability conflicts, conduct remote inspections, simulate site logistics, support immersive safety training, improve real-time communication between on-site and off-site teams and connect BIM/digital twin data with live project decision-making (Johri *et al.*, 2024). Such capabilities are especially relevant for improving execution-stage activities because they move digital technologies beyond design representation towards collaborative planning, monitoring, training, inspection and operational decision support. However, despite this potential, adoption remains limited and fragmented, making it necessary to systematically investigate the barriers, research trends and implementation pathways associated with metaverse use in construction.

Other than these aforementioned studies, the existing body of knowledge on metaverse adoption within the construction industry remains scant. Hadavi and Alizadehsalehi (Hadavi and Alizadehsalehi, 2024a) focused on the AECO industry and investigated the issues of

utilising the metaverse and mentioned four categories of metaverse adoption *viz.*: technical, social, regulatory and economic issues. Chen et al. (Chen *et al.*, 2024) identified the most important barriers to metaverse adoption in the construction industry using a political-economic-social-technological framework. They [*ibid*] concluded that the top barriers are scalability, lack of policy incentives and immature business models. Maqsoom et al. (Maqsoom *et al.*, 2023) focused on developing countries and investigated the adoption of mixed reality. Utilising a relative importance index (RII), they concluded that the top barriers to the adoption of MR are high cost of initial investment, public perception of the technology being immature, limited demand and difficulty accessing relevant experts' knowledge. Although the knowledge contributions of previous studies cannot be contested, the following shortcomings are observed and concomitant research questions formulated:

- Existing literature has not provided a Scientometric analyses of previous studies on the metaverse's adoption barriers in the construction industry. This leads to formulating the first research question (RQ1) *viz.*: "What is the trend of investigating the metaverse's adoption barriers in the construction industry?"
- Previous studies have not conducted a systematic literature review (SLR) to identify the metaverse's adoption barriers in the construction industry and the intricate relationships between these. Some studies hitherto undertaken have narrow focuses (Al-Sabbag *et al.*, 2024), are confined to specific geographical regions (Zhang, 2022), and often address barriers that may not be relevant in other national contexts (Kuo and Choi, 2024b). Hence, the second research question (RQ2) formulated is: "What are the metaverse's adoption barriers and are there any relationships between these?"
- Previous studies in this area have yet to conduct a comprehensive quality assessment for the existing literature utilising multiple criteria decision-making (MCDM) techniques, making it difficult to identify studies with the greatest research impact. Therefore, the third research question (RQ3) posed is: "How can the most impactful articles in this area be identified?"
- Hitherto, there has been no conceptual framework delineated for the broader adoption of this technology within the sector. Thus, this state-of-the-art SLR poses the research question (RQ4): "What are the steps to be followed for the maximised realisation of the metaverse in the construction industry?"

- Previous studies have not suggested detailed future research pathways on the adoption of metaverse in the construction industry, leading to the fifth research question (RQ5) *viz.*: “What are limitations in this area and what future pathways can be proposed?”

This study will tackle the mentioned gaps within the prevailing body of knowledge by conducting a comprehensive SLR on the adoption of the metaverse in the construction industry. Specifically, this study contributes to knowledge by: a) investigating the trend of relevant studies through a comprehensive Scientometric analysis; b) identifying the metaverse’s adoption barriers (and any interrelationships between these) through conducting an SLR; c) proposing a novel procedure for ranking papers in SLRs, followed by applying the procedure for ranking the identified barriers; d) proposing a conceptual framework for the wider adoption of the metaverse; and e) discussing future pathways on the metaverse’s adoption.

2.0 REVIEW METHODOLOGY

The SLR has become firmly established among experts and researchers due to its structured and comprehensive methodology (Suo *et al.*, 2025; Verdelho Trindade *et al.*, 2023). In SLRs, all relevant literature on a particular research question or topic is systematically identified, assessed and analysed thus, providing a comprehensive and holistic approach to literature investigation(s) (Balali *et al.*, 2023). Therefore, the SLR is adopted in this present study to address all the research questions previously delineated i.e. RQ1-RQ5. The specific approach proposed for this SLR consists of five stages *viz.*: a) the identification of records; b) Scientometric analysis of the identified records; c) quality assessment of the identified records; d) extraction of barriers and relationships analysis among them; e) proposal of a conceptual framework; and f) discussions on limitations and suggesting future research pathways – refer to Figure 1.

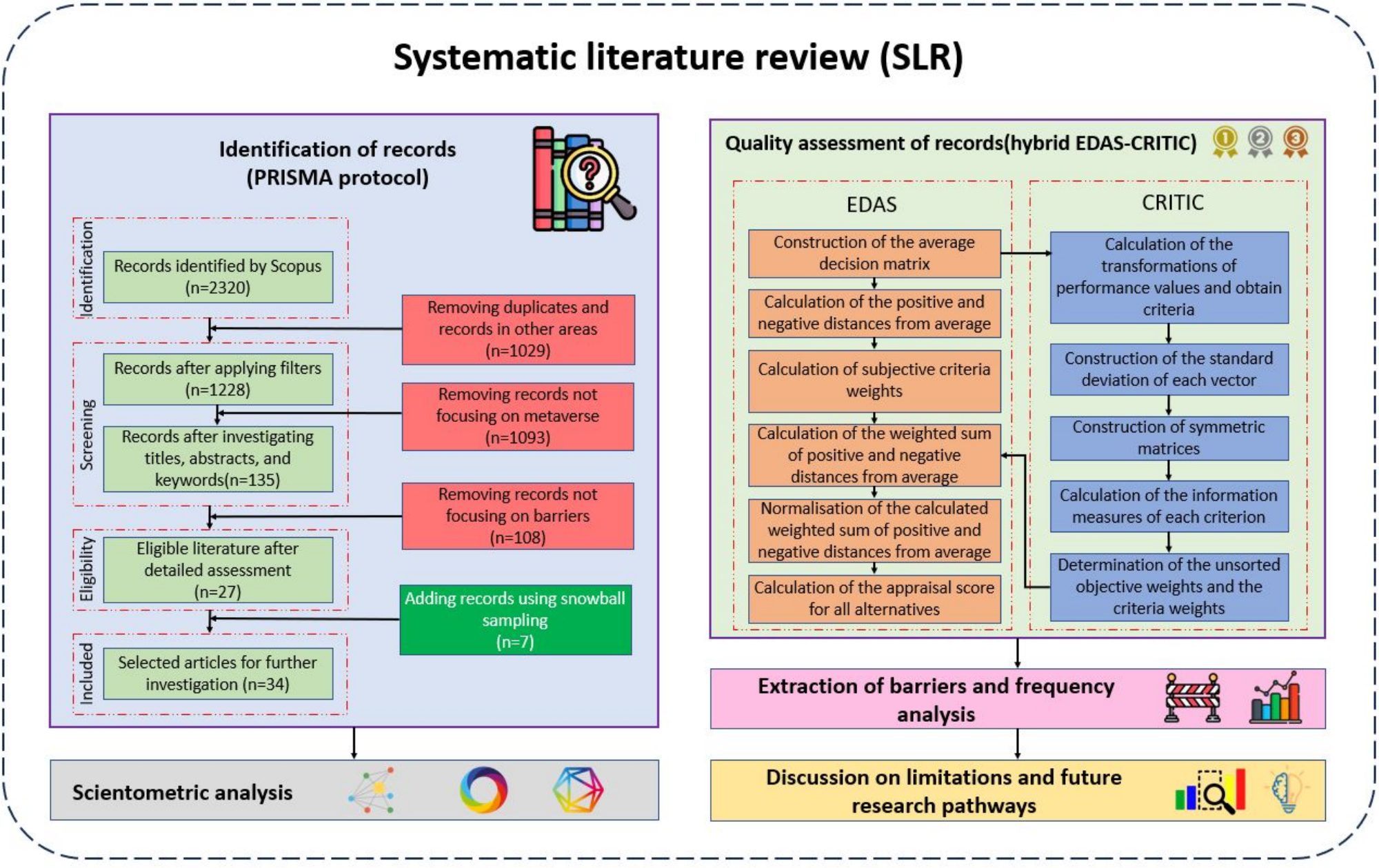


Figure 1 – Review framework

2.1 Identification of records

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach was adopted to guide the identification, screening, eligibility assessment, and inclusion of publication records, following (Balali *et al.*, 2022). Scopus was selected as the sole bibliographic database for this systematic literature review because it provides broad multidisciplinary coverage, indexes a large volume of peer-reviewed journals relevant to construction management, digitalisation, BIM, engineering and built environment research, and offers consistent metadata required for transparent search, filtering and reproducible screening (Bayramova *et al.*, 2024). Compared with narrower discipline-specific databases, Scopus is particularly suitable for this review because metaverse adoption in construction is an interdisciplinary topic spanning construction, engineering, management, digital technologies, immersive environments and sustainability studies. The use of a single database also reduced duplication and improved the consistency of the search strategy, inclusion criteria and bibliometric extraction process. To mitigate the risk of missing relevant studies, snowballing was subsequently undertaken to identify additional publications not captured through the initial database search.

Carefully crafted keywords were formulated to ensure a comprehensive search regime based on the guidelines provided by PICO (Population, Intervention, Comparison, Outcome) and SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type) method [47]. The formulated keywords are: "Metaverse" OR "Virtual Reality" OR "Augmented Reality" OR "Mixed Reality" OR "Extended Reality" OR "Digital Twin" OR "Virtual Environment" OR "Immersive Technology" AND "Construction" OR "Construction Industry" OR "Building Industry" OR "Civil Engineering" OR "Construction Project" OR "Construction Management" AND "Barrier" OR "Challenge" OR "Obstacle" OR "Hurdle" OR "Limitation" OR "Impediment" OR "Constraint".

The keyword search initially returned 2,320 documents. A staged screening process was then applied in accordance with the PRISMA protocol, as illustrated in Figure 1. First, duplicate records and records outside the relevant subject areas were removed, reducing the number of records to 1,228. Second, the titles, abstracts and

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keywords of these records were screened to assess their relevance to the metaverse and its enabling technologies in the construction context. This stage excluded 1,093 records that did not focus on metaverse-related concepts, leaving 135 records for further consideration. Third, these 135 records were assessed in relation to the focus of the review, particularly whether they discussed adoption barriers, challenges, limitations, constraints or implementation issues associated with metaverse or related immersive technologies in construction. This resulted in the exclusion of 108 records that did not focus on barriers, leaving 27 eligible studies.

The snowballing process was conducted after the initial eligibility assessment to strengthen the completeness of the review and reduce the risk of excluding relevant studies not captured through the database search. Backward snowballing was applied by examining the reference lists of the 27 eligible studies to identify additional publications that were directly relevant to metaverse-related technologies, construction/AECO contexts and adoption barriers or implementation challenges. Candidate studies identified through this process were screened using the same eligibility criteria applied during the main review, including relevance to the construction industry, connection to the metaverse or enabling immersive technologies, and explicit discussion of adoption barriers, challenges, limitations or implementation issues. Studies that did not meet these criteria were excluded. This process resulted in seven additional records, increasing the final sample to 34 studies.

2.2 Scientometric analysis

Scientometric analysis is a quantitative method for examining the structure, development and relationships within a body of scientific literature. In systematic literature reviews, it complements qualitative synthesis by enabling researchers to map publication trends, influential sources, collaboration patterns, co-citation structures and keyword relationships within a research field. This is particularly useful for emerging and interdisciplinary topics, such as metaverse adoption in construction, where knowledge is distributed across different technological, managerial and built environment domains. By using bibliographic metadata, scientometric analysis can reveal how a research area has evolved, which journals and authors have shaped the discourse, and which themes are gaining prominence.

Previous studies have demonstrated the value of scientometric analysis for identifying knowledge clusters, research hotspots and future research directions in construction and built environment research (Kuoribo and Mahmoud, 2022). Accordingly, scientometric analysis was adopted in this study to provide a structured overview of the evolution, intellectual structure and thematic concentration of metaverse-related research in construction.

The scientometric analysis conducted in this SLR comprised four stages: journal citation analysis, keyword co-occurrence analysis, co-author analysis and network citation analysis. Further information regarding each of the utilised analyses is provided in Section 3.

2.3 Quality assessment of records

Quality assessment of the identified records in an SLR is essential because it enables readers to identify studies with the greatest research impact (Balali and Yunusa-kaltungo, 2024a). However, several factors must be considered if a truly comprehensive quality assessment is secured, which consequently makes the analysis sophisticated. Hence, this study proposes a novel procedure for quality assessment of the identified records using multiple attribute decision-making (MADM) techniques. MADM techniques facilitate the selection process by enabling the simultaneous consideration of multiple criteria (Xu *et al.*, 2020). According to Balali and Yunusa-Kaltungo (Balali and Yunusa-kaltungo, 2024b), the initial stage in formulating an MADM problem is to identify the selection criteria and alternatives. In this study, the identified articles are considered as the alternatives. Also, multiple metrics extracted from Scopus and Web of Science (WoS) were determined and set as the selection criteria - refer to Table 1.

Table 1 - Selection criteria for the quality assessment of the identified records

Code	Source	Criterion	Further explanation
C1	WoS	Citation/years of publication	Division of the number of article's citation to the number of years since published.
C2	WoS	Quartile by Impact Factor	Quartile of the journal where article is published based on Impact Factor.
C3	WoS	Quartile by Journal Citation Index	Quartile of the journal where article is published based on Journal Citation Index.
C4	WoS	Impact Factor	Impact Factor of the journal where the article is published.
C5	WoS	Journal Citation Index	Journal Citation Index of the journal where the article is published.
C6	Scopus	Citation/years of publication	Division of the number of article's citation to the number of years since published.
C7	Scopus	CiteScore	CiteScore of the journal where the article is published.
C8	Scopus	Quartile by CiteScore	Quartile of the journal where article is published based on journals' CiteScore.

- a) Citation of the articles divided by the number of years since published, as suggested by (Balali and Yunusa-kaltungo, 2024a). This criterion was extracted from both Scopus and WoS and denoted as C1 and C6, respectively.
- b) Impact Factor (IF) of the journal (based on WoS), denoted by C4.
- c) Journal Citation Index (JCI) (based on WoS) denoted by C5.
- d) CiteScore of the journal (based on Scopus) denoted by C7.
- e) Quartile of the journal where article is published was utilised based on Impact Factor (IF), Journal Citation Index (JCI), and CiteScore of the corresponding journal, denoted by C2, C3, and C8, respectively. Records received scores of 4-1 for quartiles 1-4, respectively. More specifically, a record published in a Q1 and Q4 journal obtained the score of 4 and 1, respectively.

The EDAS (Evaluation based on Distance from Average Solution) and CRITIC (Criteria Importance Through Intercriteria Correlation) methods were selected and hybridised because they provide complementary strengths for the quality assessment of records in this review. More specifically, EDAS is appropriate for ranking alternatives in multi-attribute decision-making problems because it evaluates each alternative according to its positive and negative distance from the average solution rather than relying only on ideal or anti-ideal solutions (Balali and Yunusa-kaltungo, 2025a). This makes it suitable for comparing literature records with heterogeneous performance across several bibliometric and journal-quality indicators. Moreover, EDAS is computationally efficient and less demanding than older pairwise-comparison-based techniques, such as AHP, particularly when several criteria and alternatives are involved (Stevic *et al.*, 2018). CRITIC was selected because it provides an objective mechanism for determining criterion weights by considering both the variability of each criterion and the correlation between criteria. This is important in the present study because several quality assessment indicators, such as citation-related metrics and journal impact metrics, may overlap or correlate with one another (Mishra *et al.*, 2022). Hybridising EDAS with CRITIC therefore allows the ranking process to benefit from the simplicity and ranking capability of EDAS while incorporating objective criterion weights derived from the information contained in the decision matrix. This reduces excessive subjectivity and improves the robustness of the quality assessment process. Accordingly, a hybrid methodology was utilised for solving the MADM problem by combining EDAS and CRITIC methods.

Steps of applying the proposed methodology for quality assessment of the identified records is explained as follows (Balali and Yunusa-kaltungo, 2025b; Li *et al.*, 2021):

Step 1: construction of the decision matrix (X) as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

where x_{ij} denotes the performance of the i th record with respect to the j th criterion.

Also, the number of selection criteria and records are denoted by n and m , respectively.

Step 2: normalisation of matrix X to determine the average solution as follows:

$$AV_j = \frac{\sum_{i=1}^n x_{ij}}{n} \quad (2)$$

Step 3: calculation of positive (PDA) and negative (NDA) distances of all the elements of matrix X from the average solution is conducted in this step. Assume beneficial and non-beneficial criteria are denoted by BC and NBC, respectively.

Then, PDA and PDA are calculated as follows:

$$PDA_{ij} = \begin{cases} \frac{\max(0, x_{ij} - AV_j)}{AV_j}, & j \in BCs \\ \frac{\max(0, AV_j - x_{ij})}{AV_j}, & j \in NBCs \end{cases} \quad (3)$$

$$NDA_{ij} = \begin{cases} \frac{\max(0, AV_j - x_{ij})}{AV_j}, & j \in BCs \\ \frac{\max(0, x_{ij} - AV_j)}{AV_j}, & j \in NBCs \end{cases} \quad (4)$$

Step 4: calculation of the standard deviation σ_j and the correlation coefficient ρ_{ij} between criteria as follows:

$$\sigma_j = \sqrt{\frac{1}{m} \sum_{i=1}^m (x_{ij} - \bar{x}_{ij})^2} \quad (5)$$

$$\rho_{ij} = Cov(X_i, X_j) / (\sigma_i, \sigma_j) \quad (6)$$

Where the average value of alternative i is shown by $\bar{x}_{ij}$. Also, $Cov(X_i, X_j)$ denotes the covariance between row i and row j of the matrix X .

Step 5: calculation of the objective weights of the criteria as follows:

$$w_j = \frac{\sigma_j \sum_{i=1}^n (1 - \rho_{ij})}{\sum_{j=1}^n (\sigma_j \sum_{i=1}^n (1 - \rho_{ij}))} \quad (7)$$

Where the weights of criterion j is denoted by w_j .

Step 6: calculation of the weighted values of PDA and NDA , denoted by SP and SN , respectively, as follows:

$$SP_{ij} = \sum_{j=1}^m w_j PDA_{ij} \quad (8)$$

$$SN_{ij} = \sum_{j=1}^m w_j NDA_{ij} \quad (9)$$

Step 7: normalisation of the values of SP and SN , denoted by NSP and NSN , respectively, as follows:

$$NSP_{ij} = \frac{SP_i}{\max_i SP_i} \quad (10)$$

$$NSN_{ij} = \frac{SN_i}{\max_i SN_i} \quad (11)$$

Step 8: Calculation of the compromise score for alternatives (AS) as follows:

$$AS_i = \frac{NSP_{ij} + NSN_{ij}}{2} \quad (12)$$

2.4 Extraction of barriers and relationship analysis

In this stage, the included records were precisely investigated to extract the metaverse's adoption barriers, followed by generating a heatmap on the relationships among the identified barriers. Further information analysis is provided in Section 3.

2.5 Development of conceptual framework

A conceptual framework was then developed and suggested for wider adoption of metaverse. More specifically, this conceptual framework ensures a systematic transition from awareness to full-scale adoption of metaverse technologies through a

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structured, step-by-step approach. Further information analysis is provided in Section 3.

3.0 RESULTS AND DISCUSSION

Figure 2 illustrates the trend in research publications related to the metaverse and associated technologies. The number of publications per annum remained relatively stable from 1995-2016, with only 34 studies published in 2016. However, the number of publications started to increase steadily from 2017, with a notable surge from 2020 onwards, reflecting a growing interest in metaverse technologies among researchers. By 2022 and 2023, the number of publications experienced a sharp rise, reaching 301 in 2023 and 418 in 2024, highlighting the rapid expansion of metaverse-related research. This surge is largely attributed to the increasing maturity of metaverse technologies and their application across various sectors. The observed trend of publications clearly demonstrates a strong and continuous growth in metaverse research, expecting more number of studies within the following years.

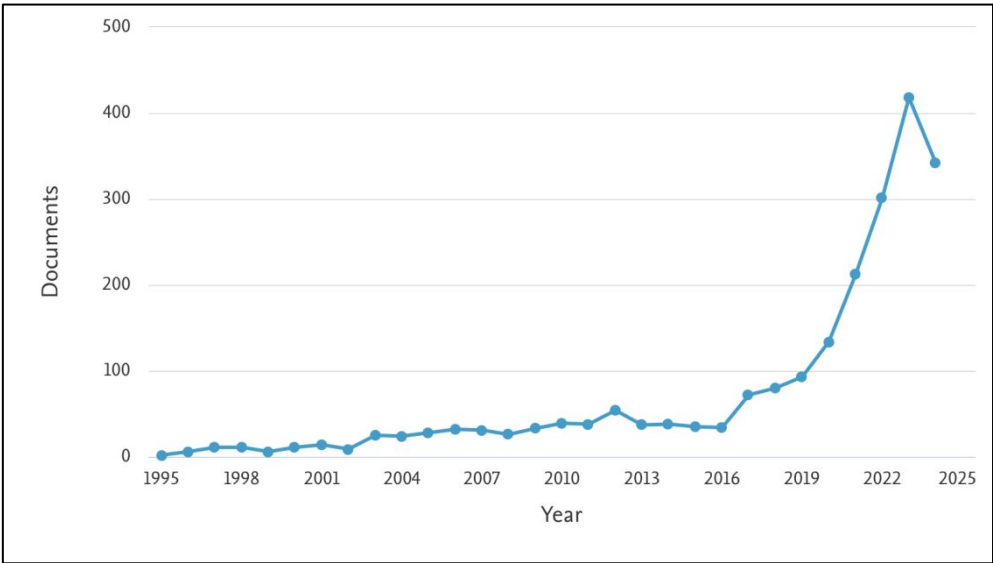


Figure 2 - Distribution of records in years

3.1 Journal co-citation analysis

Figure 3 illustrates the citation relationships and thematic relevance among 20 journals, highlighting both the influence of individual journals and the interactions between various publications. The metaverse is an inherently interdisciplinary research area, extending beyond

computer technology into various fields such as architecture, engineering, social sciences and design. The connections between journals and conferences suggest strong collaboration and knowledge exchange across these domains. Notably, key nodes such as "Automation in Construction," "Lecture Notes in Computer Science," "Advanced Engineering Information" and "IEEE Access" occupy central positions in the network, signifying their substantial influence in metaverse research. This network visualisation offers a comprehensive academic map, showcasing the complexity and interdisciplinary nature of studies conducted.

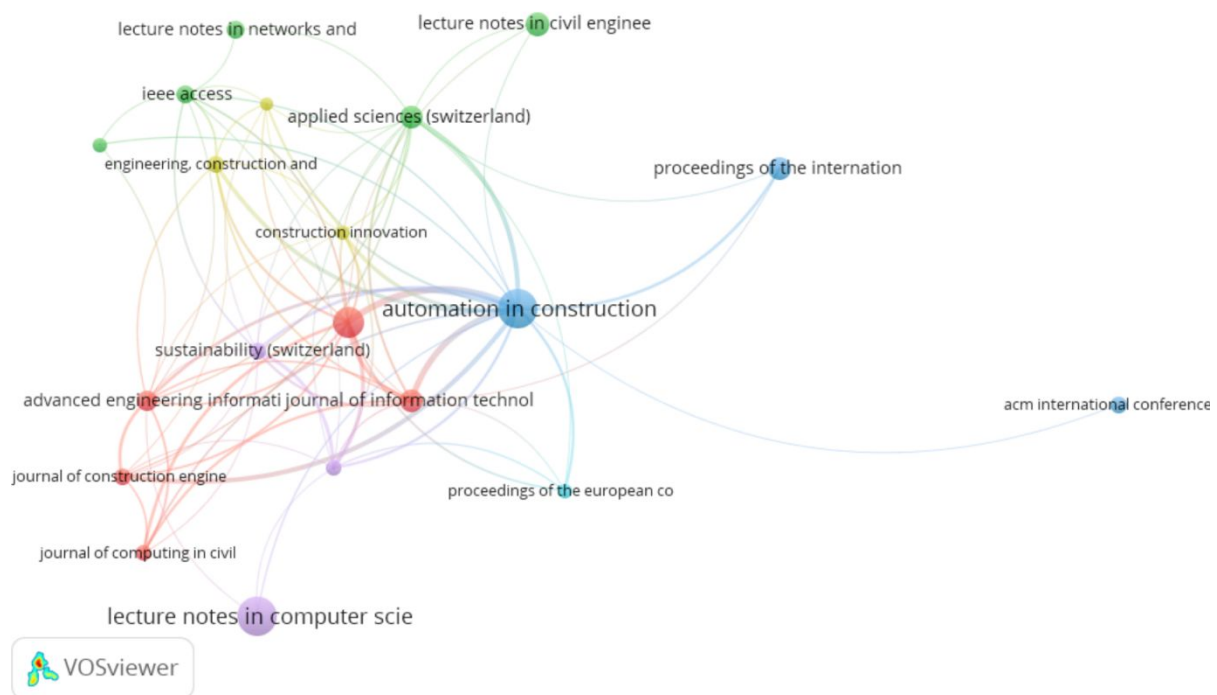


Figure 3 - Journal co-citation network of records

3.2 Keyword co-occurrence analysis

Figure 4 illustrates the co-occurrence relationships among keywords from 34 core publications, showcasing their interconnections within the academic literature. A minimum occurrence threshold of five was applied, identifying nine keywords that met this criterion. The connections between these keywords reveal how various concepts are discussed together in the research literature, with the thickness of the lines representing the frequency of co-occurrence, i.e. thicker lines indicate more frequent co-mention. Four distinct clusters illustrate the evolving landscape of metaverse-related research. The “metaverse” and “metaverses” form the conceptual

core, representing the foundation upon which other technological and industrial applications are built. Their strong connections to “virtual reality” and “augmented reality” highlight the pivotal role these technologies play in enabling immersive digital environments. The recent emergence of metaverse-related studies suggests a growing academic and industrial interest in expanding its applications beyond entertainment into sectors such as construction and architecture.

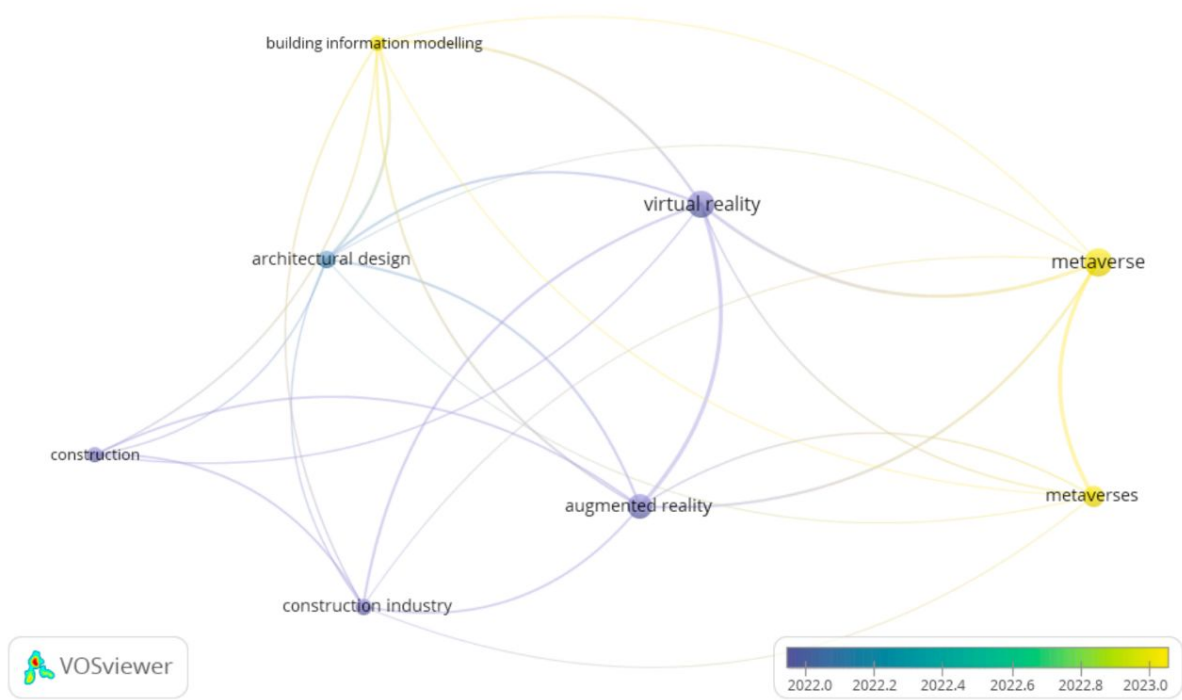


Figure 4 - Keyword co-occurrence map of records

The technological backbone of this research lies within “virtual reality”, “augmented reality”, “construction” and “construction industry”, which are clustered together due to their interdependent nature. VR and AR provide tools for creating and navigating digital spaces, while the construction sector represents a key area of application. Integrating these technologies is facilitating advancements in virtual site inspections, digital twin modelling and AR-assisted project management. While the connection between the “metaverse” and “construction” is evident, research in this area is embryonic, suggesting future studies will likely refine how these tools enhance productivity, safety and collaboration in construction workflows. Two isolated but significant clusters are “building information

modelling” and “architectural design” which indicate specialised yet underdeveloped research domains within the metaverse framework. As a crucial tool for digital construction, BIM has the innate potential to integrate seamlessly with metaverse platforms for enhanced design collaboration and real-time project simulation. Similarly, architectural design stands alone in the diagram, reflecting a growing but fragmented interest in how immersive digital environments can transform architectural visualisation and planning. As research progresses, these fields will likely become more interconnected, leading to a more cohesive integration of metaverse technologies across digital modelling, construction, and industrial applications.

3.3 Country co-authorship analysis

The academic collaboration between different countries is visualised in Figure 5 considering the threshold of five to which clearly highlights key contributors to the identified records. Each node represents a country, with the connecting lines indicating collaborative relationships. In total, 9 countries are depicted as interconnected in metaverse research. The size of each node reflects the extent of a country's contribution to the field. Notably, the UK, China and US are prominent, signifying their substantial involvement and widespread international collaborations. The figure also reveals numerous links between European countries (such as the UK and France) and Asian countries (such as China and India), illustrating the strong presence of cross-regional collaboration within this area of study.

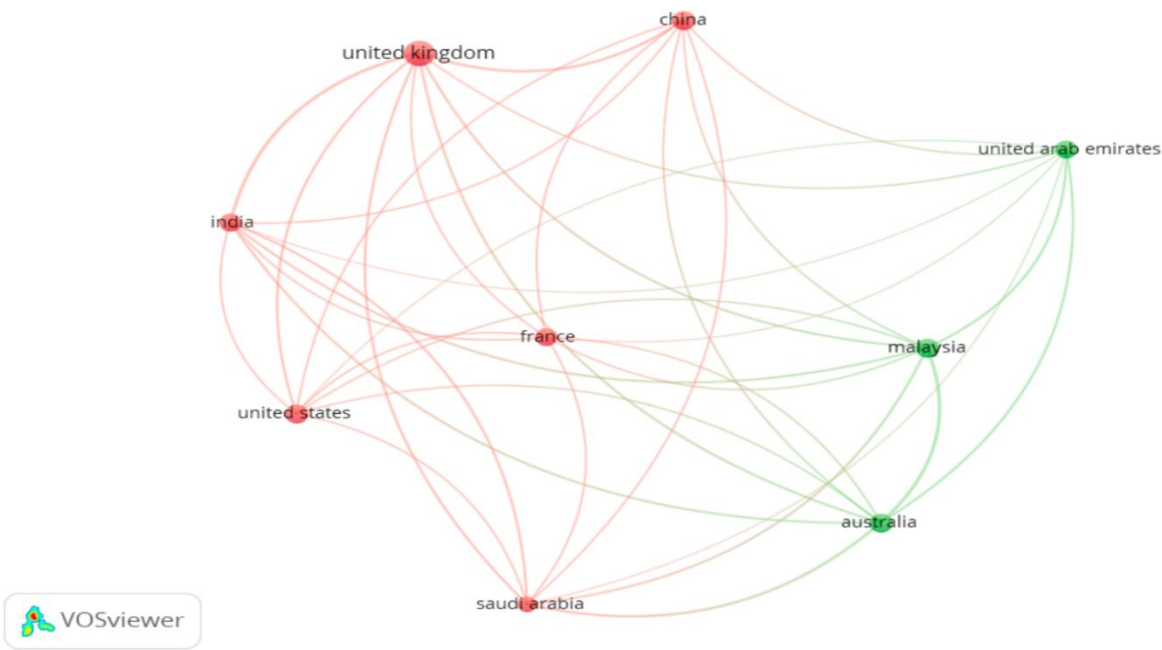


Figure 5 - Country co-authorship network of records

3.4 Researcher co-authorship analysis

The relationships among authors of the identified records is illustrated in Figure 6, with connecting lines representing their collaborative efforts. Among 145 authors, only four are interconnected, forming two distinct clusters. The red lines indicate a higher frequency of joint research and collaborative projects. Notably, Al-Sharafi M.A., Al-Emran M., and Iranmanesh M. co-authored a paper titled "Drivers and Barriers Affecting Metaverse Adoption: A Systematic Review, Theoretical Framework, and Avenues for Future Research" (Al-Sharafi *et al.*, 2023a), published in the International Journal of Human-Computer Interaction. Also, Al-Emran M. stands out as a central figure in this network, engaging in active collaborations with other researchers.

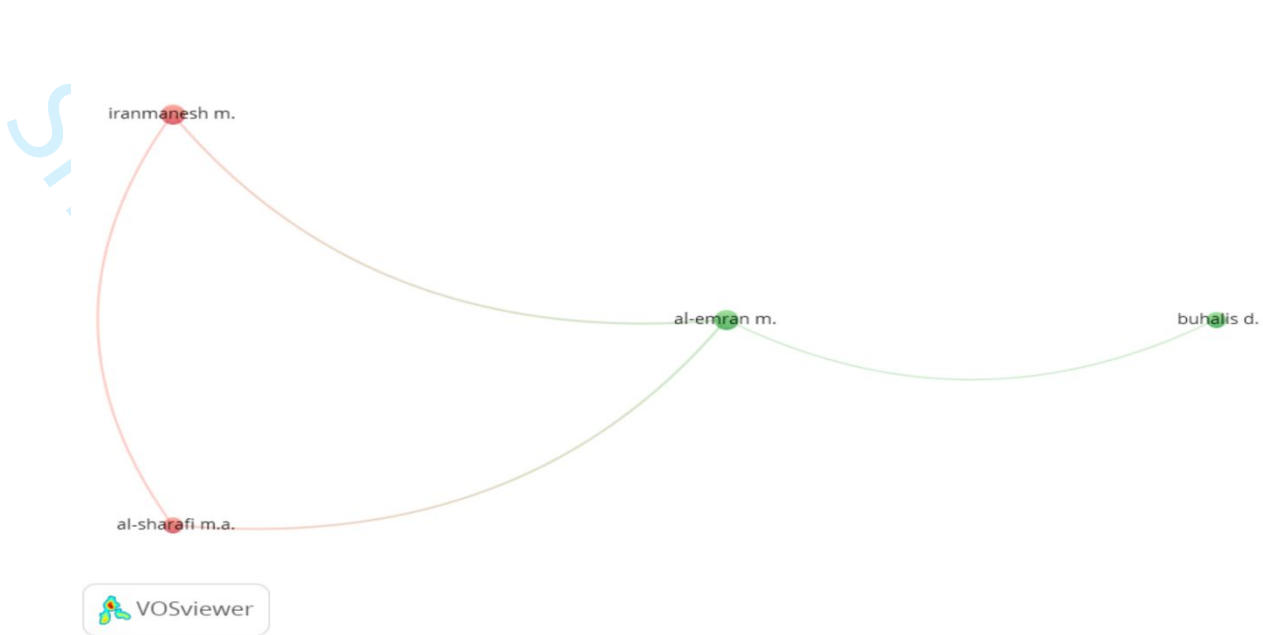


Figure 6 - Individual co-authorship network of records

3.5 Author co-citation analysis

Figures 7 and 8 display a network visualisation and a density visualisation, respectively, providing a detailed analysis of collaboration and citation patterns within the academic network. In the network visualisation, the size of the nodes represents the influence or impact of each author, while in the density visualisation, brighter regions indicate areas where collaboration or mutual citations are most concentrated. The visualisations highlight that Chen, J., and Wang, X., are pivotal authors within the network, as their research is widely cited, and they maintain direct connections with numerous other authors. Additionally, the density visualisation reveals a distinct cluster of collaboration involving Dwivedi, Y.K., Buhalis, D., and Hughes, I., demonstrating a strong degree of collaboration among these researchers.

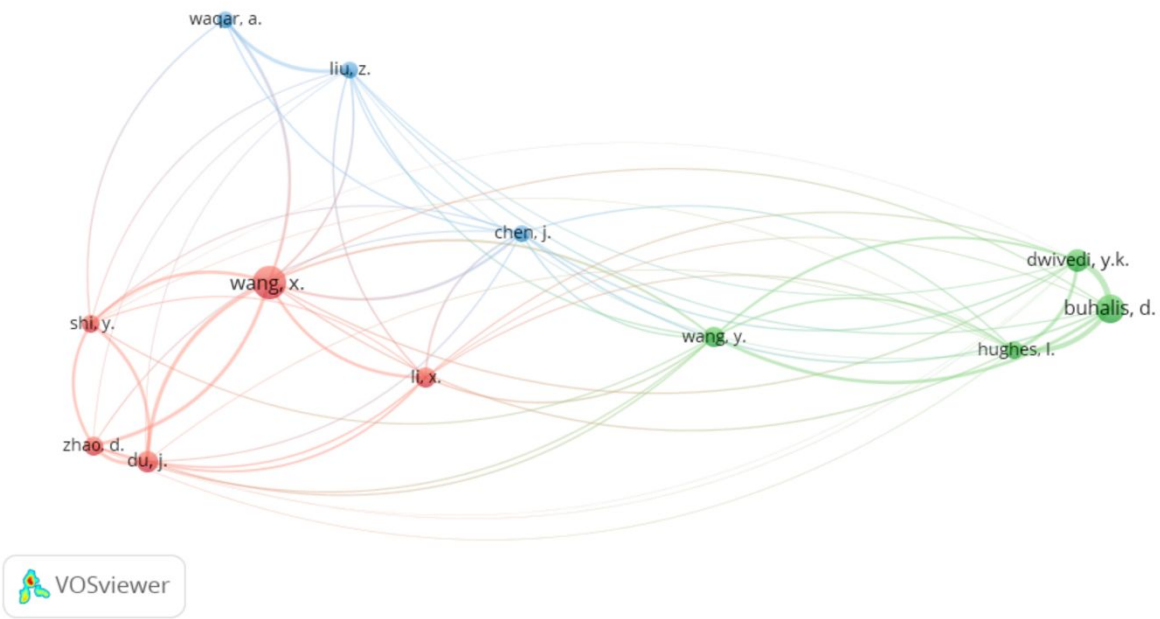


Figure 7. Author co-citation network map

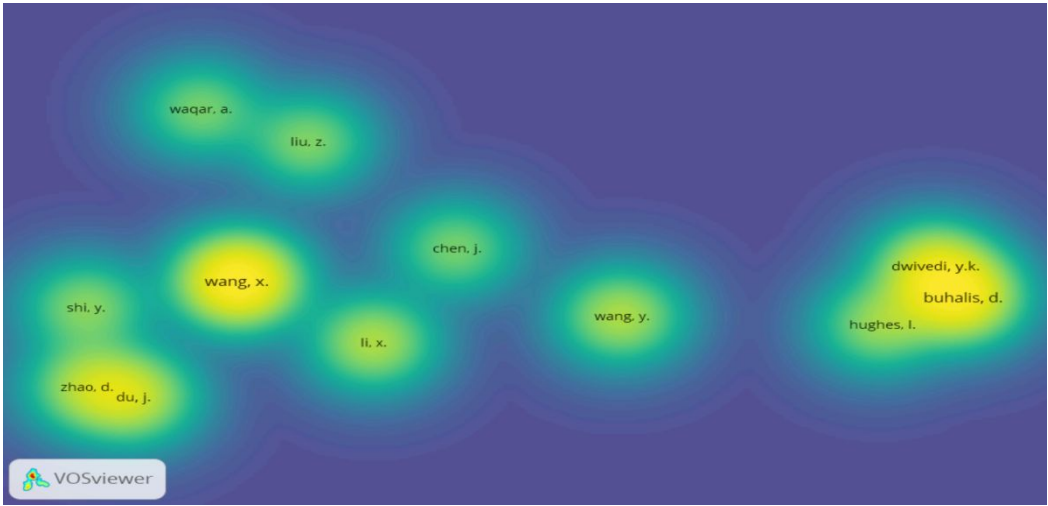


Figure 8. Author co-citation density heat map

3.6 Quality assessment

Quality assessment was conducted for the sample publications to examine their impact within the relevant body of knowledge. The hybrid EDAS-CRITIC approach

was utilised for this purpose and the results of the analysis are presented in this section. Table 2 illustrates the decision matrix, average solution values (AV) and the final weights of the selection criteria (W_j). Also, the final ranking of the records is presented in in Table 3.

According to Table 3, the top three records with the highest impacts are: 1) “Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy” by Dwivedi et al., *International Journal of Information Management* (Dwivedi *et al.*, 2022); 2) “Metaverse as a disruptive technology revolutionising tourism management and marketing” by Buhalis et al., *Tourism Management* (Buhalis *et al.*, 2023); and 3) “3D virtual worlds and the metaverse: Current status and future possibilities” by Dionisio et al., *ACM Computing Surveys* (Dionisio *et al.*, 2013). Identification of the top three studies significantly enhances the usability and practical applicability of the current SLR by ensuring that the most impactful works are systematically identified based on multiple criteria. Such knowledge directs researchers’ attention towards the studies that offer the most robust findings and substantial contributions to the field.

Table 2. Decision matrix, average solution values, and weights of the criteria

Code	C1	C2	C3	C4	C5	C6	C7	C8
LR1	2.00	4.00	4.00	9.60	1.85	3.00	19.20	4.00
LR2	3.00	3.00	3.00	3.80	1.06	4.00	9.10	4.00
LR3	0.00	3.00	3.00	3.10	0.72	0.00	3.40	4.00
LR4	10.00	4.00	4.00	9.60	1.85	9.00	19.20	4.00
LR5	12.00	4.00	4.00	11.00	2.35	14.00	20.40	4.00
LR6	10.50	4.00	4.00	10.50	1.92	8.00	220	4.00
LR7	3.50	3.00	3.00	2.90	1.09	5.00	7.50	4.00
LR8	2.50	3.00	3.00	3.60	0.74	2.50	8.10	4.00
LR9	0.00	0.00	0.00	0.00	0	0.00	1.40	3.00
LR10	17.00	4.00	4.00	6.00	1.33	29.50	12.10	4.00
LR11	20.00	4.00	4.00	7.10	1.81	32.00	13.30	4.00
LR12	98.00	4.00	4.00	10.90	9.81	137.00	24.10	4.00
LR13	46.00	4.00	4.00	9.50	2.04	60.50	30.00	4.00
LR14	9.00	4.00	4.00	8.70	1.8	12.50	17.40	4.00
LR15	16.50	4.00	4.00	9.70	1.52	20.50	20.40	4.00
LR16	2.00	3.00	3.00	3.10	0.72	2.00	3.40	4.00

LR17	5.50	3.00	3.00	1.70	0.45	9.00	4.20	4.00
LR18	9.00	3.00	4.00	3.40	0.85	10.50	9.00	4.00
LR19	7.00	4.00	4.00	4.60	1.23	7.00	10.30	4.00
LR20	0.50	3.00	3.00	3.40	0.87	1.50	9.80	4.00
LR21	72.50	3.00	3.00	2.50	0.67	118.00	6.80	3.00
LR22	3.00	3.00	3.00	3.00	0.63	2.50	7.50	4.00
LR23	7.00	3.00	3.00	3.20	0.68	7.00	5.20	3.00
LR24	7.33	4.00	3.00	2.50	0.56	13.33	5.30	3.00
LR25	10.67	4.00	4.00	9.90	2.74	15.33	21.20	4.00
LR26	229.33	4.00	4.00	20.10	5.74	353.33	53.10	4.00
LR27	4.33	4.00	4.00	9.60	1.85	6.00	19.20	4.00
LR28	25.33	4.00	4.00	9.60	1.85	33.67	19.20	4.00
LR29	8.25	4.00	4.00	9.60	1.85	9.25	19.20	4.00
LR30	17.80	4.00	4.00	4.10	0.87	22.60	8.70	4.00
LR31	8.67	4.00	4.00	9.60	1.85	11.17	19.20	4.00
LR32	20.83	4.00	4.00	9.60	1.85	24.33	19.20	4.00
LR33	8.67	4.00	3.00	2.50	0.56	14.50	5.30	3.00
LR34	30.83	4.00	4.00	23.80	5.05	49.83	33.20	4.00
AV	21.43	3.56	3.53	7.11	1.79	30.83	14.90	3.85
W_j	0.1084	0.1204	0.1204	0.1100	0.0944	0.1114	0.0795	0.2794

Table 3. Final ranking of the records

Code	SP_i	SN_i	NSP_i	NSN_i	AS_i	Rank
LR1	0.10	0.20	0.03	0.72	0.3781	20
LR2	0.01	0.34	0.00	0.52	0.2637	25
LR3	0.01	0.43	0.00	0.40	0.2022	33
LR4	0.10	0.14	0.03	0.81	0.4216	16
LR5	0.15	0.11	0.05	0.85	0.4505	11
LR6	0.13	0.14	0.05	0.81	0.4263	13
LR7	0.01	0.35	0.00	0.51	0.2547	26
LR8	0.01	0.37	0.00	0.48	0.2404	28
LR9	0.00	0.71	0.00	0.00	0.0000	34
LR10	0.04	0.08	0.01	0.89	0.4499	12
LR11	0.05	0.02	0.02	0.98	0.4969	7
LR12	1.34	0.00	0.47	1.00	0.7359	2
LR13	0.40	0.00	0.14	1.00	0.5699	4
LR14	0.08	0.13	0.03	0.82	0.4227	14
LR15	0.10	0.08	0.04	0.89	0.4645	8
LR16	0.01	0.41	0.00	0.42	0.2143	32

LR17	0.01	0.40	0.00	0.44	0.2242	31
LR18	0.03	0.29	0.01	0.60	0.3035	22
LR19	0.04	0.25	0.01	0.65	0.3338	21
LR20	0.01	0.37	0.00	0.48	0.2402	29
LR21	0.57	0.20	0.20	0.72	0.4604	9
LR22	0.01	0.39	0.00	0.46	0.2302	30
LR23	0.00	0.36	0.00	0.50	0.2490	27
LR24	0.01	0.33	0.01	0.54	0.2714	24
LR25	0.16	0.11	0.06	0.85	0.4511	10
LR26	2.85	0.00	1.00	1.00	1.0000	1
LR27	0.10	0.18	0.03	0.75	0.3939	18
LR28	0.13	0.00	0.05	1.00	0.5228	5
LR29	0.10	0.14	0.03	0.80	0.4161	17
LR30	0.04	0.17	0.01	0.76	0.3874	19
LR31	0.10	0.14	0.03	0.81	0.4224	15
LR32	0.10	0.03	0.03	0.96	0.4989	6
LR33	0.01	0.32	0.01	0.55	0.2791	23
LR34	0.65	0.00	0.23	1.00	0.6145	3

3.7 Extraction of the barriers

Following detailed investigation of the identified studies, 17 barriers to the adoption of the metaverse in the construction industry were identified and categorised into five dimensions: political, economic, social, technological and cultural barriers, as shown in Figure 9. This categorisation was adopted because the barriers extracted from the reviewed literature clustered most clearly around governance and policy conditions, economic feasibility, social acceptance, technological readiness and cultural/organisational behaviour. Although this structure is informed by macro-environmental thinking, it is not presented as a full PESTEL framework. Therefore, legal and environmental issues were not treated as separate categories unless they emerged as distinct barrier groups across the reviewed studies. Instead, legal issues are discussed within the political and social dimensions, particularly in relation to policy uncertainty, standardisation, legal disputes, data privacy and security. Environmental issues are discussed in relation to sustainability-oriented applications, future research pathways and the wider implications of metaverse adoption, rather than as a standalone adoption barrier category.

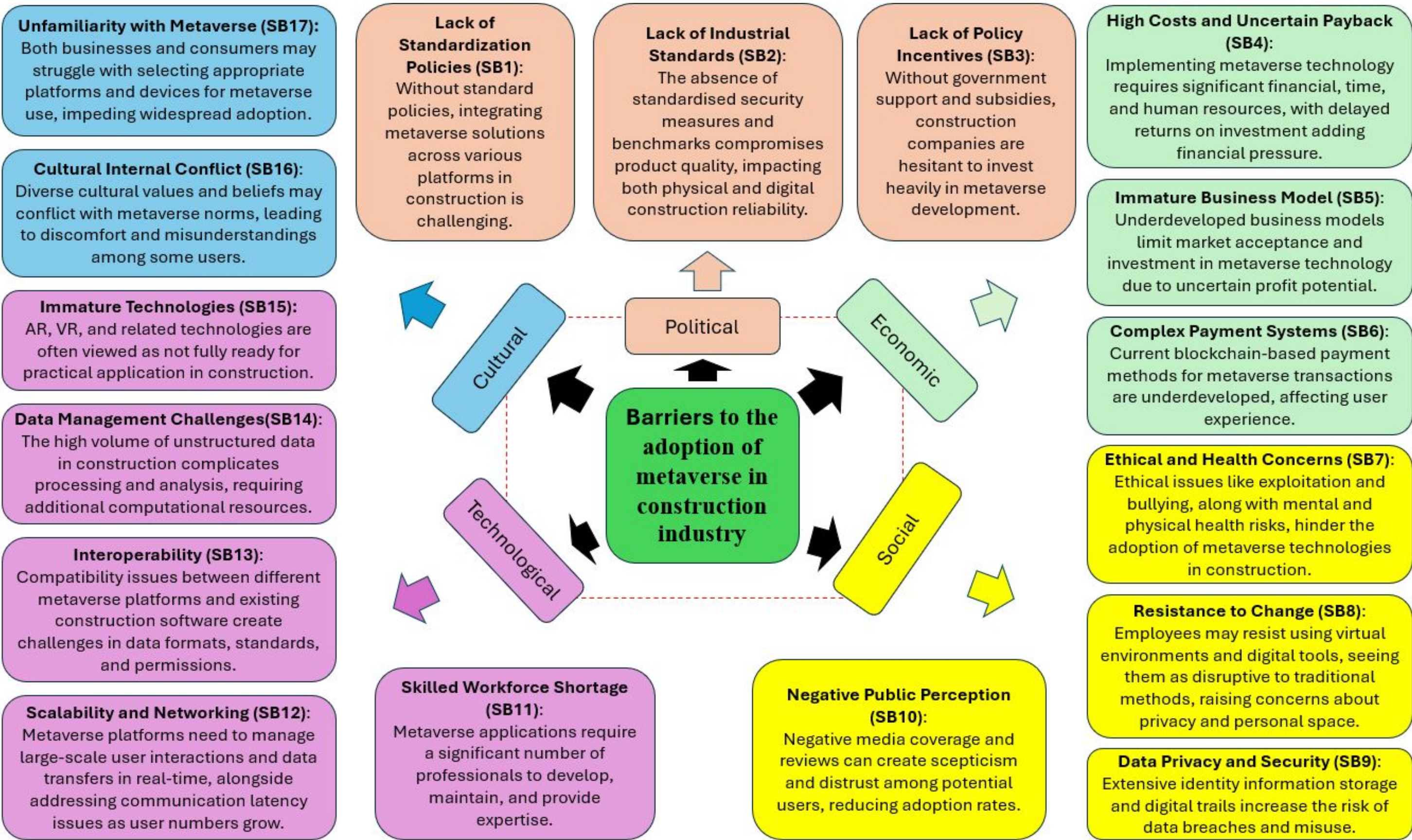


Figure 9 - Identified barriers to the adoption of metaverse in construction industry based on the adopted five-category classification

3.7.1 Political barriers

Metaverse adoption in construction industry faces significant political barriers that may severely limit its potential development. First, a notable lack of standardised policies makes the integration of metaverse solutions across different platforms extremely challenging (Chen *et al.*, 2024; Hadavi and Alizadehsalehi, 2024a; Koohang *et al.*, 2023; Mkedder and Das, 2024). Many stakeholders and complex economic activities are prone to legal disputes in the absence of a unified policy (Koohang *et al.*, 2023). Second, scant industry standards engenders a lack of uniform security measures and benchmarks, which affects product quality and compromises reliability (Chen *et al.*, 2024). This paucity of standards also hinders regulators providing effective oversight and management, further exacerbating potential risks. Finally, the lack of policy incentives, such as government support and subsidies, has led to a reluctance on the part of construction companies to invest heavily in metaverse development (Chokwitthaya *et al.*, 2020; Hadavi and Alizadehsalehi, 2024a). The development and implementation of metaverse technologies require high up-front investment in technology development, equipment procurement and professional training.

3.7.2 Economic barriers

Economic challenges are a common hurdle for most companies. First, the adoption of the metaverse requires a large investment of capital, time and human resources, and the uncertain return on investment further increases the economic pressure on enterprises (Chen *et al.*, 2024; Hennig-Thurau *et al.*, 2023). Many companies may be wary of investing due to the large initial investment and long payback period. Second, immature business models limit market acceptance and investment in metaverse technologies (Chen *et al.*, 2024). Due to the lack of clear profit models and business cases, companies have difficulty in foreseeing the profit potential of the metaverse. Finally, the current blockchain-based payment system is not perfect, which harms the economic system and user experience (Dwivedi *et al.*, 2022). The complexity of payment systems not only increases transaction costs but can also lead to social issues such as security and trusts.



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3.7.3 Social barriers

Ethical and health considerations are a major deterrent because the application of metaverse may bring about issues such as exploitation and bullying (Chen et al., 2024). Moreover, prolonged use of virtual environments may negatively affect users' mental and physical health (Chen et al., 2023). Employee resistance to change is also a major challenge because many employees may resist the use of virtual environments and digital tools, believing that these technologies will interfere with their existing work patterns (Dallasega et al., 2023). Data privacy and security issues cannot be ignored either. Metaverse technologies require the storage of large amounts of identity information and digital footprints, which increases the risk of data leakage and misuse (Al-Sharafi et al., 2023b). Sensitive data (such as construction project design and financial information), and any data leakage could have serious business and legal consequences. In addition, negative media coverage and comments about the metaverse may engender scepticism and distrust among potential users (Al-Sharafi et al., 2023b).

It should be noted that data privacy and security also carry legal implications, particularly in relation to data ownership, confidentiality, cybersecurity compliance and accountability for sensitive project information. However, these issues were retained within the social category in this study because the reviewed literature mainly discussed them in relation to user trust, stakeholder confidence, risk perception and willingness to adopt metaverse-based platforms.

3.7.4 Technical barriers

A lack of skilled workers presents a significant challenge because developing, maintaining and implementing the metaverse requires skilled professionals (Davila Delgado et al., 2020). Scalability and networking challenges are also significant technical obstacles. As the number of users grows, metaverse platforms must handle large-scale user interactions and real-time data transfers while addressing communication latency issues (Ali et al., 2021). This growth puts a high demand on network infrastructure and platform scalability. Interoperability issues cannot be ignored either because compatibility issues exist between different metaverse platforms and existing architectural software, including challenges in data formats, standards and permissions (Hadavi and Alizadehsalehi, 2024a). Data management

challenges present another significant barrier to the metaverse's adoption. Large volumes of unstructured data generated in the construction industry (e.g. 3D models, construction records, etc.) requires complex analysis, which increases the difficulty of data management (Wu *et al.*, 2024). Finally, the immaturity of the technology is also a major barrier (Pooladvand *et al.*, 2021). Although AR, VR and other related technologies are constantly evolving, there are still some technical bottlenecks and limitations to their practical application in construction (Hadavi and Alizadehsalehi, 2024a).

3.7.5 Cultural barriers

The adoption of metaverse also faces significant cultural barriers. Values and beliefs from different cultures may conflict with the norms of the metaverse, leading to discomfort and misunderstanding for some users (Mkedder and Das, 2024). Culture significantly influences consumers' willingness to engage with new technology platforms (Jiang *et al.*, 2022). The construction industry is relatively conservative, with traditional mindsets and work styles that are difficult to shift expediently (Forcael *et al.*, 2020). This intra-cultural conflict may hinder the widespread acceptance and application of the metaverse. In addition, unfamiliarity with metaverse technology among businesses and consumers increases the difficulty in selecting appropriate platforms and devices, thus affecting the metaverse's popularity (Ramadan, 2023).

3.7.6 Relationships of the identified barriers

Figure 10 provides a heatmap that demonstrates the interactions among the barriers revealed in this research. The strongest relationships among the other barriers are immature business model (SB5), unfamiliarity with metaverse (SB17) and interoperability issues (SB13). SB5 is a basic barrier that greatly influences building metaverse acceptance (Anshari *et al.*, 2022). Companies find it difficult to justify investments in metaverse technologies without a clear revenue model since uncertain financial returns and high initial costs (SB4) are apparent. Lack of a clear monetisation strategy also complicates digital asset ownership (SB6), licencing and financial transactions, so hindering companies' long-term planning ability [76]. Moreover, this uncertainty fuels organisational resistance to change (SB8) because companies hesitate to move from conventional building techniques to immersive

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digital environments devoid of obvious financial incentives. Lack of a business model also discourages investments in skilled workforce shortage (SB11), so producing a shortage of qualified professionals able to properly integrate metaverse solutions. SB17 is another important obstacle since low knowledge of its possible uses slows down industry acceptance (Nguyen *et al.*, 2024). Many builders and decision-makers doubt the advantages of the metaverse, which fuels negative public perception (SB10) and resistance to change (SB8). Education and training programs (SB11) suffer as businesses are reluctant to invest in upskilling staff members in developing technologies they do not completely grasp (Kim *et al.*, 2022). Furthermore, the lack of industry awareness lowers research and development (R&D) initiatives (SB15), so hindering developments in metaverse technologies. Consequently, the building sector remains reluctant to welcoming the digital transformation, so postponing general acceptance and application (Aljawder and Al-Karaghoul, 2024). Furthermore, SB13 presents serious technical difficulties for combining metaverse platforms with current building technologies including BIM, digital twins, and IoT. Standardised frameworks and industrial guidelines (SB1, SB2) absence results in scattered and incompatible digital systems, which makes it challenging to scale metaverse applications among many projects and stakeholders (McNamara *et al.*, 2024). These interoperability problems also affect data management (SB14) since different data formats and security concerns impede flawless cooperation. Furthermore, limiting the metaverse's capacity to operate across several platforms and so lowering its efficacy in large-scale building projects are scalability and networking constraints (SB12). Ignorance of interoperability issues will keep hindering industry-wide adoption and so restrict the full potential of metaverse technologies in construction.

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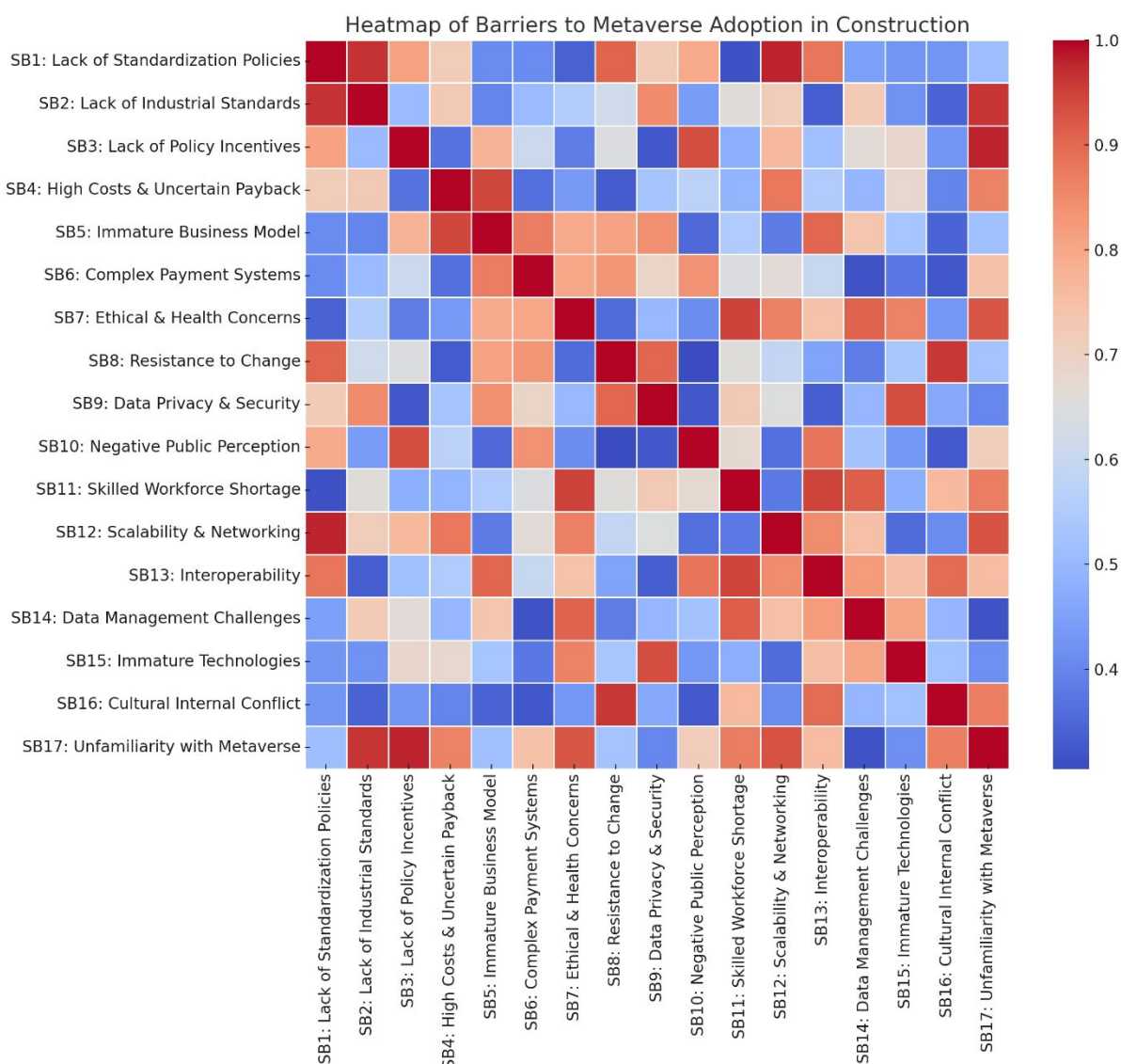


Figure 10 - The developed heatmap illustrating the relationships among the barriers

However, the least connections among the others are negative public opinion (SB10), immature technologies (SB15) and cultural internal conflict (SB16). Though it is a social and psychological barrier, SB10 has no direct bearing on industry rules, technical implementation or business feasibility. Although privacy, ethics and possible job displacement are issues when considering metaverse adoption in construction companies is mostly motivated by economic viability, return on investment (SB4) and technical feasibility (SB13) (Arowoia *et al.*, 2024). Furthermore, as more successful applications transpire over time, public opinion can evolve and it becomes a secondary issue instead of a basic barrier that instantly prevents adoption. Though SB15 is a legitimate issue, they have little bearing on

economic and policy-related obstacles including business models (SB5), financial incentives (SB3) or scalability (SB12) (Yuan *et al.*, 2024). Construction companies do not necessarily wait for technology to be completely developed before investigating its application; they are already familiar with adopting emerging digital solutions (such as BIM and digital twins) even before complete maturity. Furthermore, many metaverse-related technologies (such as VR, artificial intelligence and blockchain) are already developing on their own, thus immaturity is only a transient obstacle rather than a strongly linked obstacle. Similarly, SB16 speaks of opposition inside building companies about the move from conventional approaches to digital, immersive environments (Wang *et al.*, 2024). Although this can provide organisational difficulties, it is essentially an internal problem inside companies rather than a structural barrier affecting sectors. Unlike financial concerns (SB4, SB5) or policy-related obstacles (SB1 and SB2), cultural resistance does not always stop investment, technical advancement or legislative changes. Moreover, change management and leadership can progressively overcome cultural resistance, hence is less important in determining the instant acceptance of metaverse technologies.

3.8 Development of a conceptual framework for the wider implementation of metaverse

A conceptual framework is developed to promote the construction industry's application of the metaverse (refer to Figure 11). This model guarantees a methodical shift from awareness to full-scale industry adoption by means of a disciplined, step-by-step iterative approach. The process begins with *Stakeholder Awareness & Training*, a foundational stage that focuses on educating and preparing all relevant stakeholders to create an environment conducive to technological (Succar, 2009). Once stakeholders understand and support the technological shift, the framework progresses to *Policy & Standardization Framework*, establishing clear and robust regulatory guidelines and protocols to ensure systematic and uniform technology integration across the construction industry. Building on these regulatory frameworks, the next stage is *Investment & Infrastructure Development*; this stage secures necessary funding and develops essential infrastructure, creating a stable foundation for subsequent technological implementations, assessed through metrics like Return on Investment (ROI) and infrastructure readiness. With adequate resources in place, the framework advances to *Technology Integration (AI, VR, Blockchain)*, focusing on the practical implementation of advanced digital

technologies. These technologies significantly enhance operational efficiency, reliability, and interoperability within construction processes (Khan *et al.*, 2024).

Successful technological integration necessitates robust *Data Security & Interoperability* — this stage ensures secure data transactions and seamless communication between integrated systems, addressing cybersecurity challenges critical for safeguarding sensitive information, measured by incident rates and interoperability efficiency metrics (Hadavi and Alizadehsalehi, 2024b). With data systems secured and effectively interconnected, the framework moves to *Digital Twin & BIM Integration*. Here, Digital Twin and Building Information Modelling (BIM) technologies improve project design accuracy and operational efficiency, significantly reducing costs and enhancing planning and decision-making processes. Further enhancing project quality, the framework incorporates *Simulation & Virtual Prototyping*; this stage uses advanced simulation and virtual prototyping techniques to proactively identify and rectify design errors, substantially minimizing costs and optimizing project timelines (Huang *et al.*, 2007). Building on successful simulations, the framework proceeds to real-world *Pilot Implementation in Construction*, where technology solutions are rigorously tested to validate performance and gather critical data on stakeholder satisfaction, initial cost benefits, and practical effectiveness.

Following successful pilot implementations, the process continues to *Performance Evaluation & Optimization*. Here, comprehensive assessments identify areas of improvement, refine technologies, and measure their impacts on productivity, safety, and sustainability, guiding continuous enhancements (Waqar *et al.*, 2023). The final stage, *Industry-wide Adoption & Scaling*, disseminates successful technological solutions broadly throughout the industry. This stage emphasizes metrics such as market penetration, scalability, and long-term operational efficiency, fostering widespread adoption and sustained industry benefits. Integral to the framework is a critical feedback loop that emphasizes continuous improvement. Insights and performance outcomes from advanced stages feed back into earlier stages, particularly influencing ongoing stakeholder training, policy adjustments, and technology refinements. This iterative loop ensures continuous adaptation, knowledge sharing, and improvement, fostering sustained success, resilience, and innovation within the construction sector.

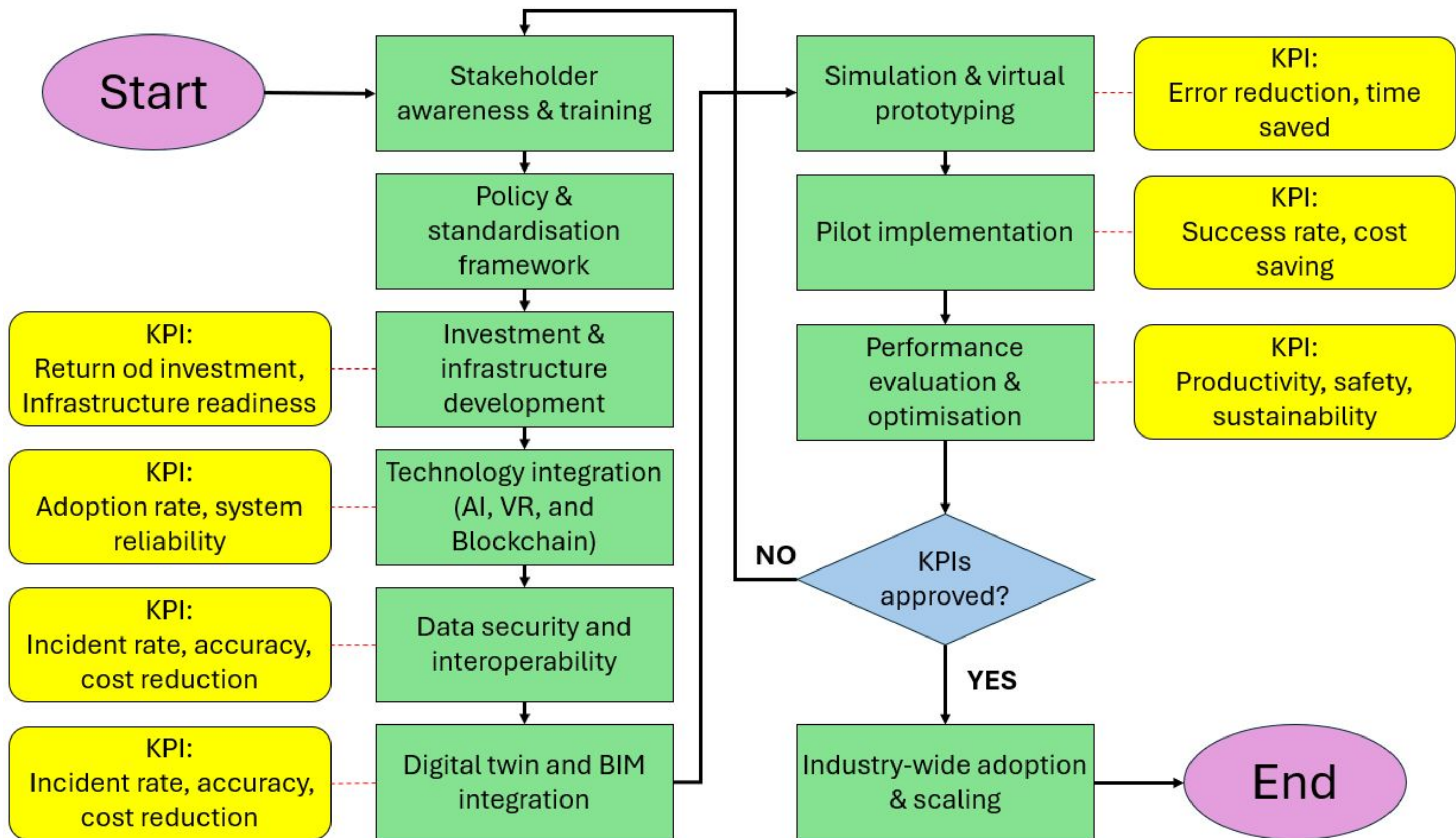


Figure 11 - Conceptual framework for metaverse implementation in construction project

4.0 LIMITATIONS OF PREVIOUS STUDIES AND FUTURE WORK

While previous studies have made valuable contributions to understanding the adoption of metaverse technologies in the construction industry, they exhibit several limitations that necessitate further investigation. A key shortcoming of prior research is the lack of a systematic approach in identifying and analysing barriers comprehensively. Most studies have focused on specific challenges, such as technical or economic constraints, without considering the interplay between multiple factors. This fragmented approach limits the holistic understanding of metaverse adoption and underscores the need for a more integrated perspective. Another limitation is the geographical concentration of studies which predominantly focus on developed countries, where infrastructure and digital literacy levels are relatively high. Consequently, the findings may not be entirely applicable to developing regions where financial constraints, regulatory challenges and limited technological accessibility pose additional barriers. Future research should aim to include diverse geographical contexts to provide a more globally relevant understanding of metaverse adoption challenges.

The absence of empirical validation is another notable gap in previous studies. While many investigations have relied on theoretical frameworks and qualitative analyses, there is a lack of data-driven research assessing the actual impact of metaverse adoption in the construction sector. Empirical studies, including case studies, pilot projects and longitudinal assessments are essential for validating theoretical insights and providing practical recommendations for industry stakeholders. Furthermore, the dynamic nature of metaverse technologies presents a challenge for researchers attempting to capture an accurate and up-to-date picture of the industry. Many studies become outdated rapidly as new technological advancements and policy developments emerge. Future research should adopt adaptive methodologies that allow continuous monitoring and reassessment of barriers to ensure relevance over time. Previous research has also tended to focus on identifying barriers rather than providing viable solutions for overcoming them. While recognising challenges is a crucial step, there is a pressing need for research that explores strategic frameworks and implementation roadmaps. Future investigations should emphasise the development of best practices, technological

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solutions, and policy recommendations that can facilitate the successful integration of metaverse technologies in the construction industry.

To advance knowledge in this field, future research should focus on several critical areas. The development of standardised frameworks is essential to guide the integration of metaverse technologies in construction. These frameworks should address interoperability, data security and ethical concerns while ensuring compliance with industry regulations. Additionally, exploring the synergy between metaverse technologies and other emerging innovations, such as digital twins, Blockchain, and artificial intelligence, can provide valuable insights into how these technologies can collectively enhance construction processes.

Another important area for future research is the quantitative assessment of metaverse adoption's impact on construction efficiency, cost savings and sustainability. While qualitative studies exist, empirical evidence is needed to measure the tangible benefits and drawbacks of metaverse implementation. Longitudinal studies tracking adoption trends over time will also be crucial in understanding how organisations adapt to and integrate metaverse technologies. Policy, regulatory and legal studies should also be prioritised to provide guidance for government agencies and industry leaders on fostering metaverse adoption, particularly in relation to data ownership, intellectual property rights, liability, cybersecurity obligations, contractual responsibility and international regulatory alignment. Research in this area should examine policy incentives, legal frameworks and international regulations that could facilitate the integration of metaverse applications into construction practices. Moreover, understanding the human factors influencing adoption, such as user experience, resistance to change and the psychological impact of working in virtual environments, will be vital for ensuring successful implementation.

Finally, the potential of metaverse technologies in promoting sustainable construction practices should be explored. At the same time, future research should also assess the environmental burden of metaverse adoption, including the energy demand of cloud infrastructure and data centres, the lifecycle impact of VR/AR

hardware, and the potential generation of electronic waste. A summary of all the existing gaps and future research pathways is illustrated in Figure 12.

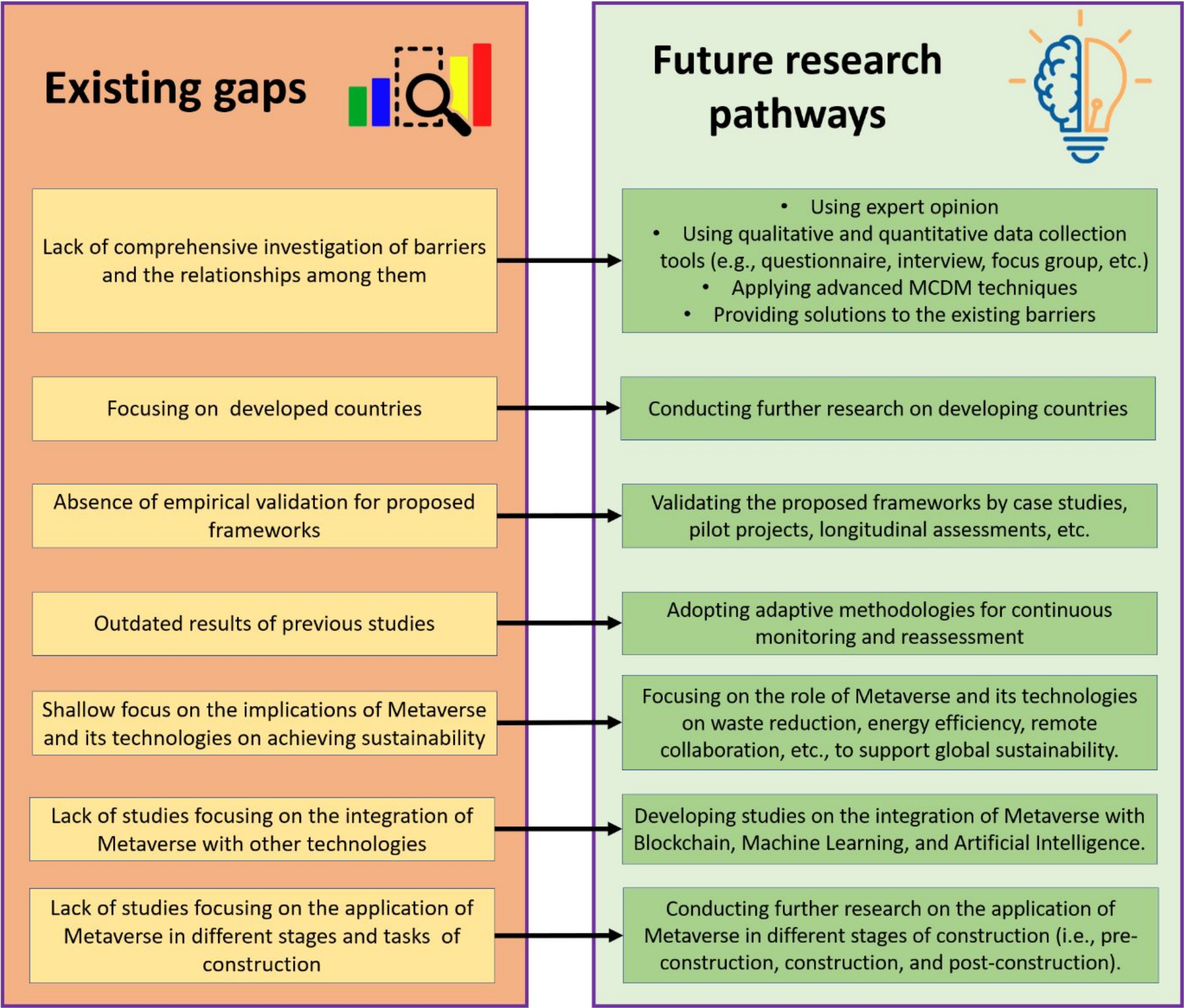


Figure 12 - Existing gaps and future research pathways

By addressing these research gaps, future studies can significantly contribute to enhancing the understanding and implementation of metaverse technologies in construction. This, in turn, will facilitate their widespread adoption, leading to improved efficiency, collaboration, and sustainability within the industry.

5.0 CONCLUSION

The metaverse presents a transformative opportunity for the construction industry by enabling immersive virtual environments for planning, design coordination, stakeholder collaboration, training, simulation, remote inspection and project execution. However, the slow adoption of metaverse technologies indicates that technological availability alone is insufficient to secure industry-wide transformation. This study therefore conducted a systematic literature review incorporating scientometric analysis, quality assessment of selected records, identification and categorisation of adoption barriers, analysis of relationships among barriers, development of a conceptual framework for wider implementation, and discussion of future research pathways. The findings show that metaverse adoption in construction is constrained by a combination of political, economic, social, technological and cultural barriers, including high implementation costs, regulatory uncertainty, lack of standardisation, technological immaturity, resistance to change, interoperability issues, immature business models and limited familiarity with metaverse applications.

A key thought-provoking observation emerging from this review is that the most influential barriers are not necessarily those that appear most visible at the point of implementation, but those that shape the wider conditions under which implementation becomes possible. In particular, interoperability issues, immature business models and unfamiliarity with the metaverse appear to operate as systemic barriers because they influence several other technical, organisational and commercial challenges. Interoperability problems restrict the integration of metaverse platforms with BIM, digital twins, IoT systems and existing project information environments. Immature business models weaken the commercial rationale for investment, making it difficult for construction firms to justify expenditure on hardware, software, training and organisational change. Similarly, unfamiliarity with the metaverse reduces stakeholder confidence, reinforces

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3 resistance to change and limits demand for experimentation. Therefore, future
4 adoption should not be understood merely as a technical transition from
5 conventional tools to immersive environments, but as a socio-technical and
6 commercial transformation requiring coordinated action across industry, policy and
7 research.
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13 For industry practitioners, the findings suggest that metaverse adoption should
14 begin with targeted, low-risk pilot applications rather than immediate full-scale
15 implementation. Construction firms can use the identified barriers as a diagnostic
16 checklist to evaluate organisational readiness, investment priorities and
17 implementation risks before adopting metaverse-based systems. Particular attention
18 should be given to pilot projects that test interoperability between metaverse
19 environments, BIM models, digital twins and project management platforms. Such
20 pilots can generate evidence on productivity gains, error reduction, safety
21 improvement, training effectiveness and cost savings. They can also help firms
22 develop more mature business cases by clarifying where metaverse applications
23 generate value, whether through reduced rework, improved coordination, enhanced
24 stakeholder engagement, remote collaboration, or better lifecycle asset management.
25 In this respect, the conceptual framework proposed in this study can support
26 practitioners in moving from awareness and training to policy alignment,
27 infrastructure investment, technology integration, pilot implementation and eventual
28 scaling.
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43 For policymakers and professional bodies, the findings highlight the need to create
44 an enabling environment for responsible metaverse adoption in construction. Policy
45 interventions should prioritise the development of interoperability standards, data
46 governance protocols, cybersecurity requirements, ethical guidelines and
47 procurement mechanisms that encourage experimentation while protecting project
48 stakeholders. Public-sector clients can play an important role by supporting
49 demonstrator projects, funding innovation testbeds and embedding digital-readiness
50 requirements into procurement frameworks. Targeted incentives, such as innovation
51 grants, tax relief, training subsidies and collaborative industry-academic
52 programmes, could also reduce the perceived risk of investment and accelerate
53 capability development among small and medium-sized construction firms. Without
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such coordinated support, the metaverse may remain limited to isolated experimental applications rather than becoming an integrated component of construction project delivery.

Future research should build directly on the barriers identified in this review by designing and testing targeted interventions. First, studies should examine interoperability solutions that connect metaverse platforms with BIM, digital twins, common data environments and IoT-enabled construction systems using open data standards and cross-platform protocols. Second, future work should develop and validate business models for metaverse adoption, including cost-benefit models, return-on-investment frameworks, lifecycle value assessments and procurement models suitable for different project sizes and organisational contexts. Third, research should investigate how unfamiliarity with the metaverse can be reduced through education, professional training, immersive demonstrations, serious games, living labs and industry-academic knowledge transfer. Fourth, longitudinal and empirical studies are needed to evaluate whether these interventions actually improve adoption readiness, user acceptance, productivity, safety, sustainability and collaboration outcomes over time. Finally, future studies should examine how metaverse adoption differs across developed, emerging and developing economies, as the feasibility of interventions may vary according to digital infrastructure, regulatory maturity, workforce skills and investment capacity.

Ultimately, this study contributes to the literature by moving beyond the identification of metaverse adoption barriers towards a more integrated understanding of how these barriers interact and how they may be addressed. Its practical contribution lies in providing industry practitioners with a structured basis for readiness assessment and staged implementation, while offering policymakers a clearer view of the institutional and regulatory support required to enable adoption. By bridging the gap between conceptual discussion and implementation-oriented guidance, this study provides a foundation for future research and practice aimed at transforming the metaverse from an emerging technological concept into a practical instrument for improving efficiency, collaboration, safety and sustainability in construction.

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**A METICULOUS INVESTIGATION INTO THE APPLICATION OF METAVERSE
IN CONSTRUCTION INDUSTRY: A SYSTEMATIC LITERATURE REVIEW**

ABSTRACT

Purpose

The construction industry is increasingly exploring the metaverse as a transformative digital paradigm to enhance collaboration, efficiency and project delivery. However, the current body of knowledge remains fragmented, lacking a comprehensive synthesis of adoption barriers, research trends and implementation pathways. This study aims to systematically investigate (1) the evolution and trends of metaverse-related research in construction, (2) key barriers to its adoption, and (3) strategic pathways for its effective implementation. By integrating these dimensions, the study seeks to provide a holistic understanding of the metaverse ecosystem within the construction industry.

Design/methodology/approach

A systematic literature review (SLR) was conducted following the PRISMA protocol to identify relevant studies from the Scopus database. A total of 34 records were selected through rigorous screening and snowballing. Scientometric analysis was employed to examine publication trends, collaboration networks and research hotspots. A novel hybrid multi-criteria decision-making (MCDM) framework, combining Evaluation based on Distance from Average Solution (EDAS) and Criteria Importance Through Intercriteria Correlation (CRITIC), was developed to assess the quality and impact of the selected studies. Furthermore, barriers were extracted and analysed, and a conceptual framework for metaverse adoption was proposed.

Findings

The findings reveal a rapidly growing research interest in metaverse applications in construction, particularly after 2020. Key adoption barriers are categorised into political, economic, social, technological and cultural dimensions, with major challenges including high initial costs, lack of standardisation, regulatory uncertainty, technological immaturity and resistance to change. Interoperability issues, immature business models and limited awareness emerged as the most interconnected barriers. The proposed framework outlines a structured pathway from stakeholder awareness to industry-wide adoption, emphasising policy support, infrastructure development and technological integration.

Originality/value

This study contributes to the literature by integrating scientometric analysis, barrier identification, quality assessment and framework development within a unified analytical approach. Unlike prior studies that focus on isolated aspects, this research provides a comprehensive and systematic evaluation of metaverse adoption in construction. The findings offer actionable insights for policymakers, industry practitioners and researchers to facilitate strategic decision-making and accelerate digital transformation in the construction sector.

KEYWORDS

Construction; Metaverse; Barrier; Multiple Criteria Decision-Making; Digitalisation; Systematic Literature Review.

1.0 INTRODUCTION

The metaverse (and its myriad applications in different areas) continues to attract significant research attention from scholars and industry experts and is defined as a collection of immersive virtual worlds that enable people to participate in various activities using avatars (Faraji *et al.*, 2025; Hadavi and Alizadehsalehi, 2024a). Also known as “internet in 3D” and “internet plus” (Japar and Anshari, 2023), the metaverse was initially used in the novel Snow Crash in 1992 but has been used in different businesses since then (Bansal *et al.*, 2022). Several technological advancements fuel the metaverse’s evolution and include: fifth-generation mobile networks (Mendoza *et al.*, 2021); blockchain (Bayramova *et al.*, 2021); virtual reality (VR) (Johansson and Roupé, 2024); and augmented reality (AR) (Abdeen *et al.*, 2024). When combined with the metaverse, augmented VR and AR combined is known as mixed reality (MR). Artificial intelligence (AI) can also be embedded within the metaverse and is paramount to enhancing the user experience, e.g. character creation, rendering of 3D objects and personalise metaverse services (Chen *et al.*, 2024). Utilising advanced machine learning (ML) algorithms is another role of AI in metaverse, as suggested by Huynh-The *et al.* (Huynh-The *et al.*, 2023). The metaverse’s key characteristics include: scalability (Wang *et al.*, 2023); identity (Xu *et al.*, 2023); heterogeneity (Son and Jeong, 2025); interoperability (Chengoden *et al.*, 2023); immersiveness (Giang Barrera and Shah, 2023); interactivity (Park and Yoo, 2020); hyper spatiotemporality (Hadavi and Alizadehsalehi, 2024a); persistence (Lee *et al.*, 2021); and customisability (Akour *et al.*, 2022). Each of these characteristics are explained further as follows. Scalability refers to the ability to accommodate additional users and VR

regions as required; where each user has their unique identity and can get involved in different social communities and groups (Wang *et al.*, 2023). Heterogeneity encapsulates usability for varied users with different cultures, languages and accessibility needs (Son and Jeong, 2025). Users can interact with metaverse through numerous devices, platforms and virtual environments to obtain a cohesive experience (interoperability) (Chengoden *et al.*, 2023). Immersiveness allows users to have real-time and responsive interactions with each other (interactivity). Because the metaverse is not bounded by real world constraints (e.g. time and distance), it provides a hyper spatial and temporal environment where users can gain new experiences such as travel in time (hyper spatiotemporality) (Hadavi and Alizadehsalehi, 2024a). Other characteristics such as customising virtual environments (customisability), as well as existence users (even when they are offline (persistence)), further empowers the utilisation of metaverse (Lee *et al.*, 2021).

In the context of construction, the metaverse can be understood as an integrated, persistent and interactive digital environment in which physical assets, project information, stakeholders and construction processes are virtually represented and connected. Unlike standalone VR or AR applications, the metaverse combines immersive visualisation, real-time data exchange, digital twins, BIM, AI, IoT and blockchain-enabled information management to create a shared virtual project environment (Oyeyipo *et al.*, 2025). This environment can support users in interacting with design models, construction sequences, site conditions, resources and project decisions in ways that are difficult to achieve through conventional two-dimensional documentation or fragmented digital platforms. Therefore, the metaverse should not be viewed merely as a visualisation tool, but as a broader socio-technical ecosystem capable of linking people, processes and digital assets across the project lifecycle (Lucchi, 2023).

Metaverse has been adopted in various industrial sectors including: agriculture (Almessabi and Al-kfairy, 2024; Büyükkakin and Soylu, 2023); manufacturing (Amaizu *et al.*, 2024; Hosseini *et al.*, 2024); healthcare (Letafati and Otoum, 2024; Wu *et al.*, 2024); finance (Ariful Islam Mozumder *et al.*, 2023; Banaeian Far *et al.*, 2023); transportation (Anjum *et al.*, 2024; Kuo and Choi, 2024a); energy (Liu *et al.*, 2024; Luong *et al.*, 2024); hospitality and tourism (Petr and Caudan, 2024; Triviño-Tarradas *et al.*, 2024); education (Alsamh *et al.*, 2024; Singh and Singh, 2024); and telecommunication (Noisri *et al.*, 2024). However, in the construction industry adoption has been sluggish and indeed, the sector is regarded as one of slowest adapters to technological innovations (Diaz Schery *et al.*, 2026; Hadavi and Alizadehsalehi, 2024a). Sector

pioneers include An et al. (An *et al.*, 2025) who developed a framework for using the metaverse in participatory building design in Hong Kong and applied the prototype to five pilot studies. Tran et al. (Tran *et al.*, 2024) developed a common data environment digital platform to enhance the cooperation among stakeholders within the architecture, engineering, construction and operations (AECO) industry. Zaman et al. (Zaman *et al.*, 2023) investigated the potential applications and benefits of BIM-enabled facility management in construction industry to engender greater connectivity between facility managers and field workers thus, managing tasks more effectively through a commonly shared virtual environment. Al-Sabbag et al. (Al-Sabbag *et al.*, 2024) proposed a real-time distributed collaborative system to aid on- and off-site inspectors to perform synchronous structural inspections. Adami et al. (Adami *et al.*, 2021) assessed the effectiveness of VR-based training on improving the knowledge, skills and safety behaviour of the US construction workers, using qualitative and quantitative approaches.

The need to explore the metaverse in the construction industry is particularly important because construction projects are characterised by fragmented supply chains, temporary multi-organisational teams, geographically dispersed stakeholders, complex design information, safety-critical site operations and frequent coordination problems (Hosseini *et al.*, 2025). These characteristics directly affect project execution, where delays, rework, information loss, design clashes, poor communication and safety incidents can undermine productivity and performance. Metaverse-enabled environments can potentially facilitate project execution by allowing stakeholders to rehearse construction sequences before site implementation, visualise and resolve design or constructability conflicts, conduct remote inspections, simulate site logistics, support immersive safety training, improve real-time communication between on-site and off-site teams and connect BIM/digital twin data with live project decision-making (Johri *et al.*, 2024). Such capabilities are especially relevant for improving execution-stage activities because they move digital technologies beyond design representation towards collaborative planning, monitoring, training, inspection and operational decision support. However, despite this potential, adoption remains limited and fragmented, making it necessary to systematically investigate the barriers, research trends and implementation pathways associated with metaverse use in construction.

Other than these aforementioned studies, the existing body of knowledge on metaverse adoption within the construction industry remains scant. Hadavi and Alizadehsalehi (Hadavi and Alizadehsalehi, 2024a) focused on the AECO industry and investigated the issues of

utilising the metaverse and mentioned four categories of metaverse adoption *viz.*: technical, social, regulatory and economic issues. Chen et al. (Chen *et al.*, 2024) identified the most important barriers to metaverse adoption in the construction industry using a political-economic-social-technological framework. They [*ibid*] concluded that the top barriers are scalability, lack of policy incentives and immature business models. Maqsoom et al. (Maqsoom *et al.*, 2023) focused on developing countries and investigated the adoption of mixed reality. Utilising a relative importance index (RII), they concluded that the top barriers to the adoption of MR are high cost of initial investment, public perception of the technology being immature, limited demand and difficulty accessing relevant experts' knowledge. Although the knowledge contributions of previous studies cannot be contested, the following shortcomings are observed and concomitant research questions formulated:

- Existing literature has not provided a Scientometric analyses of previous studies on the metaverse's adoption barriers in the construction industry. This leads to formulating the first research question (RQ1) *viz.*: "What is the trend of investigating the metaverse's adoption barriers in the construction industry?"
- Previous studies have not conducted a systematic literature review (SLR) to identify the metaverse's adoption barriers in the construction industry and the intricate relationships between these. Some studies hitherto undertaken have narrow focuses (Al-Sabbag *et al.*, 2024), are confined to specific geographical regions (Zhang, 2022), and often address barriers that may not be relevant in other national contexts (Kuo and Choi, 2024b). Hence, the second research question (RQ2) formulated is: "What are the metaverse's adoption barriers and are there any relationships between these?"
- Previous studies in this area have yet to conduct a comprehensive quality assessment for the existing literature utilising multiple criteria decision-making (MCDM) techniques, making it difficult to identify studies with the greatest research impact. Therefore, the third research question (RQ3) posed is: "How can the most impactful articles in this area be identified?"
- Hitherto, there has been no conceptual framework delineated for the broader adoption of this technology within the sector. Thus, this state-of-the-art SLR poses the research question (RQ4): "What are the steps to be followed for the maximised realisation of the metaverse in the construction industry?"

- Previous studies have not suggested detailed future research pathways on the adoption of metaverse in the construction industry, leading to the fifth research question (RQ5) *viz.*: “What are limitations in this area and what future pathways can be proposed?”

This study will tackle the mentioned gaps within the prevailing body of knowledge by conducting a comprehensive SLR on the adoption of the metaverse in the construction industry. Specifically, this study contributes to knowledge by: a) investigating the trend of relevant studies through a comprehensive Scientometric analysis; b) identifying the metaverse’s adoption barriers (and any interrelationships between these) through conducting an SLR; c) proposing a novel procedure for ranking papers in SLRs, followed by applying the procedure for ranking the identified barriers; d) proposing a conceptual framework for the wider adoption of the metaverse; and e) discussing future pathways on the metaverse’s adoption.

2.0 REVIEW METHODOLOGY

The SLR has become firmly established among experts and researchers due to its structured and comprehensive methodology (Suo *et al.*, 2025; Verdelho Trindade *et al.*, 2023). In SLRs, all relevant literature on a particular research question or topic is systematically identified, assessed and analysed thus, providing a comprehensive and holistic approach to literature investigation(s) (Balali *et al.*, 2023). Therefore, the SLR is adopted in this present study to address all the research questions previously delineated i.e. RQ1-RQ5. The specific approach proposed for this SLR consists of five stages *viz.*: a) the identification of records; b) Scientometric analysis of the identified records; c) quality assessment of the identified records; d) extraction of barriers and relationships analysis among them; e) proposal of a conceptual framework; and f) discussions on limitations and suggesting future research pathways – refer to Figure 1.

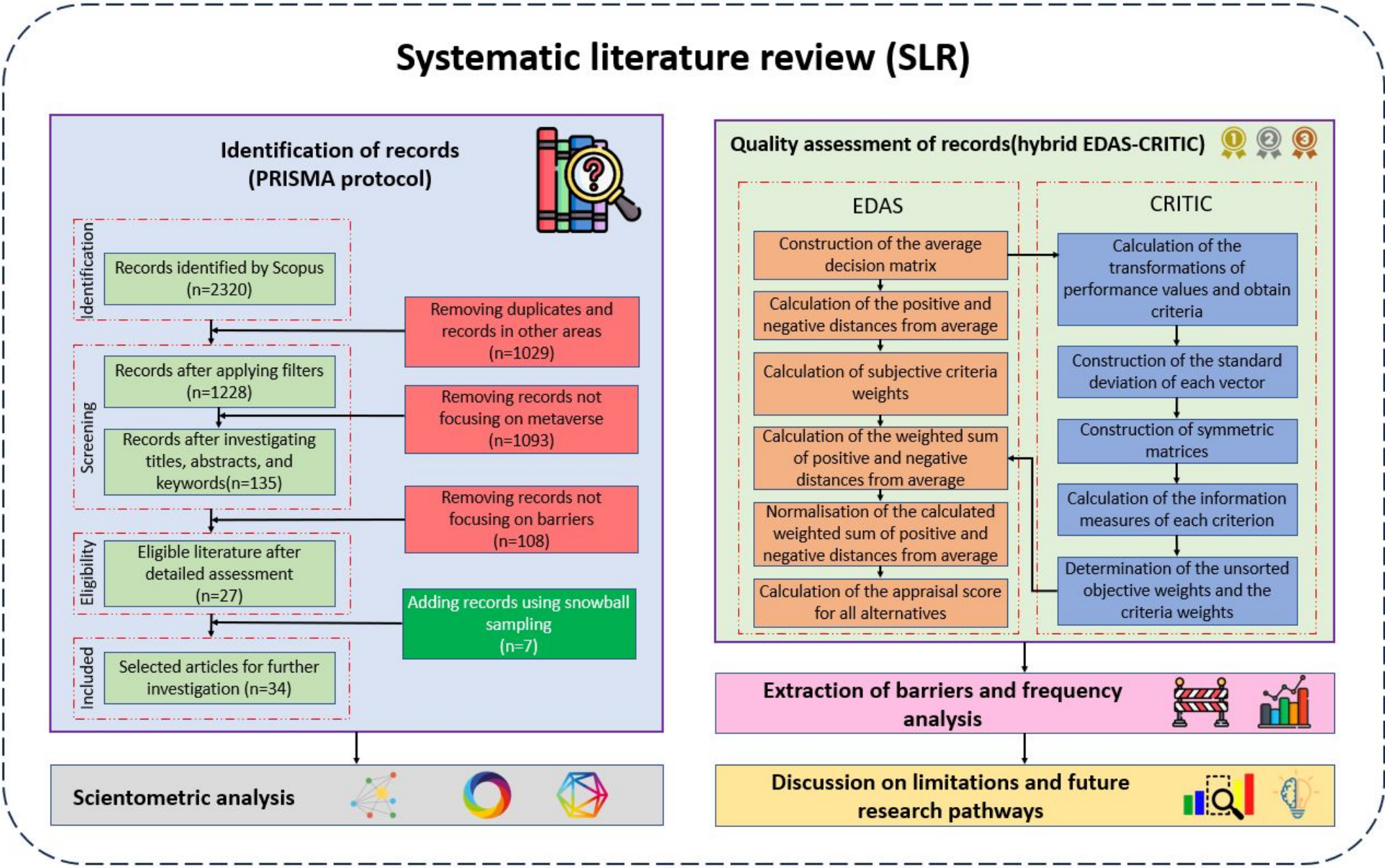


Figure 1 – Review framework

2.1 Identification of records

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach was adopted to guide the identification, screening, eligibility assessment, and inclusion of publication records, following (Balali *et al.*, 2022). Scopus was selected as the sole bibliographic database for this systematic literature review because it provides broad multidisciplinary coverage, indexes a large volume of peer-reviewed journals relevant to construction management, digitalisation, BIM, engineering and built environment research, and offers consistent metadata required for transparent search, filtering and reproducible screening (Bayramova *et al.*, 2024). Compared with narrower discipline-specific databases, Scopus is particularly suitable for this review because metaverse adoption in construction is an interdisciplinary topic spanning construction, engineering, management, digital technologies, immersive environments and sustainability studies. The use of a single database also reduced duplication and improved the consistency of the search strategy, inclusion criteria and bibliometric extraction process. To mitigate the risk of missing relevant studies, snowballing was subsequently undertaken to identify additional publications not captured through the initial database search.

Carefully crafted keywords were formulated to ensure a comprehensive search regime based on the guidelines provided by PICO (Population, Intervention, Comparison, Outcome) and SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type) method [47]. The formulated keywords are: "Metaverse" OR "Virtual Reality" OR "Augmented Reality" OR "Mixed Reality" OR "Extended Reality" OR "Digital Twin" OR "Virtual Environment" OR "Immersive Technology" AND "Construction" OR "Construction Industry" OR "Building Industry" OR "Civil Engineering" OR "Construction Project" OR "Construction Management" AND "Barrier" OR "Challenge" OR "Obstacle" OR "Hurdle" OR "Limitation" OR "Impediment" OR "Constraint".

The keyword search initially returned 2,320 documents. A staged screening process was then applied in accordance with the PRISMA protocol, as illustrated in Figure 1. First, duplicate records and records outside the relevant subject areas were removed, reducing the number of records to 1,228. Second, the titles, abstracts and

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keywords of these records were screened to assess their relevance to the metaverse and its enabling technologies in the construction context. This stage excluded 1,093 records that did not focus on metaverse-related concepts, leaving 135 records for further consideration. Third, these 135 records were assessed in relation to the focus of the review, particularly whether they discussed adoption barriers, challenges, limitations, constraints or implementation issues associated with metaverse or related immersive technologies in construction. This resulted in the exclusion of 108 records that did not focus on barriers, leaving 27 eligible studies.

The snowballing process was conducted after the initial eligibility assessment to strengthen the completeness of the review and reduce the risk of excluding relevant studies not captured through the database search. Backward snowballing was applied by examining the reference lists of the 27 eligible studies to identify additional publications that were directly relevant to metaverse-related technologies, construction/AECO contexts and adoption barriers or implementation challenges. Candidate studies identified through this process were screened using the same eligibility criteria applied during the main review, including relevance to the construction industry, connection to the metaverse or enabling immersive technologies, and explicit discussion of adoption barriers, challenges, limitations or implementation issues. Studies that did not meet these criteria were excluded. This process resulted in seven additional records, increasing the final sample to 34 studies.

2.2 Scientometric analysis

Scientometric analysis is a quantitative method for examining the structure, development and relationships within a body of scientific literature. In systematic literature reviews, it complements qualitative synthesis by enabling researchers to map publication trends, influential sources, collaboration patterns, co-citation structures and keyword relationships within a research field. This is particularly useful for emerging and interdisciplinary topics, such as metaverse adoption in construction, where knowledge is distributed across different technological, managerial and built environment domains. By using bibliographic metadata, scientometric analysis can reveal how a research area has evolved, which journals and authors have shaped the discourse, and which themes are gaining prominence.

Previous studies have demonstrated the value of scientometric analysis for identifying knowledge clusters, research hotspots and future research directions in construction and built environment research (Kuoribo and Mahmoud, 2022).

Accordingly, scientometric analysis was adopted in this study to provide a structured overview of the evolution, intellectual structure and thematic concentration of metaverse-related research in construction.

The scientometric analysis conducted in this SLR comprised four stages: journal citation analysis, keyword co-occurrence analysis, co-author analysis and network citation analysis. Further information regarding each of the utilised analyses is provided in Section 3.

2.3 Quality assessment of records

Quality assessment of the identified records in an SLR is essential because it enables readers to identify studies with the greatest research impact (Balali and Yunusa-kaltungo, 2024a). However, several factors must be considered if a truly comprehensive quality assessment is secured, which consequently makes the analysis sophisticated. Hence, this study proposes a novel procedure for quality assessment of the identified records using multiple attribute decision-making (MADM) techniques. MADM techniques facilitate the selection process by enabling the simultaneous consideration of multiple criteria (Xu *et al.*, 2020).

According to Balali and Yunusa-Kaltungo (Balali and Yunusa-kaltungo, 2024b), the initial stage in formulating an MADM problem is to identify the selection criteria and alternatives. In this study, the identified articles are considered as the alternatives. Also, multiple metrics extracted from Scopus and Web of Science (WoS) were determined and set as the selection criteria - refer to Table 1.

Table 1 - Selection criteria for the quality assessment of the identified records

Code	Source	Criterion	Further explanation
C1	WoS	Citation/years of publication	Division of the number of article's citation to the number of years since published.
C2	WoS	Quartile by Impact Factor	Quartile of the journal where article is published based on Impact Factor.
C3	WoS	Quartile by Journal Citation Index	Quartile of the journal where article is published based on Journal Citation Index.
C4	WoS	Impact Factor	Impact Factor of the journal where the article is published.
C5	WoS	Journal Citation Index	Journal Citation Index of the journal where the article is published.
C6	Scopus	Citation/years of publication	Division of the number of article's citation to the number of years since published.
C7	Scopus	CiteScore	CiteScore of the journal where the article is published.
C8	Scopus	Quartile by CiteScore	Quartile of the journal where article is published based on journals' CiteScore.

- a) Citation of the articles divided by the number of years since published, as suggested by (Balali and Yunusa-kaltungo, 2024a). This criterion was extracted from both Scopus and WoS and denoted as C1 and C6, respectively.
- b) Impact Factor (IF) of the journal (based on WoS), denoted by C4.
- c) Journal Citation Index (JCI) (based on WoS) denoted by C5.
- d) CiteScore of the journal (based on Scopus) denoted by C7.
- e) Quartile of the journal where article is published was utilised based on Impact Factor (IF), Journal Citation Index (JCI), and CiteScore of the corresponding journal, denoted by C2, C3, and C8, respectively. Records received scores of 4-1 for quartiles 1-4, respectively. More specifically, a record published in a Q1 and Q4 journal obtained the score of 4 and 1, respectively.

The EDAS (Evaluation based on Distance from Average Solution) and CRITIC (Criteria Importance Through Intercriteria Correlation) methods were selected and hybridised because they provide complementary strengths for the quality assessment of records in this review. More specifically, EDAS is appropriate for ranking alternatives in multi-attribute decision-making problems because it evaluates each alternative according to its positive and negative distance from the average solution rather than relying only on ideal or anti-ideal solutions (Balali and Yunusa-kaltungo, 2025a). This makes it suitable for comparing literature records with heterogeneous performance across several bibliometric and journal-quality indicators. Moreover, EDAS is computationally efficient and less demanding than older pairwise-comparison-based techniques, such as AHP, particularly when several criteria and alternatives are involved (Stevic *et al.*, 2018). CRITIC was selected because it provides an objective mechanism for determining criterion weights by considering both the variability of each criterion and the correlation between criteria. This is important in the present study because several quality assessment indicators, such as citation-related metrics and journal impact metrics, may overlap or correlate with one another (Mishra *et al.*, 2022). Hybridising EDAS with CRITIC therefore allows the ranking process to benefit from the simplicity and ranking capability of EDAS while incorporating objective criterion weights derived from the information contained in the decision matrix. This reduces excessive subjectivity and improves the robustness of the quality assessment process. Accordingly, a hybrid methodology was utilised for solving the MADM problem by combining EDAS and CRITIC methods.

Steps of applying the proposed methodology for quality assessment of the identified records is explained as follows (Balali and Yunusa-kaltungo, 2025b; Li *et al.*, 2021):

Step 1: construction of the decision matrix (X) as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

where x_{ij} denotes the performance of the i th record with respect to the j th criterion.

Also, the number of selection criteria and records are denoted by n and m , respectively.

Step 2: normalisation of matrix X to determine the average solution as follows:

$$AV_j = \frac{\sum_{i=1}^n x_{ij}}{n} \quad (2)$$

Step 3: calculation of positive (PDA) and negative (NDA) distances of all the elements of matrix X from the average solution is conducted in this step. Assume beneficial and non-beneficial criteria are denoted by BC and NBC, respectively.

Then, PDA and NDA are calculated as follows:

$$PDA_{ij} = \begin{cases} \frac{\max(0, x_{ij} - AV_j)}{AV_j}, & j \in BCs \\ \frac{\max(0, AV_j - x_{ij})}{AV_j}, & j \in NBCs \end{cases} \quad (3)$$

$$NDA_{ij} = \begin{cases} \frac{\max(0, AV_j - x_{ij})}{AV_j}, & j \in BCs \\ \frac{\max(0, x_{ij} - AV_j)}{AV_j}, & j \in NBCs \end{cases} \quad (4)$$

Step 4: calculation of the standard deviation σ_j and the correlation coefficient ρ_{ij} between criteria as follows:

$$\sigma_j = \sqrt{\frac{1}{m} \sum_{i=1}^m (x_{ij} - \bar{x}_{ij})^2} \quad (5)$$

$$\rho_{ij} = Cov(X_i, X_j) / (\sigma_i, \sigma_j) \quad (6)$$

Where the average value of alternative i is shown by $\bar{x}_{ij}$. Also, $Cov(X_i, X_j)$ denotes the covariance between row i and row j of the matrix X .

Step 5: calculation of the objective weights of the criteria as follows:

$$w_j = \frac{\sigma_j \sum_{i=1}^n (1 - \rho_{ij})}{\sum_{j=1}^n (\sigma_j \sum_{i=1}^n (1 - \rho_{ij}))} \quad (7)$$

Where the weights of criterion j is denoted by w_j .

Step 6: calculation of the weighted values of PDA and NDA , denoted by SP and SN , respectively, as follows:

$$SP_{ij} = \sum_{j=1}^m w_j PDA_{ij} \quad (8)$$

$$SN_{ij} = \sum_{j=1}^m w_j NDA_{ij} \quad (9)$$

Step 7: normalisation of the values of SP and SN , denoted by NSP and NSN , respectively, as follows:

$$NSP_{ij} = \frac{SP_i}{\max_i SP_i} \quad (10)$$

$$NSN_{ij} = \frac{SN_i}{\max_i SN_i} \quad (11)$$

Step 8: Calculation of the compromise score for alternatives (AS) as follows:

$$AS_i = \frac{NSP_{ij} + NSN_{ij}}{2} \quad (12)$$

2.4 Extraction of barriers and relationship analysis

In this stage, the included records were precisely investigated to extract the metaverse's adoption barriers, followed by generating a heatmap on the relationships among the identified barriers. Further information analysis is provided in Section 3.

2.5 Development of conceptual framework

A conceptual framework was then developed and suggested for wider adoption of metaverse. More specifically, this conceptual framework ensures a systematic transition from awareness to full-scale adoption of metaverse technologies through a

structured, step-by-step approach. Further information analysis is provided in Section 3.

3.0 RESULTS AND DISCUSSION

Figure 2 illustrates the trend in research publications related to the metaverse and associated technologies. The number of publications per annum remained relatively stable from 1995-2016, with only 34 studies published in 2016. However, the number of publications started to increase steadily from 2017, with a notable surge from 2020 onwards, reflecting a growing interest in metaverse technologies among researchers. By 2022 and 2023, the number of publications experienced a sharp rise, reaching 301 in 2023 and 418 in 2024, highlighting the rapid expansion of metaverse-related research. This surge is largely attributed to the increasing maturity of metaverse technologies and their application across various sectors. The observed trend of publications clearly demonstrates a strong and continuous growth in metaverse research, expecting more number of studies within the following years.

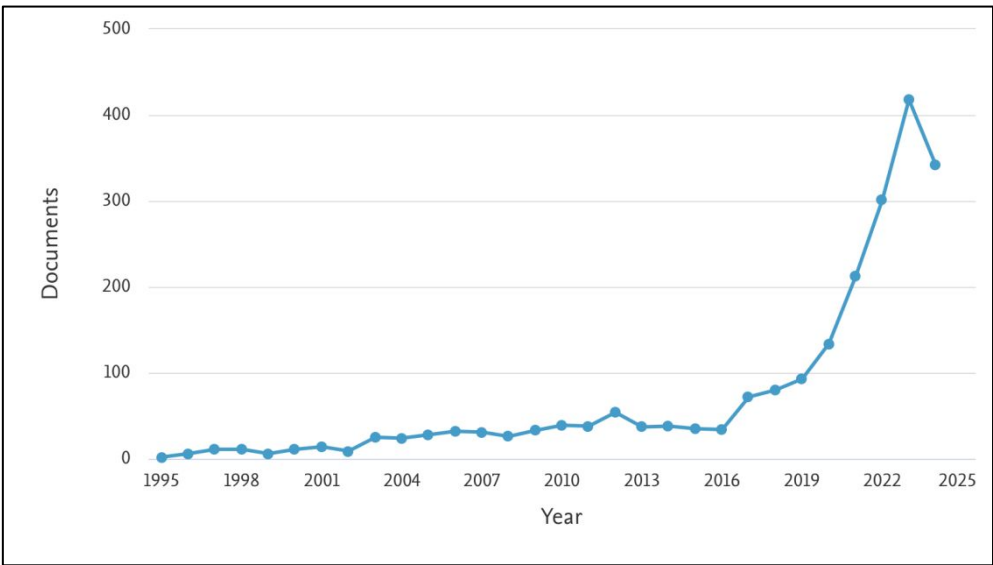


Figure 2 - Distribution of records in years

3.1 Journal co-citation analysis

Figure 3 illustrates the citation relationships and thematic relevance among 20 journals, highlighting both the influence of individual journals and the interactions between various publications. The metaverse is an inherently interdisciplinary research area, extending beyond

computer technology into various fields such as architecture, engineering, social sciences and design. The connections between journals and conferences suggest strong collaboration and knowledge exchange across these domains. Notably, key nodes such as "Automation in Construction," "Lecture Notes in Computer Science," "Advanced Engineering Information" and "IEEE Access" occupy central positions in the network, signifying their substantial influence in metaverse research. This network visualisation offers a comprehensive academic map, showcasing the complexity and interdisciplinary nature of studies conducted.

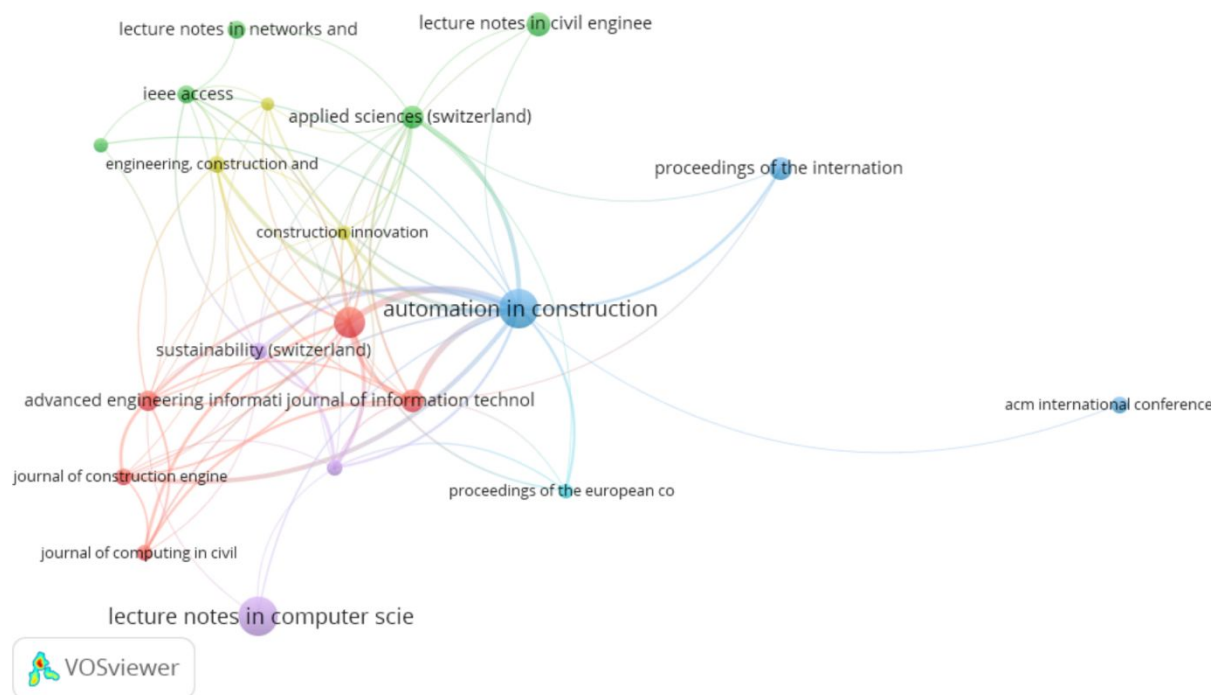


Figure 3 - Journal co-citation network of records

3.2 Keyword co-occurrence analysis

Figure 4 illustrates the co-occurrence relationships among keywords from 34 core publications, showcasing their interconnections within the academic literature. A minimum occurrence threshold of five was applied, identifying nine keywords that met this criterion. The connections between these keywords reveal how various concepts are discussed together in the research literature, with the thickness of the lines representing the frequency of co-occurrence, i.e. thicker lines indicate more frequent co-mention. Four distinct clusters illustrate the evolving landscape of metaverse-related research. The “metaverse” and “metaverses” form the conceptual

core, representing the foundation upon which other technological and industrial applications are built. Their strong connections to “virtual reality” and “augmented reality” highlight the pivotal role these technologies play in enabling immersive digital environments. The recent emergence of metaverse-related studies suggests a growing academic and industrial interest in expanding its applications beyond entertainment into sectors such as construction and architecture.

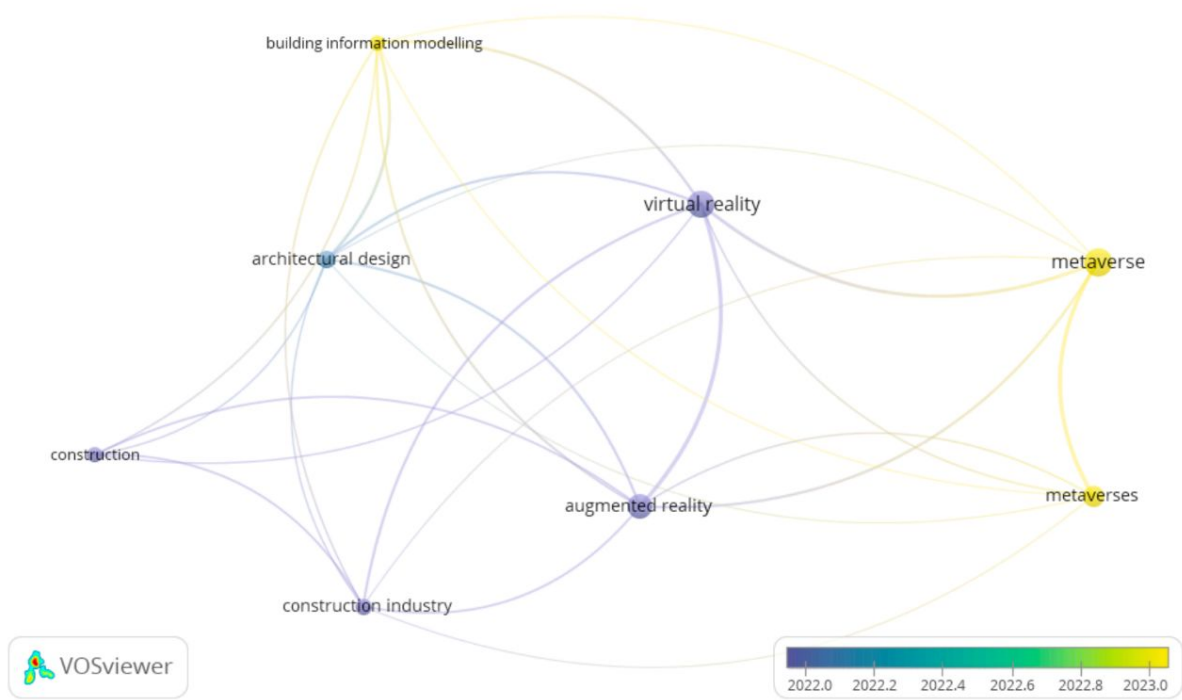


Figure 4 - Keyword co-occurrence map of records

The technological backbone of this research lies within “virtual reality”, “augmented reality”, “construction” and “construction industry”, which are clustered together due to their interdependent nature. VR and AR provide tools for creating and navigating digital spaces, while the construction sector represents a key area of application. Integrating these technologies is facilitating advancements in virtual site inspections, digital twin modelling and AR-assisted project management. While the connection between the “metaverse” and “construction” is evident, research in this area is embryonic, suggesting future studies will likely refine how these tools enhance productivity, safety and collaboration in construction workflows. Two isolated but significant clusters are “building information

modelling” and “architectural design” which indicate specialised yet underdeveloped research domains within the metaverse framework. As a crucial tool for digital construction, BIM has the innate potential to integrate seamlessly with metaverse platforms for enhanced design collaboration and real-time project simulation. Similarly, architectural design stands alone in the diagram, reflecting a growing but fragmented interest in how immersive digital environments can transform architectural visualisation and planning. As research progresses, these fields will likely become more interconnected, leading to a more cohesive integration of metaverse technologies across digital modelling, construction, and industrial applications.

3.3 Country co-authorship analysis

The academic collaboration between different countries is visualised in Figure 5 considering the threshold of five to which clearly highlights key contributors to the identified records. Each node represents a country, with the connecting lines indicating collaborative relationships. In total, 9 countries are depicted as interconnected in metaverse research. The size of each node reflects the extent of a country's contribution to the field. Notably, the UK, China and US are prominent, signifying their substantial involvement and widespread international collaborations. The figure also reveals numerous links between European countries (such as the UK and France) and Asian countries (such as China and India), illustrating the strong presence of cross-regional collaboration within this area of study.

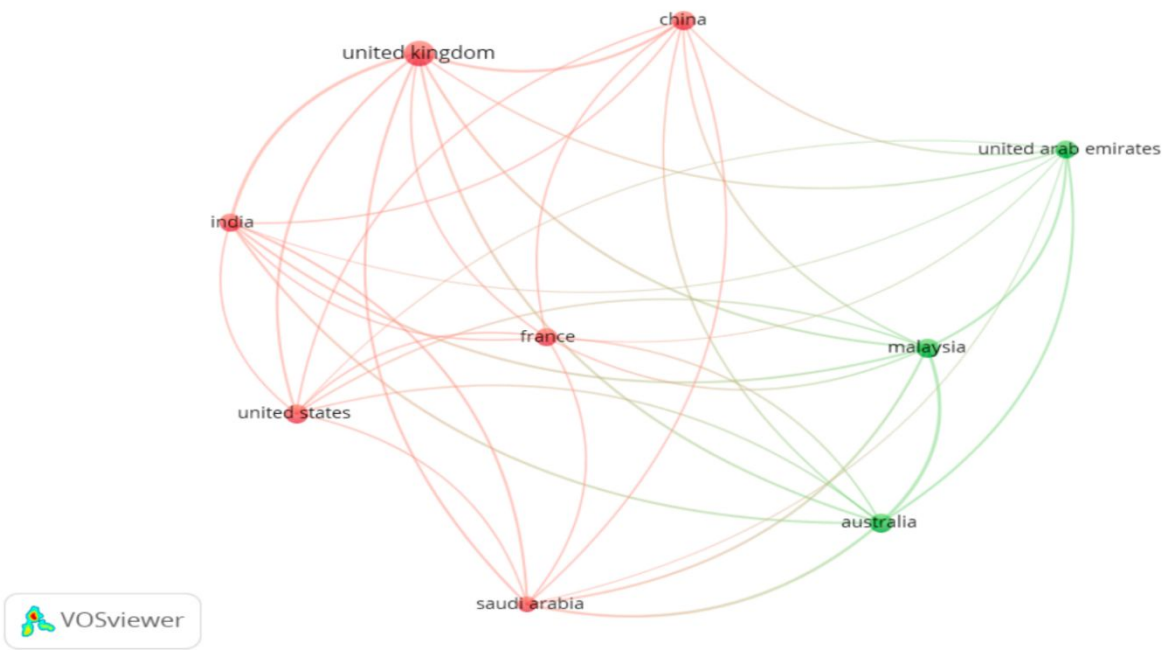


Figure 5 - Country co-authorship network of records

3.4 Researcher co-authorship analysis

The relationships among authors of the identified records is illustrated in Figure 6, with connecting lines representing their collaborative efforts. Among 145 authors, only four are interconnected, forming two distinct clusters. The red lines indicate a higher frequency of joint research and collaborative projects. Notably, Al-Sharafi M.A., Al-Emran M., and Iranmanesh M. co-authored a paper titled "Drivers and Barriers Affecting Metaverse Adoption: A Systematic Review, Theoretical Framework, and Avenues for Future Research" (Al-Sharafi *et al.*, 2023a), published in the International Journal of Human-Computer Interaction. Also, Al-Emran M. stands out as a central figure in this network, engaging in active collaborations with other researchers.

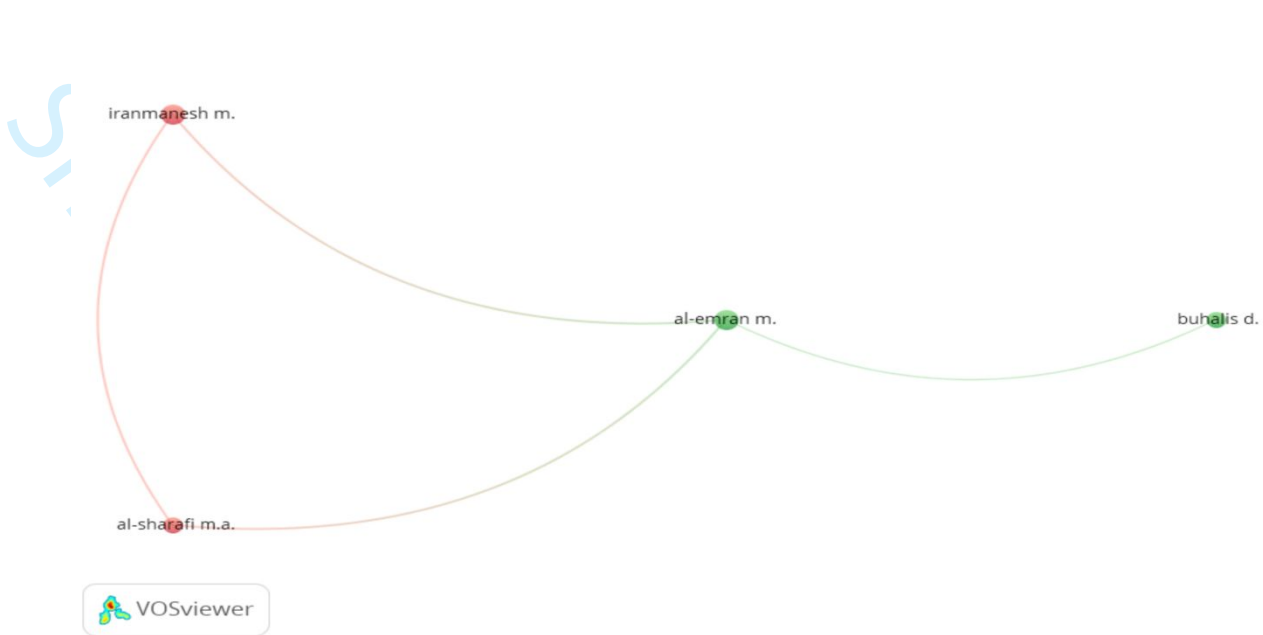


Figure 6 - Individual co-authorship network of records

3.5 Author co-citation analysis

Figures 7 and 8 display a network visualisation and a density visualisation, respectively, providing a detailed analysis of collaboration and citation patterns within the academic network. In the network visualisation, the size of the nodes represents the influence or impact of each author, while in the density visualisation, brighter regions indicate areas where collaboration or mutual citations are most concentrated. The visualisations highlight that Chen, J., and Wang, X., are pivotal authors within the network, as their research is widely cited, and they maintain direct connections with numerous other authors. Additionally, the density visualisation reveals a distinct cluster of collaboration involving Dwivedi, Y.K., Buhalis, D., and Hughes, I., demonstrating a strong degree of collaboration among these researchers.

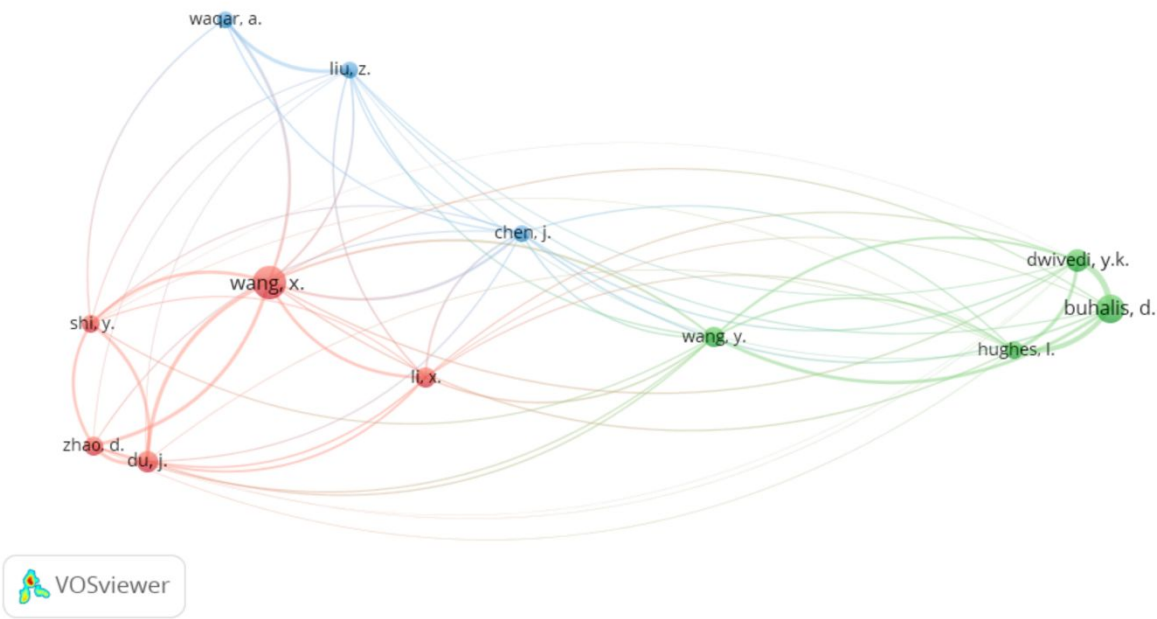


Figure 7. Author co-citation network map

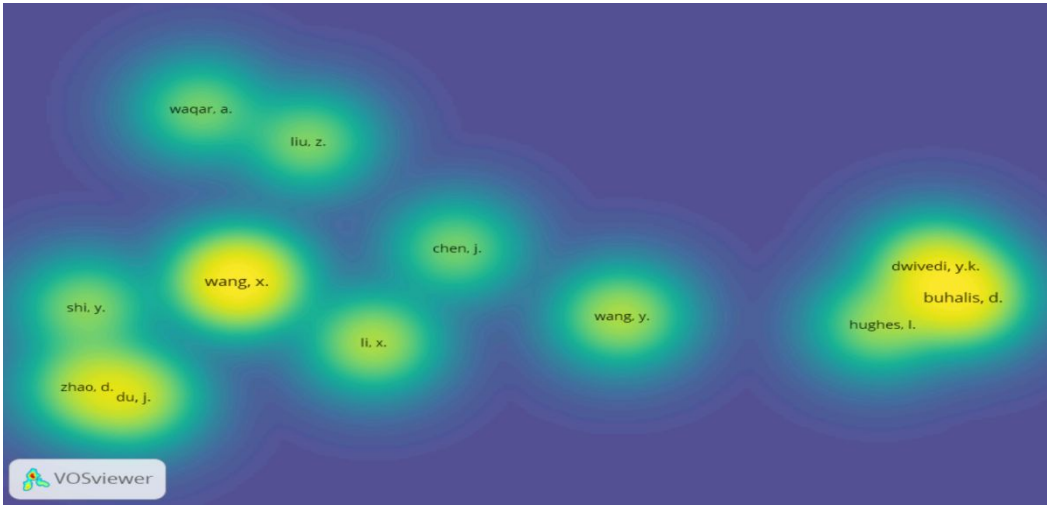


Figure 8. Author co-citation density heat map

3.6 Quality assessment

Quality assessment was conducted for the sample publications to examine their impact within the relevant body of knowledge. The hybrid EDAS-CRITIC approach

was utilised for this purpose and the results of the analysis are presented in this section. Table 2 illustrates the decision matrix, average solution values (AV) and the final weights of the selection criteria (W_j). Also, the final ranking of the records is presented in in Table 3.

According to Table 3, the top three records with the highest impacts are: 1) “Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy” by Dwivedi et al., International Journal of Information Management (Dwivedi *et al.*, 2022); 2) “Metaverse as a disruptive technology revolutionising tourism management and marketing” by Buhalis et al., Tourism Management (Buhalis *et al.*, 2023); and 3) “3D virtual worlds and the metaverse: Current status and future possibilities” by Dionisio et al., ACM Computing Surveys (Dionisio *et al.*, 2013). Identification of the top three studies significantly enhances the usability and practical applicability of the current SLR by ensuring that the most impactful works are systematically identified based on multiple criteria. Such knowledge directs researchers’ attention towards the studies that offer the most robust findings and substantial contributions to the field.

Table 2. Decision matrix, average solution values, and weights of the criteria

Code	C1	C2	C3	C4	C5	C6	C7	C8
LR1	2.00	4.00	4.00	9.60	1.85	3.00	19.20	4.00
LR2	3.00	3.00	3.00	3.80	1.06	4.00	9.10	4.00
LR3	0.00	3.00	3.00	3.10	0.72	0.00	3.40	4.00
LR4	10.00	4.00	4.00	9.60	1.85	9.00	19.20	4.00
LR5	12.00	4.00	4.00	11.00	2.35	14.00	20.40	4.00
LR6	10.50	4.00	4.00	10.50	1.92	8.00	220	4.00
LR7	3.50	3.00	3.00	2.90	1.09	5.00	7.50	4.00
LR8	2.50	3.00	3.00	3.60	0.74	2.50	8.10	4.00
LR9	0.00	0.00	0.00	0.00	0	0.00	1.40	3.00
LR10	17.00	4.00	4.00	6.00	1.33	29.50	12.10	4.00
LR11	20.00	4.00	4.00	7.10	1.81	32.00	13.30	4.00
LR12	98.00	4.00	4.00	10.90	9.81	137.00	24.10	4.00
LR13	46.00	4.00	4.00	9.50	2.04	60.50	30.00	4.00
LR14	9.00	4.00	4.00	8.70	1.8	12.50	17.40	4.00
LR15	16.50	4.00	4.00	9.70	1.52	20.50	20.40	4.00
LR16	2.00	3.00	3.00	3.10	0.72	2.00	3.40	4.00

LR17	5.50	3.00	3.00	1.70	0.45	9.00	4.20	4.00
LR18	9.00	3.00	4.00	3.40	0.85	10.50	9.00	4.00
LR19	7.00	4.00	4.00	4.60	1.23	7.00	10.30	4.00
LR20	0.50	3.00	3.00	3.40	0.87	1.50	9.80	4.00
LR21	72.50	3.00	3.00	2.50	0.67	118.00	6.80	3.00
LR22	3.00	3.00	3.00	3.00	0.63	2.50	7.50	4.00
LR23	7.00	3.00	3.00	3.20	0.68	7.00	5.20	3.00
LR24	7.33	4.00	3.00	2.50	0.56	13.33	5.30	3.00
LR25	10.67	4.00	4.00	9.90	2.74	15.33	21.20	4.00
LR26	229.33	4.00	4.00	20.10	5.74	353.33	53.10	4.00
LR27	4.33	4.00	4.00	9.60	1.85	6.00	19.20	4.00
LR28	25.33	4.00	4.00	9.60	1.85	33.67	19.20	4.00
LR29	8.25	4.00	4.00	9.60	1.85	9.25	19.20	4.00
LR30	17.80	4.00	4.00	4.10	0.87	22.60	8.70	4.00
LR31	8.67	4.00	4.00	9.60	1.85	11.17	19.20	4.00
LR32	20.83	4.00	4.00	9.60	1.85	24.33	19.20	4.00
LR33	8.67	4.00	3.00	2.50	0.56	14.50	5.30	3.00
LR34	30.83	4.00	4.00	23.80	5.05	49.83	33.20	4.00
AV	21.43	3.56	3.53	7.11	1.79	30.83	14.90	3.85
W_j	0.1084	0.1204	0.1204	0.1100	0.0944	0.1114	0.0795	0.2794

Table 3. Final ranking of the records

Code	SP_i	SN_i	NSP_i	NSN_i	AS_i	Rank
LR1	0.10	0.20	0.03	0.72	0.3781	20
LR2	0.01	0.34	0.00	0.52	0.2637	25
LR3	0.01	0.43	0.00	0.40	0.2022	33
LR4	0.10	0.14	0.03	0.81	0.4216	16
LR5	0.15	0.11	0.05	0.85	0.4505	11
LR6	0.13	0.14	0.05	0.81	0.4263	13
LR7	0.01	0.35	0.00	0.51	0.2547	26
LR8	0.01	0.37	0.00	0.48	0.2404	28
LR9	0.00	0.71	0.00	0.00	0.0000	34
LR10	0.04	0.08	0.01	0.89	0.4499	12
LR11	0.05	0.02	0.02	0.98	0.4969	7
LR12	1.34	0.00	0.47	1.00	0.7359	2
LR13	0.40	0.00	0.14	1.00	0.5699	4
LR14	0.08	0.13	0.03	0.82	0.4227	14
LR15	0.10	0.08	0.04	0.89	0.4645	8
LR16	0.01	0.41	0.00	0.42	0.2143	32

LR17	0.01	0.40	0.00	0.44	0.2242	31
LR18	0.03	0.29	0.01	0.60	0.3035	22
LR19	0.04	0.25	0.01	0.65	0.3338	21
LR20	0.01	0.37	0.00	0.48	0.2402	29
LR21	0.57	0.20	0.20	0.72	0.4604	9
LR22	0.01	0.39	0.00	0.46	0.2302	30
LR23	0.00	0.36	0.00	0.50	0.2490	27
LR24	0.01	0.33	0.01	0.54	0.2714	24
LR25	0.16	0.11	0.06	0.85	0.4511	10
LR26	2.85	0.00	1.00	1.00	1.0000	1
LR27	0.10	0.18	0.03	0.75	0.3939	18
LR28	0.13	0.00	0.05	1.00	0.5228	5
LR29	0.10	0.14	0.03	0.80	0.4161	17
LR30	0.04	0.17	0.01	0.76	0.3874	19
LR31	0.10	0.14	0.03	0.81	0.4224	15
LR32	0.10	0.03	0.03	0.96	0.4989	6
LR33	0.01	0.32	0.01	0.55	0.2791	23
LR34	0.65	0.00	0.23	1.00	0.6145	3

3.7 Extraction of the barriers

Following detailed investigation of the identified studies, 17 barriers to the adoption of the metaverse in the construction industry were identified and categorised into five dimensions: political, economic, social, technological and cultural barriers, as shown in Figure 9. This categorisation was adopted because the barriers extracted from the reviewed literature clustered most clearly around governance and policy conditions, economic feasibility, social acceptance, technological readiness and cultural/organisational behaviour. Although this structure is informed by macro-environmental thinking, it is not presented as a full PESTEL framework. Therefore, legal and environmental issues were not treated as separate categories unless they emerged as distinct barrier groups across the reviewed studies. Instead, legal issues are discussed within the political and social dimensions, particularly in relation to policy uncertainty, standardisation, legal disputes, data privacy and security. Environmental issues are discussed in relation to sustainability-oriented applications, future research pathways and the wider implications of metaverse adoption, rather than as a standalone adoption barrier category.

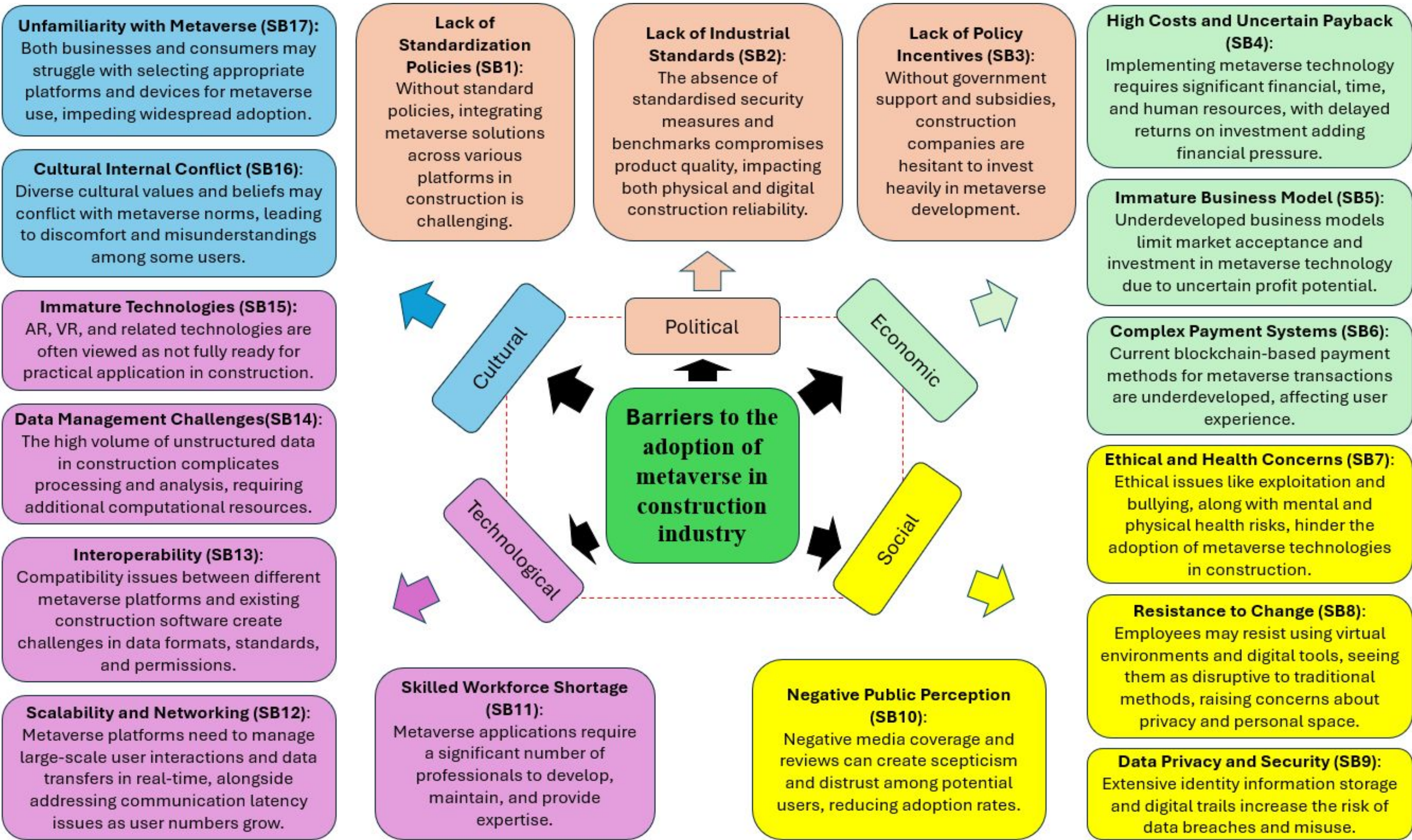


Figure 9 - Identified barriers to the adoption of metaverse in construction industry based on the adopted five-category classification

3.7.1 Political barriers

Metaverse adoption in construction industry faces significant political barriers that may severely limit its potential development. First, a notable lack of standardised policies makes the integration of metaverse solutions across different platforms extremely challenging (Chen *et al.*, 2024; Hadavi and Alizadehsalehi, 2024a; Koohang *et al.*, 2023; Mkedder and Das, 2024). Many stakeholders and complex economic activities are prone to legal disputes in the absence of a unified policy (Koohang *et al.*, 2023). Second, scant industry standards engenders a lack of uniform security measures and benchmarks, which affects product quality and compromises reliability (Chen *et al.*, 2024). This paucity of standards also hinders regulators providing effective oversight and management, further exacerbating potential risks. Finally, the lack of policy incentives, such as government support and subsidies, has led to a reluctance on the part of construction companies to invest heavily in metaverse development (Chokwitthaya *et al.*, 2020; Hadavi and Alizadehsalehi, 2024a). The development and implementation of metaverse technologies require high up-front investment in technology development, equipment procurement and professional training.

3.7.2 Economic barriers

Economic challenges are a common hurdle for most companies. First, the adoption of the metaverse requires a large investment of capital, time and human resources, and the uncertain return on investment further increases the economic pressure on enterprises (Chen *et al.*, 2024; Hennig-Thurau *et al.*, 2023). Many companies may be wary of investing due to the large initial investment and long payback period. Second, immature business models limit market acceptance and investment in metaverse technologies (Chen *et al.*, 2024). Due to the lack of clear profit models and business cases, companies have difficulty in foreseeing the profit potential of the metaverse. Finally, the current blockchain-based payment system is not perfect, which harms the economic system and user experience (Dwivedi *et al.*, 2022). The complexity of payment systems not only increases transaction costs but can also lead to social issues such as security and trusts.

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3.7.3 *Social barriers*

Ethical and health considerations are a major deterrent because the application of metaverse may bring about issues such as exploitation and bullying (Chen et al., 2024). Moreover, prolonged use of virtual environments may negatively affect users' mental and physical health (Chen et al., 2023). Employee resistance to change is also a major challenge because many employees may resist the use of virtual environments and digital tools, believing that these technologies will interfere with their existing work patterns (Dallasega et al., 2023). Data privacy and security issues cannot be ignored either. Metaverse technologies require the storage of large amounts of identity information and digital footprints, which increases the risk of data leakage and misuse (Al-Sharafi et al., 2023b). Sensitive data (such as construction project design and financial information), and any data leakage could have serious business and legal consequences. In addition, negative media coverage and comments about the metaverse may engender scepticism and distrust among potential users (Al-Sharafi et al., 2023b).

It should be noted that data privacy and security also carry legal implications, particularly in relation to data ownership, confidentiality, cybersecurity compliance and accountability for sensitive project information. However, these issues were retained within the social category in this study because the reviewed literature mainly discussed them in relation to user trust, stakeholder confidence, risk perception and willingness to adopt metaverse-based platforms.

3.7.4 *Technical barriers*

A lack of skilled workers presents a significant challenge because developing, maintaining and implementing the metaverse requires skilled professionals (Davila Delgado et al., 2020). Scalability and networking challenges are also significant technical obstacles. As the number of users grows, metaverse platforms must handle large-scale user interactions and real-time data transfers while addressing communication latency issues (Ali et al., 2021). This growth puts a high demand on network infrastructure and platform scalability. Interoperability issues cannot be ignored either because compatibility issues exist between different metaverse platforms and existing architectural software, including challenges in data formats, standards and permissions (Hadavi and Alizadehsalehi, 2024a). Data management

challenges present another significant barrier to the metaverse's adoption. Large volumes of unstructured data generated in the construction industry (e.g. 3D models, construction records, etc.) requires complex analysis, which increases the difficulty of data management (Wu *et al.*, 2024). Finally, the immaturity of the technology is also a major barrier (Pooladvand *et al.*, 2021). Although AR, VR and other related technologies are constantly evolving, there are still some technical bottlenecks and limitations to their practical application in construction (Hadavi and Alizadehsalehi, 2024a).

3.7.5 Cultural barriers

The adoption of metaverse also faces significant cultural barriers. Values and beliefs from different cultures may conflict with the norms of the metaverse, leading to discomfort and misunderstanding for some users (Mkedder and Das, 2024). Culture significantly influences consumers' willingness to engage with new technology platforms (Jiang *et al.*, 2022). The construction industry is relatively conservative, with traditional mindsets and work styles that are difficult to shift expediently (Forcael *et al.*, 2020). This intra-cultural conflict may hinder the widespread acceptance and application of the metaverse. In addition, unfamiliarity with metaverse technology among businesses and consumers increases the difficulty in selecting appropriate platforms and devices, thus affecting the metaverse's popularity (Ramadan, 2023).

3.7.6 Relationships of the identified barriers

Figure 10 provides a heatmap that demonstrates the interactions among the barriers revealed in this research. The strongest relationships among the other barriers are immature business model (SB5), unfamiliarity with metaverse (SB17) and interoperability issues (SB13). SB5 is a basic barrier that greatly influences building metaverse acceptance (Anshari *et al.*, 2022). Companies find it difficult to justify investments in metaverse technologies without a clear revenue model since uncertain financial returns and high initial costs (SB4) are apparent. Lack of a clear monetisation strategy also complicates digital asset ownership (SB6), licencing and financial transactions, so hindering companies' long-term planning ability [76]. Moreover, this uncertainty fuels organisational resistance to change (SB8) because companies hesitate to move from conventional building techniques to immersive

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digital environments devoid of obvious financial incentives. Lack of a business model also discourages investments in skilled workforce shortage (SB11), so producing a shortage of qualified professionals able to properly integrate metaverse solutions. SB17 is another important obstacle since low knowledge of its possible uses slows down industry acceptance (Nguyen *et al.*, 2024). Many builders and decision-makers doubt the advantages of the metaverse, which fuels negative public perception (SB10) and resistance to change (SB8). Education and training programs (SB11) suffer as businesses are reluctant to invest in upskilling staff members in developing technologies they do not completely grasp (Kim *et al.*, 2022). Furthermore, the lack of industry awareness lowers research and development (R&D) initiatives (SB15), so hindering developments in metaverse technologies. Consequently, the building sector remains reluctant to welcoming the digital transformation, so postponing general acceptance and application (Aljawder and Al-Karaghoul, 2024). Furthermore, SB13 presents serious technical difficulties for combining metaverse platforms with current building technologies including BIM, digital twins, and IoT. Standardised frameworks and industrial guidelines (SB1, SB2) absence results in scattered and incompatible digital systems, which makes it challenging to scale metaverse applications among many projects and stakeholders (McNamara *et al.*, 2024). These interoperability problems also affect data management (SB14) since different data formats and security concerns impede flawless cooperation. Furthermore, limiting the metaverse's capacity to operate across several platforms and so lowering its efficacy in large-scale building projects are scalability and networking constraints (SB12). Ignorance of interoperability issues will keep hindering industry-wide adoption and so restrict the full potential of metaverse technologies in construction.

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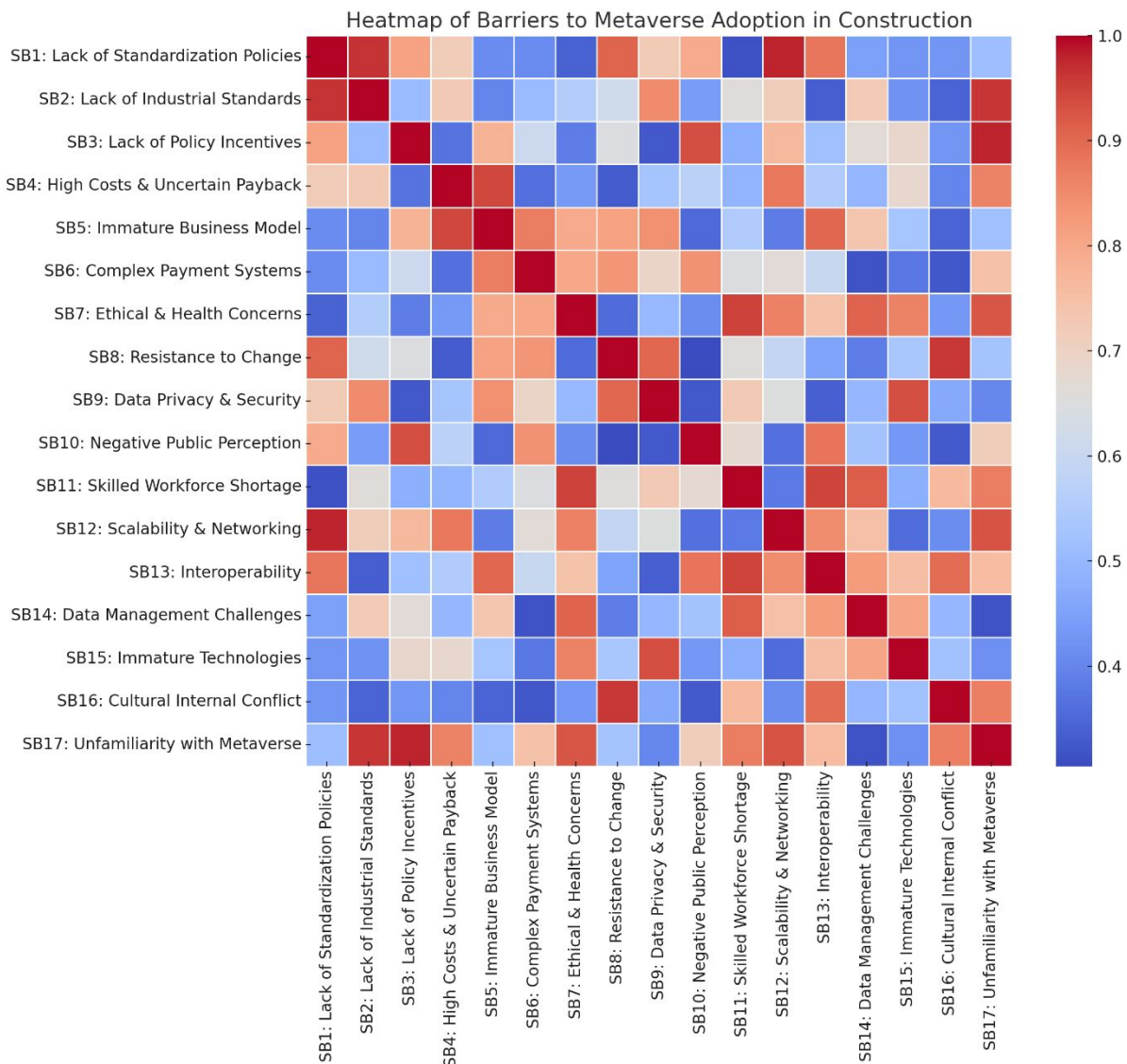


Figure 10 - The developed heatmap illustrating the relationships among the barriers

However, the least connections among the others are negative public opinion (SB10), immature technologies (SB15) and cultural internal conflict (SB16). Though it is a social and psychological barrier, SB10 has no direct bearing on industry rules, technical implementation or business feasibility. Although privacy, ethics and possible job displacement are issues when considering metaverse adoption in construction companies is mostly motivated by economic viability, return on investment (SB4) and technical feasibility (SB13) (Arowoiya *et al.*, 2024). Furthermore, as more successful applications transpire over time, public opinion can evolve and it becomes a secondary issue instead of a basic barrier that instantly prevents adoption. Though SB15 is a legitimate issue, they have little bearing on

economic and policy-related obstacles including business models (SB5), financial incentives (SB3) or scalability (SB12) (Yuan *et al.*, 2024). Construction companies do not necessarily wait for technology to be completely developed before investigating its application; they are already familiar with adopting emerging digital solutions (such as BIM and digital twins) even before complete maturity. Furthermore, many metaverse-related technologies (such as VR, artificial intelligence and blockchain) are already developing on their own, thus immaturity is only a transient obstacle rather than a strongly linked obstacle. Similarly, SB16 speaks of opposition inside building companies about the move from conventional approaches to digital, immersive environments (Wang *et al.*, 2024). Although this can provide organisational difficulties, it is essentially an internal problem inside companies rather than a structural barrier affecting sectors. Unlike financial concerns (SB4, SB5) or policy-related obstacles (SB1 and SB2), cultural resistance does not always stop investment, technical advancement or legislative changes. Moreover, change management and leadership can progressively overcome cultural resistance, hence is less important in determining the instant acceptance of metaverse technologies.

3.8 Development of a conceptual framework for the wider implementation of metaverse

A conceptual framework is developed to promote the construction industry's application of the metaverse (refer to Figure 11). This model guarantees a methodical shift from awareness to full-scale industry adoption by means of a disciplined, step-by-step iterative approach. The process begins with *Stakeholder Awareness & Training*, a foundational stage that focuses on educating and preparing all relevant stakeholders to create an environment conducive to technological (Succar, 2009). Once stakeholders understand and support the technological shift, the framework progresses to *Policy & Standardization Framework*, establishing clear and robust regulatory guidelines and protocols to ensure systematic and uniform technology integration across the construction industry. Building on these regulatory frameworks, the next stage is *Investment & Infrastructure Development*; this stage secures necessary funding and develops essential infrastructure, creating a stable foundation for subsequent technological implementations, assessed through metrics like Return on Investment (ROI) and infrastructure readiness. With adequate resources in place, the framework advances to *Technology Integration (AI, VR, Blockchain)*, focusing on the practical implementation of advanced digital

technologies. These technologies significantly enhance operational efficiency, reliability, and interoperability within construction processes (Khan *et al.*, 2024).

Successful technological integration necessitates robust *Data Security & Interoperability* — this stage ensures secure data transactions and seamless communication between integrated systems, addressing cybersecurity challenges critical for safeguarding sensitive information, measured by incident rates and interoperability efficiency metrics (Hadavi and Alizadehsalehi, 2024b). With data systems secured and effectively interconnected, the framework moves to *Digital Twin & BIM Integration*. Here, Digital Twin and Building Information Modelling (BIM) technologies improve project design accuracy and operational efficiency, significantly reducing costs and enhancing planning and decision-making processes. Further enhancing project quality, the framework incorporates *Simulation & Virtual Prototyping*; this stage uses advanced simulation and virtual prototyping techniques to proactively identify and rectify design errors, substantially minimizing costs and optimizing project timelines (Huang *et al.*, 2007). Building on successful simulations, the framework proceeds to real-world *Pilot Implementation in Construction*, where technology solutions are rigorously tested to validate performance and gather critical data on stakeholder satisfaction, initial cost benefits, and practical effectiveness.

Following successful pilot implementations, the process continues to *Performance Evaluation & Optimization*. Here, comprehensive assessments identify areas of improvement, refine technologies, and measure their impacts on productivity, safety, and sustainability, guiding continuous enhancements (Waqar *et al.*, 2023). The final stage, *Industry-wide Adoption & Scaling*, disseminates successful technological solutions broadly throughout the industry. This stage emphasizes metrics such as market penetration, scalability, and long-term operational efficiency, fostering widespread adoption and sustained industry benefits. Integral to the framework is a critical feedback loop that emphasizes continuous improvement. Insights and performance outcomes from advanced stages feed back into earlier stages, particularly influencing ongoing stakeholder training, policy adjustments, and technology refinements. This iterative loop ensures continuous adaptation, knowledge sharing, and improvement, fostering sustained success, resilience, and innovation within the construction sector.

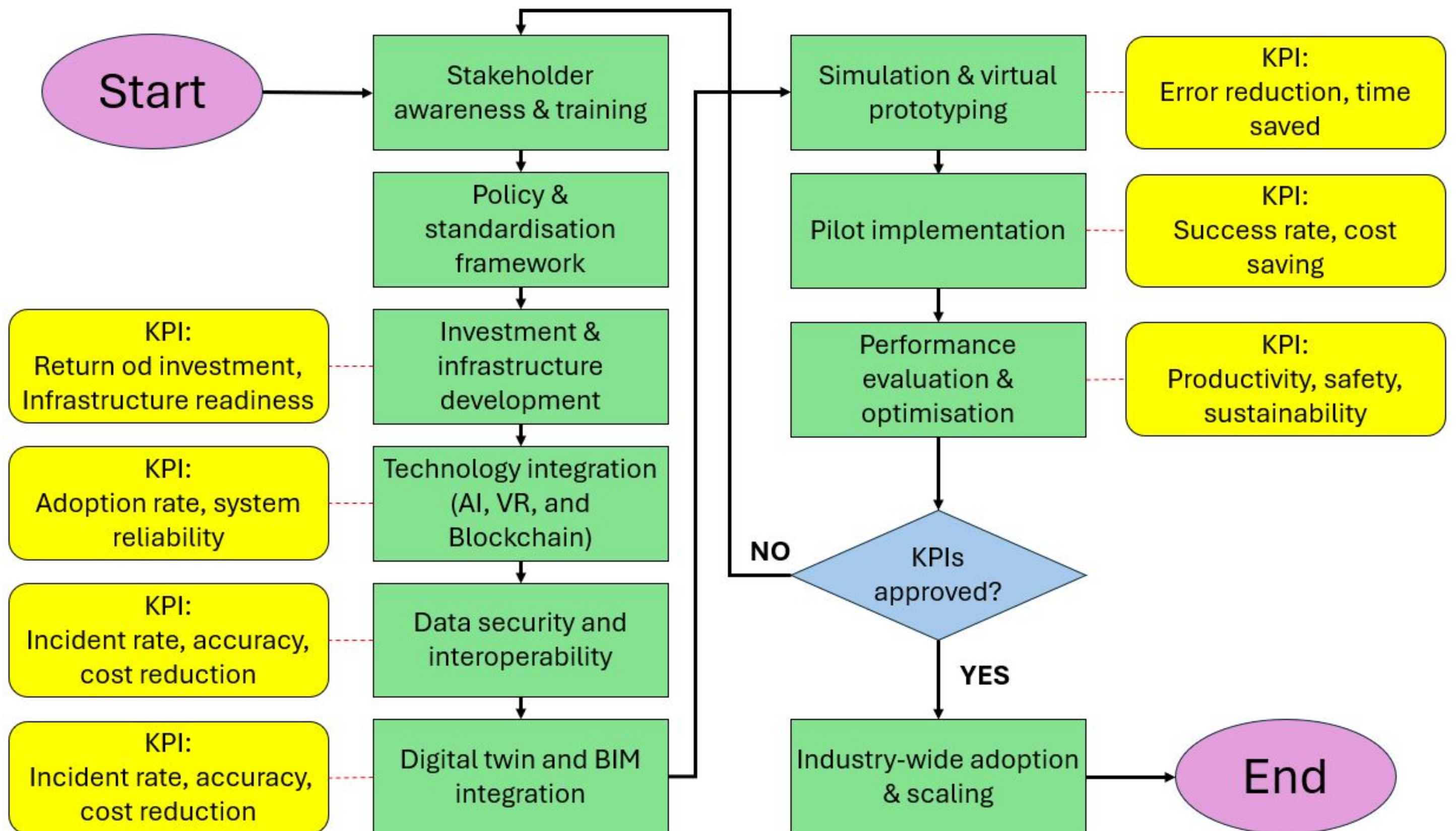


Figure 11 - Conceptual framework for metaverse implementation in construction project

4.0 LIMITATIONS OF PREVIOUS STUDIES AND FUTURE WORK

While previous studies have made valuable contributions to understanding the adoption of metaverse technologies in the construction industry, they exhibit several limitations that necessitate further investigation. A key shortcoming of prior research is the lack of a systematic approach in identifying and analysing barriers comprehensively. Most studies have focused on specific challenges, such as technical or economic constraints, without considering the interplay between multiple factors. This fragmented approach limits the holistic understanding of metaverse adoption and underscores the need for a more integrated perspective. Another limitation is the geographical concentration of studies which predominantly focus on developed countries, where infrastructure and digital literacy levels are relatively high. Consequently, the findings may not be entirely applicable to developing regions where financial constraints, regulatory challenges and limited technological accessibility pose additional barriers. Future research should aim to include diverse geographical contexts to provide a more globally relevant understanding of metaverse adoption challenges.

The absence of empirical validation is another notable gap in previous studies. While many investigations have relied on theoretical frameworks and qualitative analyses, there is a lack of data-driven research assessing the actual impact of metaverse adoption in the construction sector. Empirical studies, including case studies, pilot projects and longitudinal assessments are essential for validating theoretical insights and providing practical recommendations for industry stakeholders. Furthermore, the dynamic nature of metaverse technologies presents a challenge for researchers attempting to capture an accurate and up-to-date picture of the industry. Many studies become outdated rapidly as new technological advancements and policy developments emerge. Future research should adopt adaptive methodologies that allow continuous monitoring and reassessment of barriers to ensure relevance over time. Previous research has also tended to focus on identifying barriers rather than providing viable solutions for overcoming them. While recognising challenges is a crucial step, there is a pressing need for research that explores strategic frameworks and implementation roadmaps. Future investigations should emphasise the development of best practices, technological

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solutions, and policy recommendations that can facilitate the successful integration of metaverse technologies in the construction industry.

To advance knowledge in this field, future research should focus on several critical areas. The development of standardised frameworks is essential to guide the integration of metaverse technologies in construction. These frameworks should address interoperability, data security and ethical concerns while ensuring compliance with industry regulations. Additionally, exploring the synergy between metaverse technologies and other emerging innovations, such as digital twins, Blockchain, and artificial intelligence, can provide valuable insights into how these technologies can collectively enhance construction processes.

Another important area for future research is the quantitative assessment of metaverse adoption's impact on construction efficiency, cost savings and sustainability. While qualitative studies exist, empirical evidence is needed to measure the tangible benefits and drawbacks of metaverse implementation. Longitudinal studies tracking adoption trends over time will also be crucial in understanding how organisations adapt to and integrate metaverse technologies. Policy, regulatory and legal studies should also be prioritised to provide guidance for government agencies and industry leaders on fostering metaverse adoption, particularly in relation to data ownership, intellectual property rights, liability, cybersecurity obligations, contractual responsibility and international regulatory alignment. Research in this area should examine policy incentives, legal frameworks and international regulations that could facilitate the integration of metaverse applications into construction practices. Moreover, understanding the human factors influencing adoption, such as user experience, resistance to change and the psychological impact of working in virtual environments, will be vital for ensuring successful implementation.

Finally, the potential of metaverse technologies in promoting sustainable construction practices should be explored. At the same time, future research should also assess the environmental burden of metaverse adoption, including the energy demand of cloud infrastructure and data centres, the lifecycle impact of VR/AR

hardware, and the potential generation of electronic waste. A summary of all the existing gaps and future research pathways is illustrated in Figure 12.

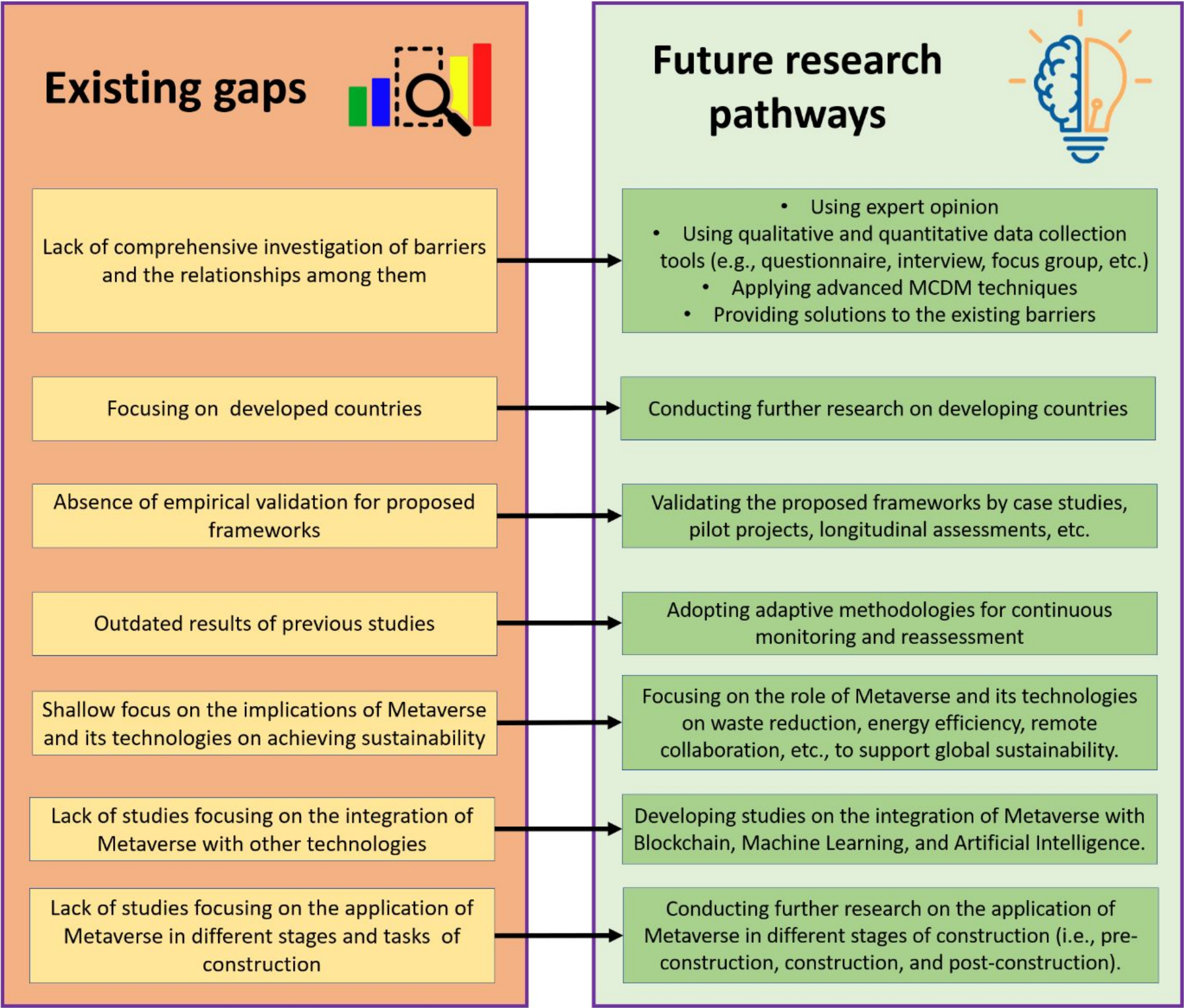


Figure 12 - Existing gaps and future research pathways

By addressing these research gaps, future studies can significantly contribute to enhancing the understanding and implementation of metaverse technologies in construction. This, in turn, will facilitate their widespread adoption, leading to improved efficiency, collaboration, and sustainability within the industry.

5.0 CONCLUSION

The metaverse presents a transformative opportunity for the construction industry by enabling immersive virtual environments for planning, design coordination, stakeholder collaboration, training, simulation, remote inspection and project execution. However, the slow adoption of metaverse technologies indicates that technological availability alone is insufficient to secure industry-wide transformation. This study therefore conducted a systematic literature review incorporating scientometric analysis, quality assessment of selected records, identification and categorisation of adoption barriers, analysis of relationships among barriers, development of a conceptual framework for wider implementation, and discussion of future research pathways. The findings show that metaverse adoption in construction is constrained by a combination of political, economic, social, technological and cultural barriers, including high implementation costs, regulatory uncertainty, lack of standardisation, technological immaturity, resistance to change, interoperability issues, immature business models and limited familiarity with metaverse applications.

A key thought-provoking observation emerging from this review is that the most influential barriers are not necessarily those that appear most visible at the point of implementation, but those that shape the wider conditions under which implementation becomes possible. In particular, interoperability issues, immature business models and unfamiliarity with the metaverse appear to operate as systemic barriers because they influence several other technical, organisational and commercial challenges. Interoperability problems restrict the integration of metaverse platforms with BIM, digital twins, IoT systems and existing project information environments. Immature business models weaken the commercial rationale for investment, making it difficult for construction firms to justify expenditure on hardware, software, training and organisational change. Similarly, unfamiliarity with the metaverse reduces stakeholder confidence, reinforces

resistance to change and limits demand for experimentation. Therefore, future adoption should not be understood merely as a technical transition from conventional tools to immersive environments, but as a socio-technical and commercial transformation requiring coordinated action across industry, policy and research.

For industry practitioners, the findings suggest that metaverse adoption should begin with targeted, low-risk pilot applications rather than immediate full-scale implementation. Construction firms can use the identified barriers as a diagnostic checklist to evaluate organisational readiness, investment priorities and implementation risks before adopting metaverse-based systems. Particular attention should be given to pilot projects that test interoperability between metaverse environments, BIM models, digital twins and project management platforms. Such pilots can generate evidence on productivity gains, error reduction, safety improvement, training effectiveness and cost savings. They can also help firms develop more mature business cases by clarifying where metaverse applications generate value, whether through reduced rework, improved coordination, enhanced stakeholder engagement, remote collaboration, or better lifecycle asset management. In this respect, the conceptual framework proposed in this study can support practitioners in moving from awareness and training to policy alignment, infrastructure investment, technology integration, pilot implementation and eventual scaling.

For policymakers and professional bodies, the findings highlight the need to create an enabling environment for responsible metaverse adoption in construction. Policy interventions should prioritise the development of interoperability standards, data governance protocols, cybersecurity requirements, ethical guidelines and procurement mechanisms that encourage experimentation while protecting project stakeholders. Public-sector clients can play an important role by supporting demonstrator projects, funding innovation testbeds and embedding digital-readiness requirements into procurement frameworks. Targeted incentives, such as innovation grants, tax relief, training subsidies and collaborative industry-academic programmes, could also reduce the perceived risk of investment and accelerate capability development among small and medium-sized construction firms. Without

such coordinated support, the metaverse may remain limited to isolated experimental applications rather than becoming an integrated component of construction project delivery.

Future research should build directly on the barriers identified in this review by designing and testing targeted interventions. First, studies should examine interoperability solutions that connect metaverse platforms with BIM, digital twins, common data environments and IoT-enabled construction systems using open data standards and cross-platform protocols. Second, future work should develop and validate business models for metaverse adoption, including cost-benefit models, return-on-investment frameworks, lifecycle value assessments and procurement models suitable for different project sizes and organisational contexts. Third, research should investigate how unfamiliarity with the metaverse can be reduced through education, professional training, immersive demonstrations, serious games, living labs and industry-academic knowledge transfer. Fourth, longitudinal and empirical studies are needed to evaluate whether these interventions actually improve adoption readiness, user acceptance, productivity, safety, sustainability and collaboration outcomes over time. Finally, future studies should examine how metaverse adoption differs across developed, emerging and developing economies, as the feasibility of interventions may vary according to digital infrastructure, regulatory maturity, workforce skills and investment capacity.

Ultimately, this study contributes to the literature by moving beyond the identification of metaverse adoption barriers towards a more integrated understanding of how these barriers interact and how they may be addressed. Its practical contribution lies in providing industry practitioners with a structured basis for readiness assessment and staged implementation, while offering policymakers a clearer view of the institutional and regulatory support required to enable adoption. By bridging the gap between conceptual discussion and implementation-oriented guidance, this study provides a foundation for future research and practice aimed at transforming the metaverse from an emerging technological concept into a practical instrument for improving efficiency, collaboration, safety and sustainability in construction.

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This study does not involve primary research with human participants or animals. The authors confirm that Grammarly was used solely for language refinement, grammar checking and improving readability during the preparation of this manuscript. No AI-based tool was used to generate research content, conduct analysis, interpret findings, draw conclusions, or produce the scholarly arguments presented in this study.

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✚ Re: Editor in Chief

1) Please note that it is now mandatory for all authors to clarify the ethical approval process for studies involving human participants or animals. If necessary, you may anonymise details, such as replacing the university name with "XXX." This paper does not involve primary research with human participants or animals. However, please explicitly state this in the acknowledgements section. Without full compliance with this requirement, your paper cannot be accepted for publication.

- ✓ We are extremely grateful for the time spent on our manuscript. Thank you for your valuable comment. The statement is added to the "ACKNOWLEDGEMENTS" section in this version of the manuscript.

2) Ensure quality, consistency, and readability of the figures and associated captions. Please pay particular attention to Figure 1 (Review framework), Figure 9 (Identified barriers), Figure 11 (Conceptual framework), and Figure 12 (Existing gaps and future research pathways). Ensure all text within these figures is legible and that the barrier labels and framework components are clearly visible.

- ✓ Thank you for your valuable comment. The mentioned figures are updated in this version of the manuscript.

3) Ensure you provide a structured abstract as the universal requirement of all Emerald journals. Kindly check the authors' guidelines for further information.

- ✓ Thank you for your valuable comment. The abstract in this version of the manuscript follows the structured abstract as requested. In order to double check this, latest published articles by SASBE were cross-checked (e.g. <https://doi.org/10.1108/SASBE-03-2024-0079>).

4) Consider referring to and citing where relevant articles published recently in SASBE so that the journal maintains continuity in the discourse it generates.

- ✓ Thank you for your valuable comment. The following articles from SASBE were cited:
 - Diaz Schery, C.A., Caiado, R.G.G., Ivson, P., Santos, R.S. and Thadeu Corseuil, E. (2026), "An integrative framework for BIM, digital twin and generative AI convergence in construction: a multi-dimensional analysis of synergies and enabling factors", Smart and Sustainable Built Environment, pp. 1–39, doi: 10.1108/SASBE-08-2025-0502.
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5) The references are incorrectly formatted, and all references need to follow the journal requirements with no exception. Follow the author guidelines for further details. Most importantly, all references should have at least one of the followings: doi, ISBN (books only), URL (even for journal articles, where there is no doi). When you are referring to URL, you must indicate the last access date. Any reference which has none of these, must be removed from the text and bibliography. ALL references must be sorted in alphabetic order.

- ✓ Thank you for your valuable comment. References were revised and are now according to the guidelines in this version of the manuscript.

6) The whole paper needs some thorough proofreading before final submission.

- ✓ Thank you for your valuable comment. Authors confirm that the revised manuscript has undergone rigorous proofreading.

7) The Conclusions section lacks thought-provoking observations, elaboration on the directions for further research and future applications of the presented results. While five future research pathways are identified in Section 4, the Conclusions section should more explicitly discuss the practical implications for industry practitioners and policymakers, and elaborate on how the identified barriers — particularly interoperability, immature business models and unfamiliarity with metaverse — might be addressed through targeted interventions in future studies.

- ✚ Thank you for your valuable comment. The Conclusion section has been substantially expanded to provide more thought-provoking observations, clearer practical implications and more explicit future research directions. In particular, the revised Conclusion now discusses how the three most interconnected barriers identified in the study, i.e. interoperability issues, immature business models and unfamiliarity with the metaverse, represent systemic barriers that affect technical integration, investment justification and stakeholder readiness. The revised section also explains how industry practitioners can use the findings as a diagnostic checklist for readiness assessment and staged pilot implementation, and how policymakers and professional bodies can support adoption through interoperability standards, data governance protocols, innovation testbeds, procurement mechanisms and targeted incentives. Furthermore, the Conclusion now elaborates future research directions focused on testing interoperability solutions, validating business models, designing education and training interventions, and conducting longitudinal empirical studies across different economic and regulatory contexts.

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8) When you upload your revisions, please make sure that you submit a clean version (without track-changes), a track-changes version, and a table clearly indicating all changes been made. Without this, I will need to return your revisions back to you.

✚ The authors confirm that a clean version, a version with changes highlighted, and a response-to-reviewers table have been submitted.

9) In the acknowledgements, please confirm whether AI-based tools (e.g., ChatGPT, Grammarly) were used for drafting, summarising, or refining this manuscript. If AI assistance was used, specify which sections were AI-generated or AI-edited.

✚ Thank you for your valuable comment. The required statement has been added to this version of the manuscript.

Re: Reviewer 1 Comments

1. Originality: Does the paper contain new and significant information adequate to justify publication?: The manuscript needs stronger justification and discussion WHY there is a need to explore metaverse concept in construction industry; especially how it could facilitate 'execution of construction projects'. It is important that the authors explained the 'metaverse' concept in more detail in the introduction section.

- ✓ We are extremely grateful for the time spent on our manuscript. Thank you for your valuable comment. Introduction section has been revised to provide a clearer explanation of the metaverse concept and to strengthen the justification for investigating it in the construction industry. Specifically, the revised manuscript now explains the metaverse as an integrated, persistent and interactive digital environment that connects physical assets, project information, stakeholders and construction processes through technologies such as BIM, digital twins, AI, IoT, VR/AR and blockchain-enabled information management. The Introduction has also been expanded to explain why metaverse applications are particularly relevant to construction project execution, including their potential to support construction sequence rehearsal, constructability review, remote inspection, immersive safety training, site logistics simulation, real-time collaboration and project decision-making. These additions clarify the originality and practical significance of the study and strengthen the rationale for systematically investigating metaverse adoption barriers and implementation pathways in construction.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes, the research has conducted systematic literature review following the PRISMA protocol. However, more justification is required for only using Scopus database to identify relevant studies.

- ✓ Thank you for your valuable comment. Based on your request, Section 2.1 of the revised manuscript has been expanded to provide a clearer justification for using Scopus as the sole bibliographic database. The revised text explains that Scopus was selected because of its broad multidisciplinary coverage, strong relevance to construction management, BIM, digitalisation, engineering and built environment research, and its provision of consistent metadata for transparent filtering, reproducible screening and bibliometric extraction. The revision also clarifies that using a single database helped reduce duplication and improve consistency in the search strategy and screening process. To further mitigate the limitation of relying on one database, the manuscript explains that snowballing was undertaken to identify additional relevant studies not captured through the initial Scopus search.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes, the research has conducted systematic literature review following the PRISMA protocol.

However, the screening process needs to be explained in more detail how the authors screened the documents from 2320 articles to 27 articles. The eligibility assessment needs to be explained in more detail.

✓ Thank you for your valuable comment and for recognising the appropriateness of the systematic literature review approach and PRISMA protocol. In response to your recommendation, Section 2.1 has been revised to explain the screening and eligibility assessment process in greater detail and to align the description with the PRISMA flow presented in Figure 1. The revised manuscript now clarifies how the initial 2,320 records were reduced to 1,228 after removing duplicates and records outside the relevant subject areas, then to 135 after screening titles, abstracts and keywords for relevance to the metaverse and related technologies in construction, and then to 27 eligible studies after excluding records that did not focus on adoption barriers, challenges, limitations, constraints or implementation issues. The revised section also explains that snowballing added seven additional records, resulting in the final sample of 34 studies.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Good.

✓ Thank you for your positive assessment. We are pleased that the results were considered clearly presented and appropriately analysed.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: The conclusion section needs to be further expanded to explain the key benefit and novelty of this study.

✓ Thank you for your valuable comment. In response to your recommendation, the Conclusion section has been substantially expanded to better explain the key benefits, novelty and implications of the study. The revised Conclusion now clarifies that the study contributes by moving beyond the identification of metaverse adoption barriers towards an integrated understanding of how these barriers interact and how they may be addressed. It also highlights the practical value of the study for industry practitioners by explaining how the identified barriers can be used as a diagnostic checklist for organisational readiness assessment, investment prioritisation and staged implementation. Furthermore, the revised Conclusion now explains the implications for policymakers and professional bodies, particularly in relation to interoperability standards, data governance, cybersecurity, procurement mechanisms, innovation testbeds and targeted incentives. Additional discussion has also been added on future research directions, including empirical studies on interoperability solutions, business models, training interventions and longitudinal adoption outcomes. These revisions strengthen the explanation of the study's novelty and demonstrate more clearly how the findings bridge theory, practice and policy.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Good.

✓ Thank you for your valuable comment. Thank you for your positive assessment. We are pleased that the manuscript was considered clearly written and appropriate in terms of technical language, readability and communication quality.

 Re: Reviewer 2 Comments

* The snowballing exercise undertaken has been mentioned in the passing. A little more detail on how this was undertaken will make the work more robust to readers (lines 178-180).

✓ We are extremely grateful for the time spent on our manuscript. Thank you for your valuable comment. In response, Section 2.1 has been revised to provide further detail on the snowballing procedure. The revised manuscript now explains that backward snowballing was conducted after the initial eligibility assessment by examining the reference lists of the 27 eligible studies. Additional candidate studies were screened using the same eligibility criteria applied during the main review, namely relevance to metaverse-related or immersive technologies, connection to the construction/AECO context, and explicit discussion of adoption barriers, challenges, limitations or implementation issues. The revised section clarifies that seven additional records were identified through this process, increasing the final sample from 27 to 34 studies.

* A brief on scientometric analysis (the method) as relevant to literature reviews may be provided along with fundamental references to clarify the content and intent to readers (section 2.2).

✓ Thank you for your valuable comment. Section 2.2 has been revised to provide a clearer methodological explanation of scientometric analysis and its relevance to systematic literature reviews. The revised manuscript now explains scientometric analysis as a quantitative approach for examining the structure, development and relationships within a body of scientific literature. It also clarifies how scientometric analysis complements qualitative synthesis by mapping publication trends, influential sources, collaboration patterns, co-citation structures and keyword relationships. Fundamental references have been added to support this methodological explanation and to clarify why scientometric analysis is suitable for an emerging and interdisciplinary topic such as metaverse adoption in construction.

* A short justification of selecting the EDAS and CRITIC methods and then hybridising them for the research may be included in the methodology section. Though the development appears to be addressed, the reason for selecting these two methods out of a host of others, and then hybridising them appears to be missing, and needs to be justified.

✓ Thank you for your valuable comment. In response, Section 2.3 has been revised to provide a clearer justification for selecting and hybridising the EDAS and CRITIC methods. The revised manuscript now explains that EDAS was selected because it is suitable for ranking alternatives in multi-attribute decision-making problems by evaluating positive and negative distances from the average solution, making it appropriate for comparing literature records across heterogeneous quality and impact indicators. It also clarifies that EDAS is computationally efficient and less demanding than older pairwise-comparison-based methods when several criteria and alternatives are involved. CRITIC was selected because it objectively determines criterion weights by considering both criterion variability and inter-criteria correlation, which is particularly relevant because citation-based and journal-quality indicators may overlap. The revised section further explains that hybridising EDAS and CRITIC enables the

quality assessment to combine EDAS's ranking capability with CRITIC's objective weighting mechanism, thereby reducing excessive subjectivity and improving the robustness of the results.

* The PESTEL or PESTLE framework is typically employed to identify and manage external macro-environmental factors that can impact a project, business, or sector. In the case of this paper, the legal (L), and Environmental (E) issues appear to not have been included. Is there a reason for truncating this framework. If so, can it be justified. If not, then it would be good to include these elements of the framework in the work.

- ✓ Thank you for your valuable comment. We agree that the relationship between our categorisation and the conventional PESTEL/PESTLE framework required clarification. In response, Section 3.7 has been revised to explain that the study does not claim to adopt a full PESTEL framework. Instead, the barriers were categorised according to the themes that emerged most clearly from the systematic review, namely political, economic, social, technological and cultural barriers. The revised manuscript now clarifies that legal and environmental issues were not ignored; rather, they were not treated as separate categories because they did not emerge as distinct barrier groups across the reviewed studies. Legal issues are now explicitly discussed as being embedded within the political and social dimensions, particularly in relation to policy uncertainty, legal disputes, data privacy, security, accountability and stakeholder trust. Environmental issues are also clarified in Section 4, where the future research agenda now discusses both the sustainability benefits of metaverse adoption and the need to examine potential environmental burdens such as cloud/data-centre energy demand, VR/AR hardware impacts and electronic waste. These revisions justify the adopted five-category classification while addressing the reviewer's concern regarding legal and environmental considerations.

1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes.

- ✓ Thank you for your positive assessment. We are pleased that the originality and contribution of the manuscript were considered adequate to justify publication.

2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes.

- ✓ Thank you for your positive assessment. We are pleased that the manuscript was considered to demonstrate an adequate understanding of the relevant literature and to cite an appropriate range of sources.

3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes.

- ✓ Thank you for your positive assessment. We are pleased that the methodological design, theoretical basis and selected methods were considered appropriate.

4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Needs improvement.

- ✓ Thank you for your valuable comment. In response, the Conclusion section has been substantially revised to better integrate the study's results, implications and future research directions. The revised Conclusion now more explicitly ties together the scientometric findings, barrier identification, relationship analysis, conceptual framework and future research pathways. In particular, it discusses how interoperability issues, immature business models and unfamiliarity with the metaverse operate as systemic barriers that influence technical integration, investment decisions and stakeholder readiness. The revised section also provides clearer practical implications for industry practitioners and policymakers, including staged pilot implementation, readiness assessment, interoperability standards, data governance, procurement mechanisms, innovation testbeds and targeted incentives. Furthermore, the Conclusion now elaborates future research directions focused on testing interoperability solutions, validating business models, improving stakeholder familiarity through training and living labs, and conducting longitudinal empirical studies. These revisions strengthen the connection between the results and the concluding arguments of the manuscript.

5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: The paper clearly identifies a major component of a contemporary issue impacting the productivity and efficiency of the construction sector, i.e. technology absorption, and within it the use of metaverse. In doing so, it bridges a gap between theory and practice, and provides a direction for increasing technology adoption in a sector traditionally considered a laggard in the aspect. The results of the paper effectively define a pathway for improving the technical threshold of the construction sector, to catapult it in a space aligned with contemporary industrial sectors, specifically manufacturing. The findings of the paper point to these outcomes.

- ✓ Thank you for your positive and encouraging assessment. We are pleased that the manuscript was considered to bridge the gap between theory and practice and to provide a clear direction for increasing technology adoption in the construction sector. We appreciate your recognition that the study contributes to improving the sector's technological readiness and alignment with more digitally advanced industrial sectors.

6. Quality of Communication: Does the paper clearly express its case, measured against the technical language of the field and the expected knowledge of the journal's readership? Has attention been paid to the clarity of expression and readability, such as sentence structure, jargon use, acronyms, etc.: Yes, the paper is clearly written.

- ✓ Thank you for your positive assessment. We are pleased that the manuscript was considered clearly written and appropriate in terms of clarity of expression, readability and technical communication.