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# Immersive Technology and Building Information Modeling (BIM) for Sustainable Smart Cities

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**Abstract:** Research currently focuses on immersive technologies like virtual reality (VR), augmented reality (AR), and mixed reality (MR). However, there is limited exploration of their application in sustainable smart cities with Building Information Modeling (BIM), and there remains a lack of interdisciplinary integration within this domain aimed at fostering sustainable smart city development. Therefore, this paper aims to explore the development status of immersive technology and BIM in sustainable smart cities, identifying trends and research hotspots by employing a triangulation research method mixed with a quantitative method via bibliometric analysis and a qualitative method via content analysis to investigate the relationship between immersive technologies and BIM in sustainable smart cities. The results reveal a fragmented nature in the research on immersive technology and BIM in sustainable smart cities, with rapidly changing hotspots and new technologies following a cyclical pattern every 3 to 5 years. Two distinct cycles of growth were observed in the field over the last 10 years (2014–2023). The first cycle, from 2014 to 2017, represented modest growth, while the second cycle, from 2018 to 2022, showed rapid expansion, with the keywords AR, VR, MR, BIM, smart city, and smart city concept indicating the research hotspots. Immersive technologies and BIM, developed since 2017, have contributed to sustainable smart city construction. The emerging keywords AR, MR, and 360-degree VR have become research hotspots since 2021, particularly in collaborative construction. Future research trends include artificial intelligence, digitalization, AR, and MR, while building sustainability and intelligent construction have emerged as real-world applications. Additionally, this paper employs software tools to generate multidimensional knowledge maps to form a knowledge universe map at a "macro-knowledge" level followed by a "micro-knowledge" level comprising a standard knowledge system, such as lifecycle analysis, enhancing the objectivity and organization of the results and providing innovative references for future research.

**Keywords:** immersive technology; virtual reality (VR); augmented reality (AR); mixed reality (MR); building information modeling (BIM); sustainability; smart cities; lifecycle; knowledge map

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**Citation:** Liu, Z.; He, Y.; Demian, P.; Osmani, M. Immersive Technology and Building Information Modeling (BIM) for Sustainable Smart Cities. *Buildings* **2024**, *14*, 1765. https://doi.org/10.3390/buildings14061765

Academic Editor: Haifeng Liao

Received: 17 May 2024
Revised: 5 June 2024
Accepted: 7 June 2024
Published: 12 June 2024



## 1. Introduction

Immersive technology specifically refers to technologies that immerse users in the virtual environment, including virtual reality (VR), augmented reality (AR), and mixed reality (MR) [1], employ digital media, and integrate it with the natural world to provide sensory stimulation, such as visual, auditory, and tactile, resulting in simulating the real world and providing users with an immersive experience [1]. The development of Building Information Modeling (BIM) [2] has changed the traditional design paradigm of the architecture, engineering, and construction (AEC) industry. At present, although BIM has penetrated the entire lifecycle of buildings, there are still many challenges in its current application [3].

These challenges mainly cover technology, management, and user experience, of which the biggest challenge is its defect in scalability, interoperability, and remote collaboration [4,5], while unsatisfactory user experience [6] results in a decrease in work efficiency. To solve the long-term low productivity and insufficient performance of construction projects caused by these challenges, the AEC industry is actively seeking optimized solutions. The widespread adoption of digital technologies such as VR, AR, MR, artificial intelligence (AI), and digital twin brings unprecedented possibilities to BIM, making models more intelligent and digital, which significantly improves building performance and user experience [7–12], enhances dataflows for designers and users, and provides efficient and delightful intelligent building management [4].

Smart cities are a response to the challenges posed by urbanization, the digital revolution, and society's demand for more efficient and sustainable urban services, aiming to enhance the quality of life [13]. Smart cities, from their performance, features, and physical aspects, prioritize the interaction between the environment and human activities [14]. Despite the increasing attention given to immersive technologies in current research, limited efforts have been invested to explore the role of immersive technology and BIM in building sustainable smart cities. The inherent complexity and the need for new approaches to citizen engagement in smart cities that are required for the transformation of existing infrastructure [15], further highlight the significance of studying the contributions of immersive technology and BIM to smart city development and sustainability. Moreover, there is a lack of systematic investigation and analysis, resulting in one-sidedness and knowledge that limit the development and innovation in these fields. This knowledge gap restricts development and innovation in these fields. Consequently, this paper aims to examine the development status of immersive technology and BIM in the realm of sustainable smart cities, analyze emerging technologies and research hotspots, and identify future development trends.

## 2. Methodology

To achieve the aim of this paper, the following four research objectives are proposed: (1) explore the research background and current situation of immersive technology and BIM in sustainable smart cities; (2) evaluate the interrelationship between immersive technology and BIM in sustainable smart cities; (3) analyze the emerging technologies and research hotspots of immersive technology and BIM in sustainable smart cities; and (4) identify the contribution and development trend of immersive technology and BIM in sustainable smart cities.

As such, the research rationale of this paper, as shown in Figure 1, is underpinned by a "macro-knowledge" stage and a "micro-knowledge" stage. The "macro-knowledge" stage has two forms of knowledge at two levels (overlay knowledge mapping and time period knowledge mapping) presenting the knowledge universe, and these provide the basis for the exploration of bibliometric knowledge relations of all the related knowledge, such as specific knowledge network cluster, citation burst, and other detailed highlighted knowledge maps. These are linked to a "micro-knowledge stage" comprising a standard knowledge system, such as lifecycle assessment, to systematically generate knowledge and establish relationships.

The adopted research method is a triangulation method that is mixed with a quantitative method and a qualitative method, for which the research techniques for addressing the research rationale include five phases: (1) determine the research problem, (2) search the database of research literature, (3) define selection criteria and data quality standards, (4) conduct a macro-quantitative analysis, and (5) carry out a micro-qualitative analysis, of which phases 1 to 3 are for data collection and phases 4 and 5 are undertaken, as shown in Figure 2.

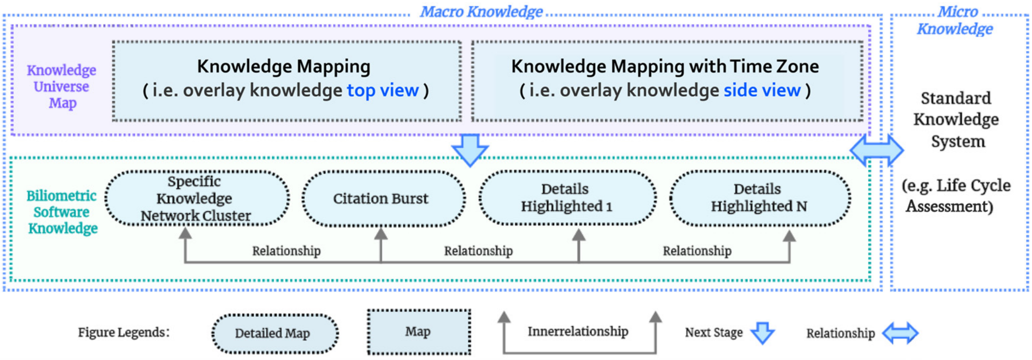


**Figure 1.** Research rationale (generated by the authors).

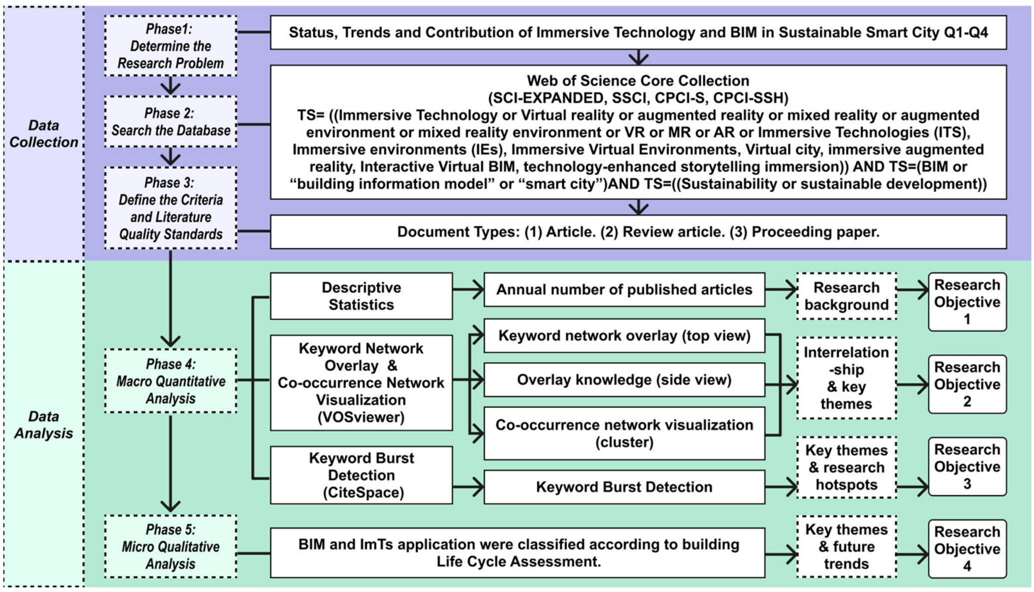


**Figure 2.** The flowchart of research techniques (generated by the authors).

### *2.1. Phase 1: Determine the Research Problem*

This paper seeks to determine the status, trends, and contribution of immersive technology and BIM in sustainable smart cities. This paper investigates four research questions: What is the research background of immersive technology and BIM development in the sustainable smart city (Q1)? What is the relationship between immersive technology and BIM within the context of a sustainable smart city (Q2)? What are the research hotspots of immersive technology and BIM in the sustainable smart city (Q3)? What is the contribution and development trend of immersive technology and BIM to sustainable smart cities (Q4)?

### *2.2. Phase 2: Search the Database*

Clarivate Analytics' Web of Science Core Collection (WoSCC), which is a comprehensive database consisting of ten sub-datasets, is increasingly being applied in academic research [16]. Hence, data from the WoSCC database were obtained. The retrieval process starts with the general keywords "immersive technology", "BIM", "sustainability", and "smart city", which are finally processed as "TS = ((Immersive Technology or VR or augmented reality or mixed reality or augmented environment or mixed reality environment or VR or MR or AR or immersive Technologies (ITS) Immersive environments (IEs), Immersive Virtual Environments, Virtual city, immersive augmented reality, Interactive Virtual BIM, technology-enhanced storytelling immersion)) AND TS = (BIM or building information model or smart city) AND TS = ((Sustainability or sustainable Development))". The search details include date ranges and the number of documents as follows: (1) date ranges from the year 2014 to 2023; (2) the number of initial documents is 67, and the final number is 65. A total of 65 data were obtained, which include the title, author, source, and abstract, and were exported as tab-separated files for subsequent quantitative analysis.

### 2.3. Phase 3: Define the Criteria and Quality Standards

The following criteria were established for filtering out irrelevant data during the automated retrieval processes: (1) repeated literature; (2) retracted publications; (3) literature not in English; (4) literature unrelated to immersive technology or BIM; and (5) literature types other than article, review article, or proceeding paper.

### 2.4. Phase 4: Macro-Quantitative Analysis

The focus of this phase is on the macroanalysis of the following three issues:

i. Issue one, which relates to Objective 1, is focused on exploring the research background of immersive technology and BIM in sustainable smart cities through descriptive statistics with the annual number of published articles, addressing research question Q1.
ii. Issue two, which is associated with Objective 2, is concentrated on identifying key themes and interrelationships of immersive technology and BIM in sustainable smart cities, which is achieved through keyword network overlay and co-occurrence network visualization via VOSviewer software tool 1.6.18, which is to evaluate the relationship between immersive technology and BIM in sustainable smart cities to achieve research question Q2.
iii. Issue three, which links to Objective 3, is set to analyze key themes of the emerging technologies and research hotspots of immersive technology and BIM in sustainable smart cities, which is achieved through keyword burst detection via the Citespace software tool 6.3 to address research question Q3.

All three issues were addressed via the macroquantitative analysis, assisted by bibliometric analysis software tools, i.e., VOSviewer 1.6.18 and Citespace 6.3, to intuitively explore the research field in the form of maps, knowledge structures, and research trends. The functionality of the VOSviewer software tool 1.6.18 is especially useful for displaying large bibliometric maps in an easy-to-interpret way [17], which were further enhanced by integrating the Citespace software tool 6.3 to demonstrate a clear and comprehensive representation of the structure and evolution of the research topic [18].

### 2.5. Phase 5: Micro-Qualitative Analysis

The focus of the micro-qualitative phase follows from the results of the previous macro-quantitative analysis, and the method used is content analysis. The key concepts, themes, and application techniques from the literature were manually categorized according to the research application and LCA frames, which were used to systematically analyze the content. The aim of the content analysis is to seek the key themes and future development trends of immersive technology and BIM in sustainable smart cities through lifecycle assessment (Objective 4), which is to address research question Q4.

## 3. Results

### 3.1. Literature Publications

A total of 65 documents were obtained, of which the number of publications and citation frequency were counted to indicate year-by-year changes, as shown in Figure 3. The number of articles on the topic of immersive technology and BIM in sustainable smart cities increased year by year since 2014, and the citation frequency of the articles showing a clear upward trend. Between 2014 and 2015, there were only two publications. From 2016, the number of publications and citation frequency grew rapidly, reaching 10 in 2017. After decreasing to two articles in 2018, the growth trend resumed in 2019. On the other hand, the frequency of citations has grown gradually, attaining 381 in 2022. The number of publications was cyclical from 2014 to 2017 and from 2017 to 2022, with a mini burst cycle period of four to five years.

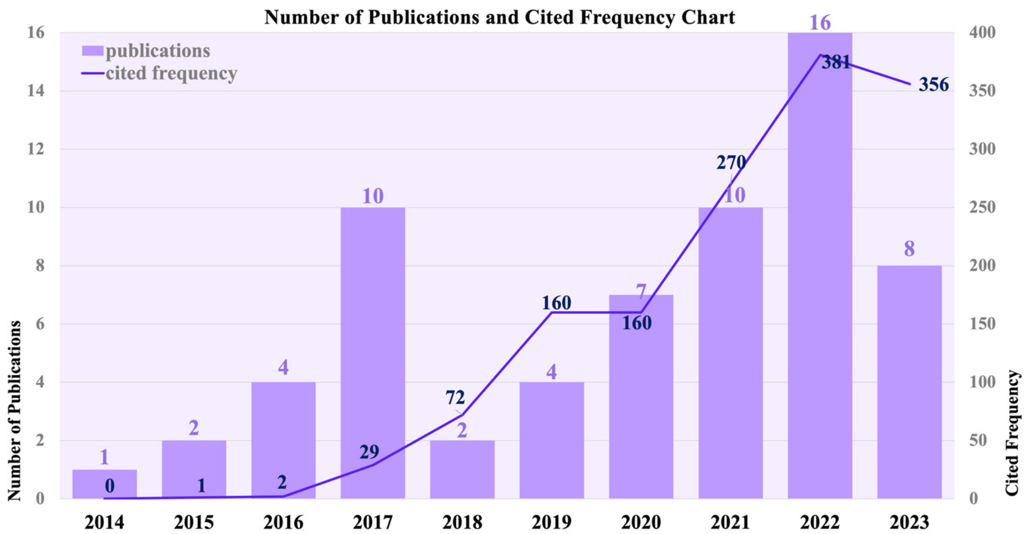


**Figure 3.** Number of publications and citation frequency of immersive technology and BIM on sustainable smart cities (generated by the authors).

## 3.2. Keyword Network Overlay (Time Period)

The key insights from the below figures and tables combine to show a more holistic and multidimensional understanding, one that accentuates the integral role of emerging immersive technologies in achieving sustainable design, construction, and operations throughout the building lifecycle in smart cities. The figures visualize the research hotspots and interdisciplinary connections, demonstrating how the focus on immersive technologies like VR, AR, and MR has shifted and diversified over time. The tables, on the other hand, synthesize and categorize the research methods and main application areas associated with these technology integrations, revealing how their convergence supports enhanced collaboration, sustainability, risk mitigation, and operational efficiency in the context of sustainable smart cities.

A total of 65 obtained data were imported into the VOSviewer software tool 1.6.18 for generating a keyword network overlay map (the overlay knowledge top view). The unit of analysis was set to "all keywords" with the counting method as "all counts", which produced a total of 2380 keywords. Due to the large number of keywords, the threshold was set to "3", resulting in 82 keywords that appear more frequently in the published articles since 2014, as shown in Figure 4. Each circle in the map represents a keyword, the size of the circle indicates how often the word appears in the literature, and the color of the circle transitions from dark blue to yellow, suggesting the chronological distribution of the keywords, determined by the year of the publication. The six colors in Figures 4–10 and Table 1 represent the average year of occurrence for each keyword. Dark blue, light blue, dark green, green, light green, and yellow represent 2017, 2018, 2019, 2020, 2021, and 2021, respectively. In VOSviewer, the "unit of analysis" refers to the type of bibliometric data being analyzed, such as documents, authors, journals, keywords, and countries. The "threshold" refers to the minimum criteria for inclusion in the visualization, specifying the minimum number of occurrences an item must have.

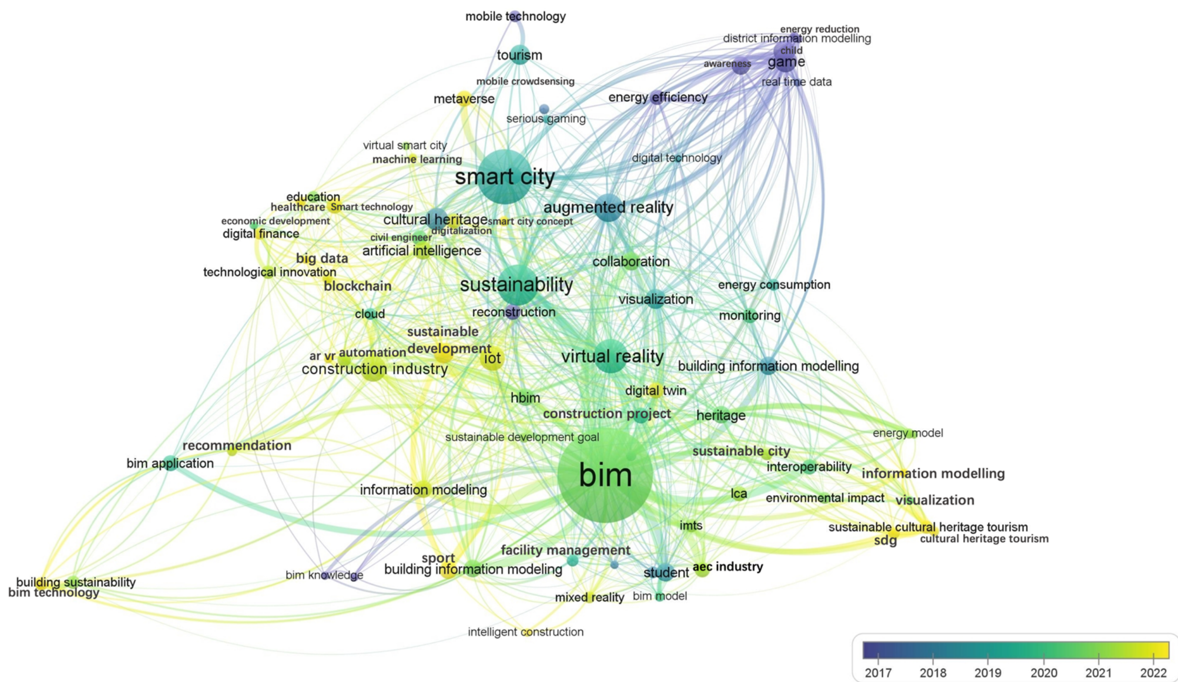


**Figure 4.** Keyword network overlay map (top view) of immersive technology and BIM in sustainable smart city via VOSviewer software tool 1.6.18 (generated by the authors).

**Table 1.** Top research keywords for technology and BIM in sustainable smart cities (generated by the authors).

| | | Keywords | | |
|---|---|---|---|---|
| **Year** | **Color [1]** | **Immersive Technology Related** | **Sustainable Smart City Related** | **Building Information Modeling Related** |
| 2017 | Dark blue | Real time data, Game, Awareness, Child | Energy reduction, Energy efficiency | District information modeling, Reconstruction |
| 2018 | Blue | Serious gaming | Cultural heritage, Mobile crowdsensing | Facility management |
| 2019 | Dark green | Augmented Reality, Virtual reality, Visualization, Student, Innovation, Cloud, Monitoring, Digital technology | Sustainability, Smart city, Energy consumption | Construction project |
| 2020 | Green | Artificial intelligence, Recommendation, IMTs, Technological innovation, BEM, Economic development, Visualization, Virtual smart city | Building sustainability, Energy model, Environmental impact, HBIM | BIM, Collaboration, AEC industry, LCA, Civil engineer |
| 2021 | Light Green | Digital twin, Informalization, Digital finance, Digitalization, Smart technology, Mixed reality, Blockchain | IOT, Sustainable development, Smart city concept | Construction industry, Interoperability |
| 2022 | Yellow | Big data, Metaverse, AR, VR | Sustainable cultural heritage, SDG, Sport, Cultural heritage conservation, Health care | Intelligent construction |

[1] The colors in Table 1 are consistent with the colors from Figure 4.

As shown in Figure 4, early research on immersive technology began to emerge around 2017 and 2018 with 12 keywords (game, cultural heritage, awareness, child, serious gaming, reconstruction, energy efficiency, energy reduction, mobile crowdsensing, facility management, real-time data, BIM knowledge) in the dark blue sections. The AR and VR publications appeared relatively early as a research hotspot in 2018 and 2020, respectively, while MR publications emerged in 2022. From 2019 to 2020, the research focus was skewed toward smart cities and sustainability, as indicated by the 14 keywords represented in the green section (Figure 4). This is gradually becoming an integration field of BIM and immersive technology, as well as the promotion of sustainable smart cities, such as AR, tourism, visualization, VR, construction projects, energy consumption, interoperability, cloud, environmental impact, Heritage Building Information Modeling, and lifecycle assessment. The latest research keywords since 2021 are shown in yellow in Figure 1 with 22 keywords: sustainable development, Internet of Things, construction industry, digital twin, sustainable cultural heritage, Sustainable Development Goals, cultural heritage conservation, Extended Reality, sport, metaverse, digital finance, AR, VR, informalization, intelligent construction, smart city concept, smart technology, interoperability, big data, blockchain, digitalization, and healthcare.

The keywords and colors illustrated in Figure 4 are reproduced in Table 1, which shows colors categorized in accordance with their respective time periods and thematic relevance. Specifically, they are classified into three themes consistent with the clustering of thematic categories depicted in Figure 4: immersive technology related; sustainable smart city related; and Building Information Modeling related.

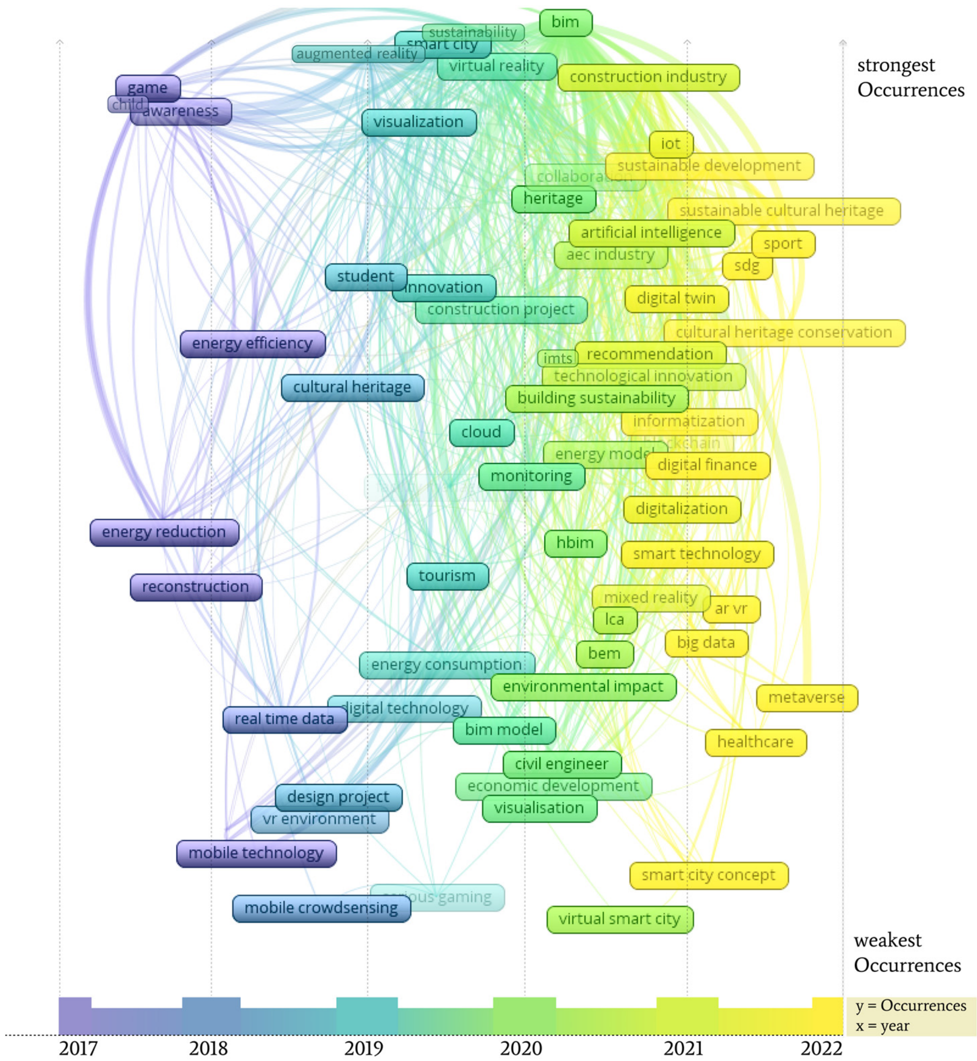


**Figure 5.** Overlay knowledge (side view) of immersive technology and BIM in sustainable smart cities from Figure 4 (generated by the authors).

As shown in Figure 5, publication time was reorganized to generate the overlay knowledge side view of the keyword network for time period visualization, which is in line with Figure 4 the overlay knowledge top view. The keywords in Figure 5 are positioned from top to bottom on the Y-axis as the sequence from the strongest to the weakest frequency of occurrence, which indicates the keywords with the highest frequency of occurrence are ranked on the top. The keywords are aligned on the X-axis from the left to the right by the average year of publication (2017 to 2022). Figure 4 emphasizes the interrelationships between keywords, However, there is still room for interpretation in terms of publication years, allowing for further investigation and analysis of the evolution and changes in keywords over time. Figures 4 and 5 are two time period maps with different perspectives (top view and side view) together forming a knowledge universe, revealing the developed trends of immersive technology and BIM in sustainable smart cities since 2014.

As shown in Figure 6, the keywords in the application areas of AR for immersive technology and BIM in sustainable smart cities from 2017 to 2018 are gaming, child, awareness, energy efficiency, district information modeling, energy reduction, reconstruction, and real-time data. The keywords, such as sustainability, smart cities, virtual reality, visualization, BIM, construction projects, cloud, and tourism, are noted in publications between 2019 and 2020. Since 2021, BIM, construction industry, IOT, sustainable development, collaboration, automation, AI, Immersive Technology, and digitalization have become emerging keywords in published articles.

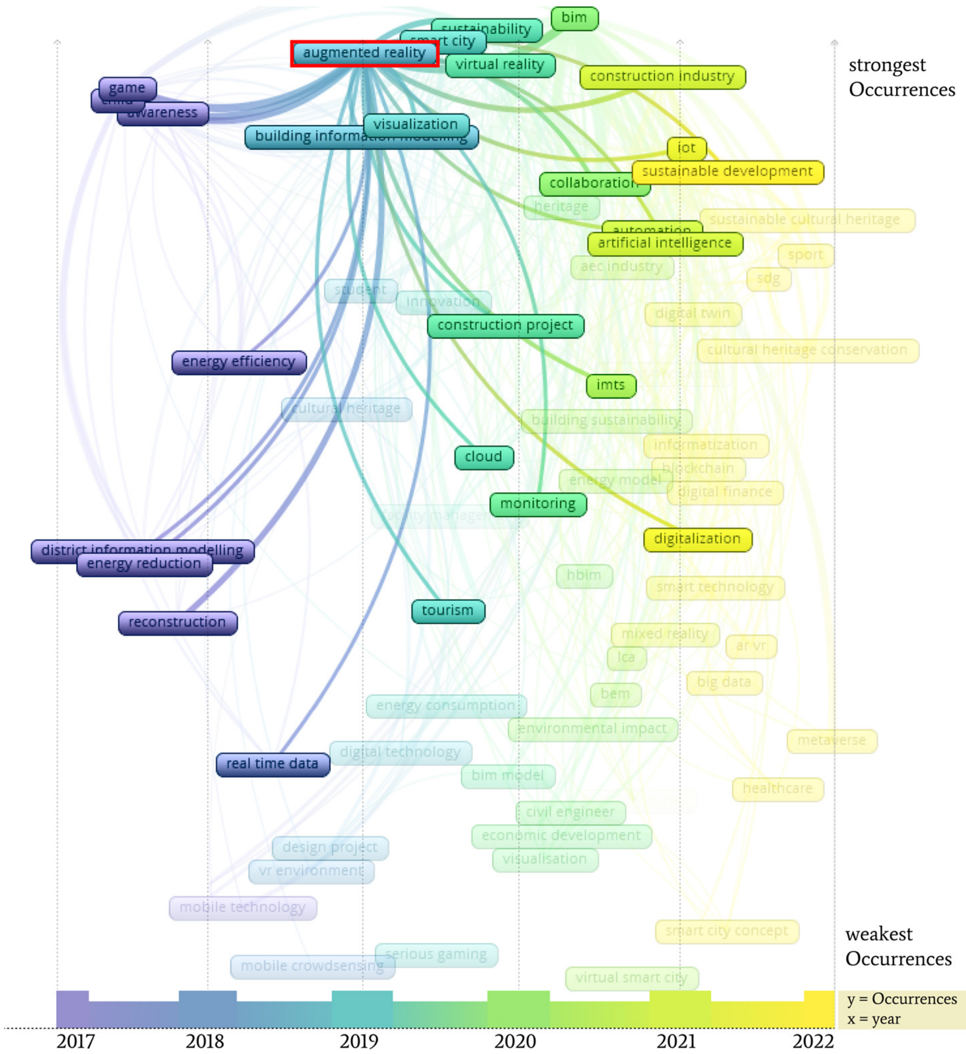


**Figure 6.** Augmented reality overlay highlighted in immersive technology and BIM in sustainable smart cities from Figure 4 (generated by the authors).

As shown in Figure 7, the keywords for the application areas of VR for immersive technology and BIM in sustainable smart cities between 2019 and 2020 are smart cities, AR, visualization, students, innovation, cultural heritage, tourism, and VR environments. From 2020 to 2021, the application keywords are focused on sustainability, BIM, heritage, interoperability, monitoring, HBIM, and visualization. In 2022, emerging application keywords such as construction industry, IOT, information modeling, sustainable development, automation, AI, AEC industry, immersive technology, energy model, and smart city concepts were noticeable in the publication field.

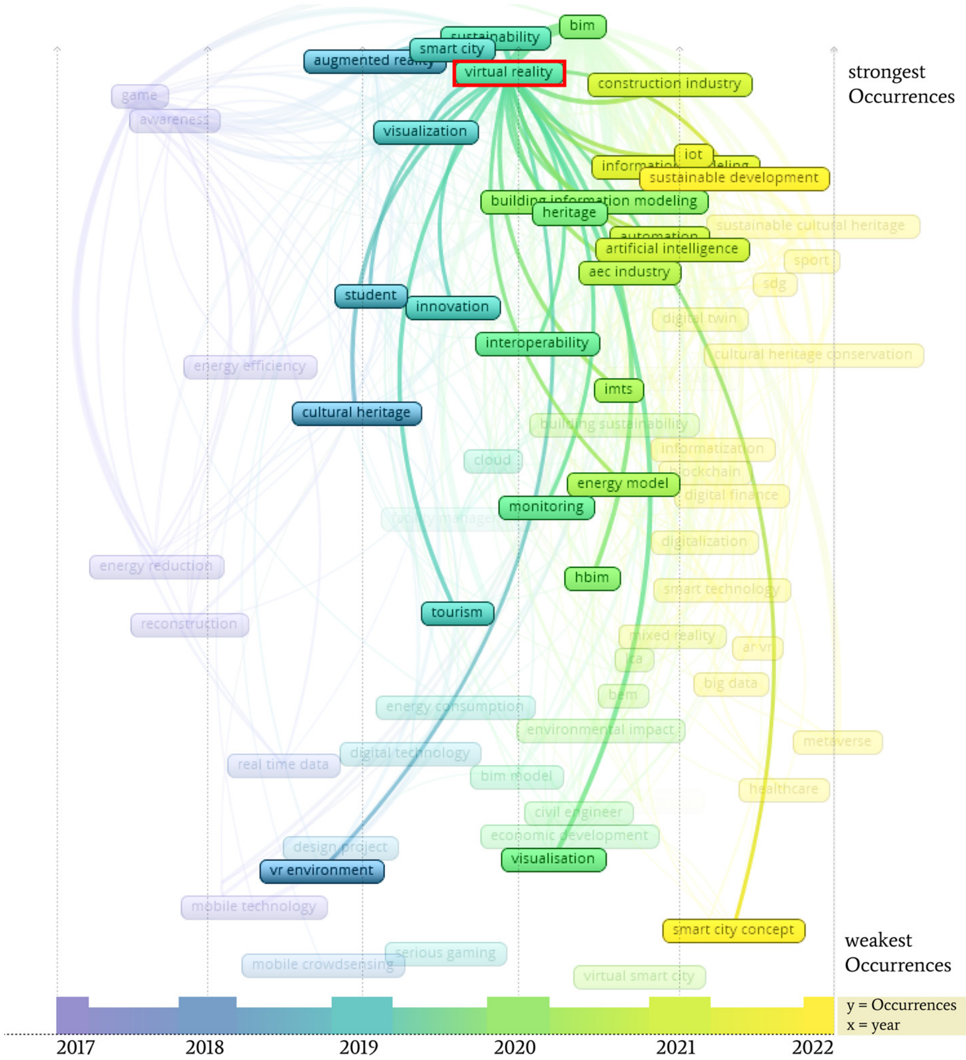


**Figure 7.** Virtual reality overlay highlighted in immersive technology and BIM in sustainable smart cities from Figure 4 (generated by the authors).

As shown in Figure 8, the keywords in the application of MR for immersive technology and BIM in sustainable smart cities were mainly associated with sustainability, facilities management, and BIM model between 2019 and 2020; BIM and collaboration in 2020 to 2021; and information modeling, sustainable development, and intelligent construction since 2022.

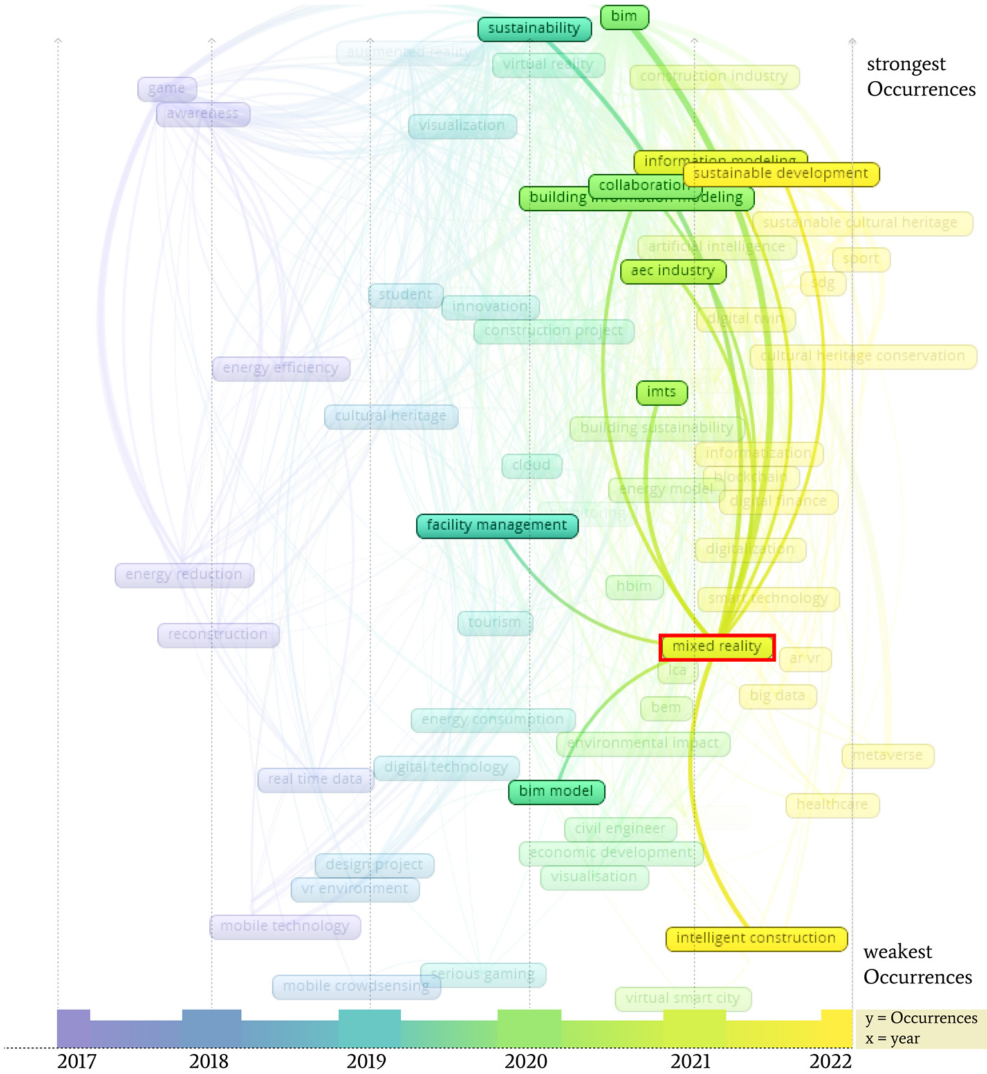


**Figure 8.** Mixed reality overlay highlighted in immersive technology and BIM in sustainable smart cities from Figure 4 (generated by the authors).

As shown in Figure 9, the keywords related to sustainability for the application area for immersive technology and BIM in sustainable smart cities between 2018 and 2019 are game, child, awareness, energy efficiency, district information modeling, energy reduction, and mobile technology. In 2020, the keywords related to sustainability are augmented reality, smart city, visualization, BIM, student, innovation, facility management, tourist, and design project. In 2021, the keywords related to sustainability are virtual reality, BIM model, civil engineer, and facilities management. Around 2020–2021, the keywords related to sustainability are IOT, information modeling, digital twin, smart technology, informatization, mixed reality, metaverse, and smart city concept.

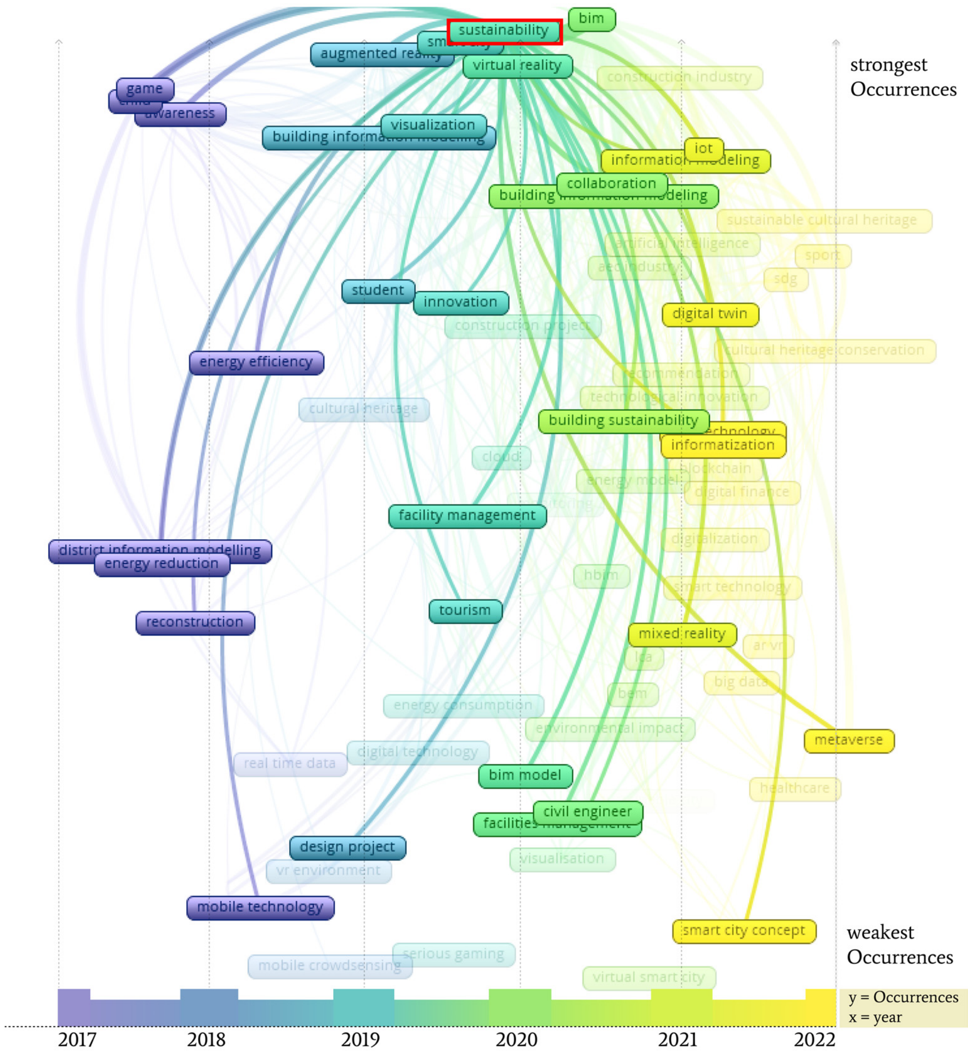


**Figure 9.** Sustainability overlay highlighted in immersive technology and BIM in sustainable smart cities from Figure 4 (generated by the authors).

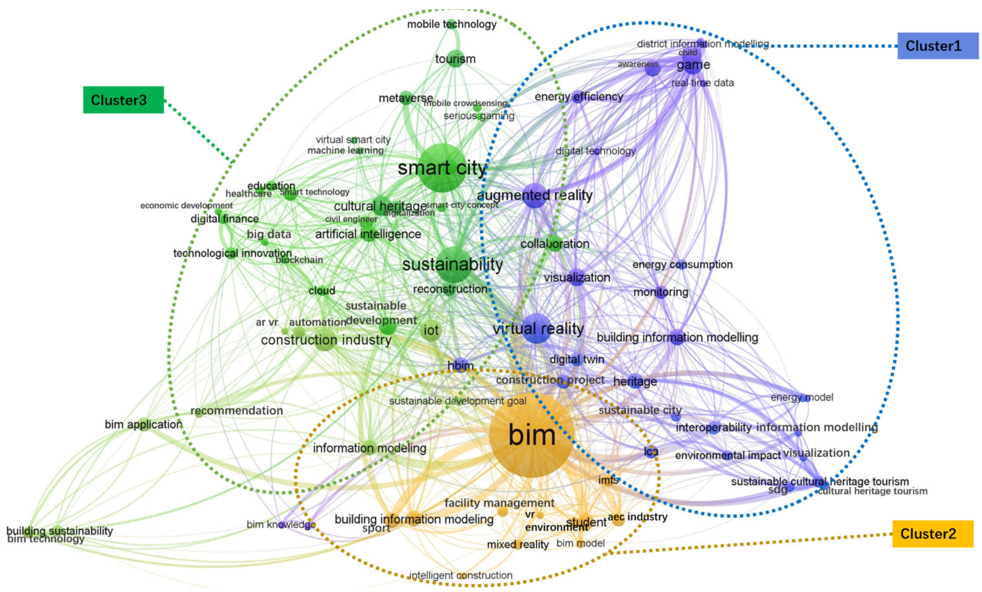


**Figure 10.** Co-occurrence network visualization (cluster) in immersive technology and BIM in sustainable smart cities via VOSviewer software tool 1.6.18 (generated by the authors).

### *3.3. Co-Occurrence Keyword Network Visualization (Clustering)*

The 65 publications obtained in Section 3.1 were imported into the VOSviewer software tool 1.6.18 to generate the keyword co-occurrence network visualization (cluster) map. As shown in Figure 10, there are 82 keywords, which are grouped into three different colored clusters. The size of each circle corresponds to the frequency of occurrence for each keyword. Larger circles indicate higher frequency. The proximity of circles indicates the strength of their connection, with closer circles indicating stronger relationships. The thickness of the connecting lines between circles suggests the strength of the relationship between keywords, and thicker lines indicate stronger connections.

As shown in Figure 10, the blue keyword cluster 1 based on immersive technology has 31 keywords that include VR, AR, visualization, digital twin, construction project, heritage, HBIM, game, child, BIM, awareness, energy efficiency, monitoring, energy consumption, interoperability, environment impact, information modeling, sustainable city, sustainable cultural heritage, cultural heritage conservation, visualization, district information modeling, energy reduction, LCA, BEM, energy model, SDG, real-time data, digital technology, BIM research, and BIM knowledge. The BIM-based yellow keyword cluster 2 is associated with 13 keywords, which comprise BIM, sport, student, AEC industry, IMTs, mixed reality, BIM model, design project, VR environment, facilities management, facility management, and intelligent construction. Green keyword based on sustainability and smart cities cluster 3 involves 38 keywords, encompassing smart city, sustainability, sustainable development, cultural heritage, tourism, AI, digitalization, innovation, metaverse, construction industry, IOT, smart technology, sustainable development, technological innovation, information modeling, BIM application, building sustainability, BIM technology, smart city concept, education, healthcare, blockchain, big data, civil engineer, cloud, collaboration, digital finance, economic development, mobile crowdsensing, mobile technology, serious gaming, AR, VR, automation, informatization, reconstruction, virtual smart city, recommendation, and machine learning.

The co-occurrence cluster network visualization shows the relationship between each keyword and cluster group. As shown in Figure 10, cluster 1 "immersive technology" is the closest, intertwined, and most strongly connected to cluster 3 "sustainable smart cities", which suggests that BIM with immersive technology is increasingly integrated into the practice of BIM in the lifecycle that enhances its potential for future research on development in sustainable smart cities. In addition, Cluster 1 "immersive technology" is closely related to cluster 2, "BIM", which indicates that the integration of immersive technology and BIM is the foundation for building sustainable smart cities, where BIM builds a bridge for the development of immersive technology in sustainable smart cities.

### *3.4. Keyword Burst Detection*

As shown in Figure 11, a keyword burst detection map was generated via Citespace, with a one-year time slice length. The top 50 keywords in terms of the number of bursts were collected under the topic of immersive technology and BIM in sustainable smart cities, indicating the emerging hotspots and research trends.

### *3.5. Immersive Technology*

As shown in Table 2, which lists immersive technology applications in sustainable smart cities, case studies are the most used method [4,5,8,19–30], followed by literature reviews [9,20,31–35], expert interviews [4,5,8,22,25,30], questionnaires [4,5,8,22,25,30], and experimentation [5,21,30].

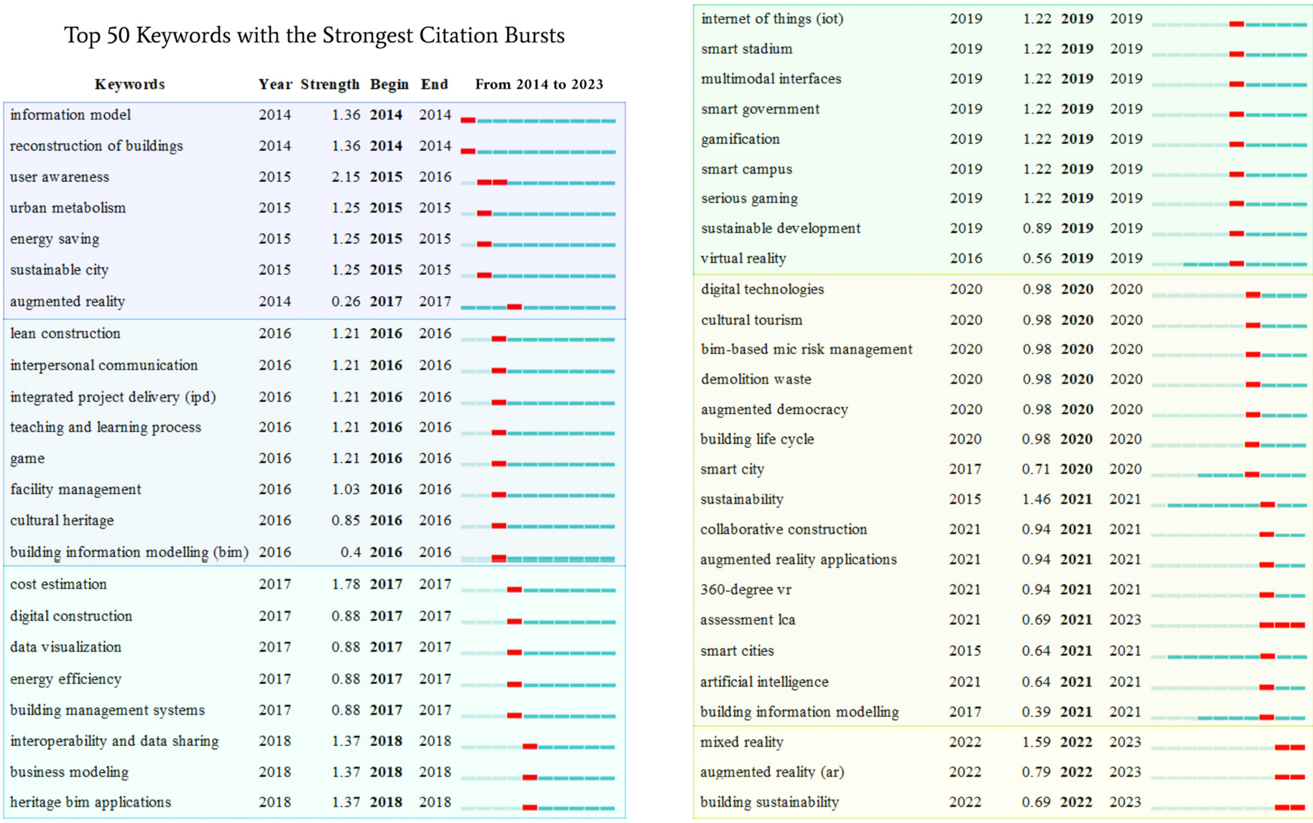


**Figure 11.** Top 50 keyword burst map in immersive technology and BIM in sustainable smart cities via Citespace software tool 6.3 (generated by authors).

**Table 2.** List of immersive technology applications in immersive technology and BIM in sustainable smart cities (designed by the authors).

| Source | Year | Research Method | Research Application |
|---|---|---|---|
| Alabdali et al. [35] | 2023 | Literature review | Sustainable rural area smart technologies, AI and IoT Infrastructure integration, VR, AR and MR building automation, Extended reality (XR) sustainable community design; |
| Srivastava et al. [33] | 2022 | Literature review | |
| Khan et al. [32] | 2021 | Literature review | |
| Wiberg et al. [25] | 2020 | Case studies, Interviews, and Questionnaire | |
| Kamari et al. [22] | 2020 | Case studies, Questionnaire, and Interviews | |
| Jamei et al. [19] | 2017 | Case studies | |
| Chew et al. [31] | 2021 | Literature review | AR and MR, Sustainable facilities management; |
| Shi et al. [4] | 2016 | Case studies, Questionnaire, and Interviews | |
| Nasralla et al. [21] | 2021 | Case studies, Experimentation | Virtual smart city healthcare; |
| Alizadehsalehi et al. [5] | 2021 | Case studies, Questionnaire and Interviews, Experimentation | VR/AR/MR for teaching energy efficiency education in smart city engineering; |
| Luca et al. [26] | 2017 | Case studies | |
| Álvarez-Marín et al. [30] | 2014 | Case studies, Questionnaire and Interviews, Experimentation | |
| Zhou et al. [9] | 2022 | Literature review | VR supports smart city public services (transportation, political participation); |
| Bourhim et al. [34] | 2020 | Literature review | |
| Panchanathan et al. [8] | 2019 | Case studies, Questionnaire and Interviews, Experimentation | |
| Predescu et al. [27] | 2019 | Case studies | |
| Briciu et al. [20] | 2020 | Literature review, Case studies | Smart tourism for cultural and travel experiences, VR/AR supporting historical heritage exchange; |
| Shih et al. [28] | 2020 | Case Studies | |
| Vasileva et al. [29] | 2017 | Case Studies | |
| Chiabrando et al. [24] | 2016 | Case Studies | |

VR is the most prevalent immersive technology used in research associated with sustainable energy performance, cultural heritage preservation, intelligent construction engineering management, facility management, sustainable engineering education, and public services of smart cities (specifically transportation and tourism). The highest number of applications is related to sustainable energy performance, followed by cultural heritage preservation, intelligent facility management, engineering education, and public services of smart cities. Additionally, the field in which AR applications are most prevalent is education, followed by building construction management, cultural heritage preservation, and smart facility management. Furthermore, MR has fewer application areas since it is a relatively new technology in immersive technology, namely building construction, landscape intelligent construction, and management, as well as engineering teaching and design.

### 3.6. Sustainable Smart City

As shown in Table 3, which lists smart city technology applications in immersive technology and BIM in sustainable smart cities since 2014, case studies [6–8,20–23,31,36–49] are the most used method for integrating smart city in immersive technology, followed by literature reviews [6,7,9,19,31,39,50–54], interviews [8,20,22,36,37,43–46], questionnaires [8,20,22,36,37,43–46], and experimentation [8,21,38,43,48,49]. A total of 12 studies are related to smart city public services, involving sustainable smart tourism, sustainable smart city planning, smart transportation, sustainable education, and sustainable healthcare in smart cities, for which the technologies used are VR and AR. Furthermore, applications that are associated with smart city sustainability are energy management and energy efficiency in sustainable development. Additionally, applications involving lifecycle assessment are green building index, sustainable building design, and facility management, for which the technologies used are VR and XR.

**Table 3.** List of smart city technology applications in immersive technology and BIM in sustainable smart cities (designed by the authors).

| Source | Year | Research Method | Research Application |
|---|---|---|---|
| Manogaran et al. [48] | 2022 | Case studies, Experimentation | Smart city climate and energy management, BIM and building energy efficiency, Sustainability performance; |
| Porsani et al. [6] | 2021 | Literature review, Case studies | |
| GhaffarianHoseini et al. [7] | 2017 | Literature review, Case studies | |
| Li et al. [53] | 2023 | Literature review | VR, MR, digital twin, Immersive reality supporting BIM, BIM facility management, Sustainable architecture, Sustainable cities; |
| Carbonari et al. [44] | 2022 | Case studies, Questionnaire, Interviews | |
| Vite et al. [45] | 2022 | Case studies, Questionnaire, Interviews | |
| Vázquez-Rowe et al. [40] | 2021 | Case studies | |
| Allam et al. [39] | 2021 | Literature review, Case studies | |
| Khoshdelnezamiha et al. [52] | 2021 | Literature review | |
| Chew et al. [31] | 2020 | Literature review, Case studies | |
| Kamari et al. [22] | 2020 | Case studies, Questionnaire, Interviews | |
| Anand et al. [51] | 2017 | Literature review | |
| Shahrokni et al. [36] | 2015 | Case studies, Questionnaire, Interviews | |
| Zhou et al. [9] | 2023 | Literature review | Sustainable development of cultural tourism, VR and AR for sustainable urban planning, Smart city public services; |
| Yaqoob et al. [54] | 2023 | Literature review | |
| Buyukdemircioglu et al. [47] | 2022 | Case studies | |
| Plata et al. [23] | 2022 | Case studies | |
| Lenfers et al. [41] | 2021 | Case studies | |
| Briciu et al. [20] | 2020 | Case studies, Questionnaire, Interviews | |
| Pournaras et al. [37] | 2020 | Case studies, Questionnaire, Interviews | |
| Panchanathan et al. [8] | 2019 | Case studies, Questionnaire, Interviews, Experimentation | |
| Vitello et al. [38] | 2018 | Case studies, Experimentation | |
| Kim et al. [50] | 2017 | Literature review | |
| Jamei et al. [19] | 2017 | Literature review | |
| Wu et al. [49] | 2022 | Case studies, Experimentation | Smart city sustainable healthcare; |
| Nasralla et al. [21] | 2021 | Case studies, Experimentation | |
| Setiawan et al. [46] | 2022 | Case studies, Questionnaire, Interviews | Teaching sustainability engineering, VR and AR gamification for sustainability education; |
| Gutierrez-Bucheli et al. [43] | 2016 | Case studies, Questionnaire, Interviews, Experimentation | |
| Osello et al. [42] | 2015 | Case studies | |

*3.7. Lifecycle Assessment*

The immersive technology and BIM across the lifecycle stages are in the light of the findings from Sections 3.2 and 3.3. The lifecycle stages are categorized into three stages:

1. Beginning stage: design, cost estimation, tendering, decision making, procurement.
2. Intermediate stage: manufacturing stage (manufacturing and construction, transportation, packaging, and other production activities) and utilization stage (operation, facility management, consumer use, maintenance, and renovation).
3. End stage: deconstruction/disassembly, reuse/remanufacturing/recycling, and waste disposal, optimization/iterative.

3.7.1. Beginning Stage

The beginning stage of the lifecycle comprises phases, such as design, decision making, manufacturing, and procurement. As shown in Table 4, most of the studies focus on the planning, design, and decision-making stages. In terms of the application areas, the majority of the studies are related to construction and sustainability [19,25,44,45], including building energy efficiency [52,55] and facility management [40]. Keywords related to sustainable smart city building are visual smart city [47] and zero-emission neighborhood (ZEN) [25]. Immersive technology, such as VR [19,43], extended reality [25], MR with AR [44], and VR immersive experiences, is implemented in the beginning stage [45].

**Table 4.** The beginning stage of the lifecycle and application areas in immersive technology and BIM in sustainable smart cities (designed by the authors).

| The Beginning Stage | | | | | | |
|---|---|---|---|---|---|---|
| Beginning Stage | | | | | | |
| **Literature Source** | **Year** | **Design** | **Decision Making** | **Manufacturing** | **Procurement** | **Application Areas** |
| Choi et al. [12] | 2022 | + | + | | | Facilities Management (FM), VR immersive experiences, BIM and Building Energy Modeling, (BEM) Interoperability, Sustainable buildings and energy performance; |
| Vázquez-Rowe et al. [40] | 2021 | | + | | | |
| Vite et al. [45] | 2021 | + | + | | | |
| Khoshdelnezamiha et al. [52] | 2020 | | + | | | |
| Jamei et al. [19] | 2017 | + | + | | | |
| Anand et al. [51] | 2017 | | + | | | |
| Santos et al. [56] | 2017 | + | + | | | |
| Li et al. [55] | 2017 | + | + | | | |
| Prebanić et al. [57] | 2021 | + | + | + | + | BIM risk management and assessment, BIM, and VR, Teaching civil engineering; |
| Kamari et al. [22] | 2020 | + | + | | + | |
| Gutierrez-Bucheli et al. [43] | 2016 | + | + | + | | |
| Buyukdemircioglu et al. [47] | 2022 | | + | | | VR, AR, and MR, Extended reality, BIM sustainable design; |
| Carbonari et al. [44] | 2022 | | + | | | |
| Wiberg et al. [25] | 2019 | + | + | + | | |

+ indicates that the literature contains the content.

The main application areas in the design stage are linked to building sustainability [12,19,25,45,55,56], BIM risk management, and assessment [22,43]. During the design and construction stage, the use of BIM-based co-design by designers and contractors maximizes project delivery improvements and collaborative efficiency, particularly in BIM risk management and assessment. Integrating BIM with MR enables stakeholders to evaluate retrofit and design projects. By displaying virtual models of alternative design solutions on existing physical facilities, stakeholders collaborate effectively and implement efficient workflows, contributing to the adoption of sustainable building design management methods [44]. Engineers, architects, and managers have differing perspectives on sustainability and energy optimization, highlighting the need to integrate new services and address stakeholder concerns. This human-centered approach would be achieved by creating a digital twin of the building, which facilitates interaction through sensors, immersive experiences, and virtual, augmented, and MR [45]. This adaptation of BIM caters to various agendas related to sustainable design and construction. In terms of building energy and sustainability, the methodology which allows designers to simulate multiple design alternatives, enhancing the speed, accuracy, and consistency of the design process [55]. The combination of BIM with VR has the ability to develop real-time visualization and traceability features for monitoring construction progress and cost estimation [56].

The decision-making stage of the building process has been the subject of extensive research, particularly in the areas of facilities management [12,22,40,43,44,47], building sustainability [19,25,51,55], and building energy [45,52,56]. Evaluating the automation of the BIM-BEM process in building design and improving the interoperability between BIM and BEM are crucial for cost savings in building energy. The application of VR and BIM in cost estimation and LCA analysis contributes to aligning data sources. BIM-based cost estimation tools utilize the Level of Development of building models to generate cost estimates, reducing the labor intensity of the estimation process and enhancing efficiency [22]. There is limited study available on the manufacturing and procurement stages, primarily focusing on BIM risk management [22,43,57] and sustainable buildings [25]. An automated green building evaluation system has been developed using visual programming as a tool for assessing the green building index based on BIM [40]. Furthermore, the integration of BIM and integrated project delivery in civil engineering project delivery education has facilitated the creation of high-precision 8DBIM models and VR applications, thereby enhancing teaching quality and students' understanding of building sustainable smart cities [43]. Utilizing the Unity game engine to create detailed visualizations and immersive experiences for stakeholders before the actual construction process begins leverages the potential of VR environments [47].

### 3.7.2. Intermediate Stage

As shown in Table 5, the main application areas in the intermediate stages are BIM collaborative efficiency [4,11,22,58], building sustainability [6,31,59,60], and facility management [10,31,58]. In terms of integrating applications with immersive technology, the technologies used in this stage are VR and AR [43], VR visualization [48], VR immersive experiences [22], and AR/VR with BIM for smart building facility management [31]. Less research has been conducted on sustainability with energy efficiency [6], sustainable development goals [28], and building sustainability [39,61]. The main technology application areas for the construction stage are building sustainability [36], BIM and immersive technology integration [44], and BIM management collaboration [11,58,61–63]. MR platforms are supported by ODAVS, a site assessment service for renovation projects, and technologies that support MR include AR and VR [44].

AI and IoT facilitate a great deal of collaboration between stakeholders in construction projects and provide information and the latest updates to the project model, thus mitigating the risks associated with a lack of understanding of the project team due to a lack of information [11]. Additionally, the improvement of the identification and analysis of potential site safety risks, as well as the enhancement of real-time communication between managers and workers, is facilitated by the use of Unmanned Aerial Vehicles, AR, and location tracking in conjunction with BIM [62]. The operation and maintenance stages are mainly related to building energy efficiency and sustainability [6,59,60] and BIM cooperation [59]. Integrating BIM with Quantity Taking, LCA, and VR enhances flexibility and efficiency [22]. BIM improves predictability, teamwork, profitability, cost reduction, time management, and client relationships [10], and the application of data-driven approaches in building operations and maintenance enables the efficient and cost-effective management of activities such as maintenance, repair, emergency management, and energy management [62]. Combining BIM with AI enhances digitization and intelligence in infrastructure management throughout the building's lifecycle [62]. The convergence of AI, IoT, 5G, and BIM technologies leads to unmanned, energy-efficient, high-efficiency, and safe building management [59]. AI and digital twin technologies contribute to efficient building operations and maintenance [60]. The main applications for the refurbishment stages are BIM collaboration and project management [61]. A modular and integrated construction risk management documentation based on BIM improves the efficiency of building sustainability performance and BIM management [61].

**Table 5.** The intermediate stage of the lifecycle and application areas in immersive technology and BIM in sustainable smart cities (designed by the authors).

| The Intermediate Stage | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Construction Stage | | Usage Stage | | | |
| **Literature Source** | **Year** | **Construction** | **Transport** | **Operations** | **Maintenance** | **Refurbishment** | **Application Areas** |
| Afzal et al. [60] | 2023 | | | + | + | | Building sustainability, Intelligent building, Facility management; |
| Jiao et al. [59] | 2023 | | | + | + | | |
| Porsani et al. [6] | 2021 | | | + | + | | |
| Chew et al. [31] | 2020 | | | | + | | |
| Shi et al. [4] | 2016 | | | + | + | | |
| Shahrokni et al. [36] | 2015 | + | + | | | | |
| Carbonari et al. [44] | 2022 | + | | | | | VR/AR immersive experiences, BIM collaboration efficiency; |
| Manogaran et al. [48] | 2022 | | | + | + | | |
| Kamari et al. [22] | 2020 | | | + | + | | |
| Fiandrino et al. [63] | 2017 | + | | + | + | | |
| Azhar et al. [10] | 2022 | | | + | + | | BIM risks and challenges, BIM collaboration and project management; |
| Ali et al. [11] | 2022 | + | | + | + | | |
| Pan et al. [62] | 2022 | + | | + | + | | |
| Darko et al. [61] | 2020 | + | | | | + | |
| Meng et al. [58] | 2020 | + | | + | + | | |

+ indicates that the literature contains the content.

### 3.7.3. End Stage

The main application areas of sustainable building and building energy efficiency are shown in Table 6 [7,40]. Most of the studies on the end-of-lifecycle stage focus on the recycling stages, and the main application area is building sustainability [40,58], while the related immersive technologies are MR [44] and VR [64]. In the context of waste disposal, the European Commission developed the Product Environmental Footprint as a common methodology for assessing the environmental performance of a product, including product recovery or recycling, which is considered in the end-of-life stage [58]. Waste management during building demolition, disposal, and recovering energy benefits sustainable development. Strategies like proper waste management, eco-friendly materials, and recycling reduce landfill waste [64].

**Table 6.** The end stage of the lifecycle and application areas in immersive technology and BIM in sustainable smart cities (designed by the authors).

| The End Stage | | | | | |
|---|---|---|---|---|---|
| End Stage | | | | | |
| **Literature Source** | **Year** | **Deconstruction** | **Disposal** | **Reuse or Recycling** | **Application Areas** |
| Caldas et al. [64] | 2022 | | | + | Sustainable buildings, |
| Vázquez-Rowe et al. [40] | 2021 | + | + | + | Circular buildings, |
| GhaffarianHoseini et al. [7] | 2017 | + | + | + | BIM collaboration facilities management, Building energy efficiency; |
| Carbonari et al. [44] | 2022 | | | + | BIM and MR, |
| Meng et al. [58] | 2020 | | | + | Building renovation design; |

+ indicates that the literature contains the content.

## 4. Discussion

### *4.1. Research Hotspots and Development Trends*

The results in Section 3.7 highlight the application of immersive technologies and BIM in all lifecycle stages. In the design stage, immersive technologies enhance sustainability, enable BIM-based co-design, and facilitate stakeholder collaboration. During decision making, research emphasizes facilities management, building sustainability, and energy optimization, with BIM-BEM integration and automated cost estimation. Limited research examines BIM for risk management and sustainable evaluation in manufacturing and procurement, but BIM integration shows potential to enhance education on sustainable smart city development. Limited research explores the manufacturing and procurement stages, mostly examining BIM-based risk management and sustainable building evaluation, while integrating BIM with integrated project delivery shows potential for enhancing education and understanding of sustainable smart city development. Limited research explores manufacturing and procurement, but integrating BIM with integrated project delivery shows potential to enhance education on sustainable smart city development. The end-of-life stages focus on building sustainability and energy efficiency. In deconstruction, the main applications involve sustainable building and energy efficiency. For the end-of-life stages, research concentrates on the recycling process and building sustainability, utilizing immersive technologies like MR and VR.

The trends in the keyword analysis provide valuable insights into the evolution and future directions of research on immersive technologies and BIM for sustainable smart cities, such as the identification of research hotspots and interdisciplinary connections. The analysis of keyword frequencies and co-occurrences over time reveals how the research focus has shifted and diversified. Emerging keywords may indicate new concepts, technologies, or applications that are gaining prominence in the field. Furthermore, clusters and relative positions of keywords provide insights into the shifting priorities, technological advancements, and collaborative efforts that will shape the future of research in this rapidly advancing area.

#### 4.1.1. Research Hotspots of Immersive Technology and BIM in Sustainable Smart Cities

The results of Section 3.5 suggest that immersive technology offers valuable support to decision makers in digital infrastructure, transportation, and energy management in urban construction, which plays a crucial role in driving cities toward a more intelligent, digital, and sustainable future. By addressing the challenges of efficient services, intelligent transportation systems, and sustainable urban environments, immersive technology enables the provision of optimized user experiences and innovative technological solutions. The integration of immersive technology and BIM was applied in various domains, such as smart transportation, public services, healthcare, cultural heritage, tourism, education, and energy conservation. In smart public services, digital programs play a vital role in innovative city planning, management, and governance, while also addressing digital inequalities. This integration enhances real-time communication between stakeholders.

Additionally, immersive technology enhances tourism experiences and cultural heritage understanding in sustainable smart cities, benefiting citizens of all ages. In education, immersive technology facilitates better student interaction, creativity, motivation, learning outcomes, and comfort, enabling active and effective participation in sustainable urban development [45]. Additionally, immersive technology, particularly AR, plays a role in promoting energy conservation and sustainability in smart cities. AR games engage children in learning about energy conservation and raise awareness about energy issues, aligning with millennials' digital interaction preferences [26]. Future research could focus on enhancing the functionality and interaction of AR and VR to fully unleash their potential in sustainable smart cities.

1. Intelligent Solutions for Public Services

The COVID-19 pandemic has accelerated the progress of digital services [65]. Digital solutions and innovative applications for smart cities have become urgent for planning, managing, and governing cities and urban infrastructure to address digital inequalities. The emerging research directions of 6G technology include digital twin, immersive reality, and mobile holography, which have an economic impact on cities equipped with digital infrastructure backbone networks that are in line with Sustainable Development Goal 11 (Sustainable Cities and Communities). In addition, the blockchain consensus has been introduced via a new paradigm, enhancing the trust of citizens in smart city construction and promoting sustainable citizen participation through smart markets [37]. The technology of citizen participation through mobile crowdsensing intelligence perception supports the operation of intelligent transportation, generates high-precision urban environment modeling and simulation instead of large-scale real testing, and promotes reasonable and sustainable urban development [38]. Further, VR and AR are used to provide an optimized stadium viewing experience, including real-time access to replay through mobile terminals, real-time viewing of games from any location and angle, from a player's point of view, better access to real-time information and statistics, and interaction with various IoT devices (i.e., holographic displays and laser projections) to enhance the game-watching experience [8].

2. Intelligence and Digitization Promote Energy Conservation and Sustainability

The decisive Energy Management Solution addresses energy shortages among users, green IoT, and green cloud infrastructure [7]. Fuzzy analytic hierarchy process methods have been employed to determine the importance of sustainability criteria in smart cities and identify sustainability indicators for designing smart cities in developing countries [50]. Additionally, a green and sustainable mobile edge computing framework has been adopted to enhance resource management in green smart cities. Interestingly, a time-scale resource allocation algorithm has been proposed for efficient resource management in green IoT [48]. Further, the Energy-efficient Area Information Modeling and Management European Project and the Smart Urban Zero Energy Building Italian national group promote energy efficiency and raise awareness of smart cities through gamification [26,42]. These projects focus on reducing energy and carbon dioxide emissions while integrating immersive technology like VR and AR in the form of children's games that enable players to grasp concepts related to energy efficiency and smart city issues by answering questions on energy-saving methods and sustainable development behavior, and players thus actively learn and develop awareness of energy conservation and interest in energy-related topics. Serious games with AR multimedia elements play a significant role in the effective development of smart cities.

3. Medical and Wearable Devices in Smart Cities

6G technology has been predicted to have an unprecedented impact on the realization of smart cities, including climate, education, agriculture, transportation, infrastructure development, and economic models. Related applications employ technologies such as remote surgery, promote the popularity of smart wearable devices, and eliminate time and space constraints [39]. As such, the medical field benefits from the adoption of remote surgery and smart wearable devices, leading to improved patient rehabilitation and sustainable smart medical services [21,38,49]. Moreover, systems can use serious VR games and IoT wearable sensors to remotely monitor the recovery of stroke patients and allow doctors to evaluate and track patients' progress, helping patients recover faster. However, it is limited by the impact of sensor failures on sustainability. To solve this problem, a sustainable VR patient rehabilitation system has been developed based on IoT sensors in a virtual smart city, which identifies faulty IoT devices through time series analysis and tests a method to quickly detect faults and support sustainability through rehabilitation simulation scenarios in virtual smart cities [21]. Furthermore, a lightweight neural network model efficiently classifies medical sensor data streams and is suitable for sustainable and smart urban applications [49].

4. Digital Development of Cultural Heritage

The ground-penetrating radar integrated with drones, VR, and AR technologies has been used to promote the conservation of monuments by creating new experiences and to improve the performance of the tourism and cultural heritage sector in a balanced and sustainable manner, of which the interdisciplinary approach to heritage management provides tools for efficient digital heritage management [23]. Three-dimensional survey techniques and BIM have been involved in the creation and management of historic heritage HBIM projects in various approaches, including data processing, the semiautomatic historical shape segmentation of complex structures, recognition and modeling processes, and 3D reconstruction of historic buildings through VR and AR [25]. Similarly, a project for inclusive cultural heritage in Europe via 3D semantic modeling adopts an inclusive approach to the real-time dynamic 3D reconstruction of the architectural and social environment, providing innovative 3D modeling of cultural heritage that is easily accessible to a wide range of user groups while developing an open standard semantic web platform for the construction of cultural heritage information models for user-friendly AR and VR applications via mobile devices [66].

5. Smart Services for Tourism

Sensor-based data collection and big data processing techniques have been implemented in cultural heritage sites [50], enhancing environmental measurement, management practices, and policymaking capabilities. Energy efficiency, early warning systems, and environmental management serve as crucial sustainability indicators. User experience varies among different groups: senior citizens focus on the historical perspective, young people value immersive experiences, and tourists seek cultural understanding. In sustainable smart cities, immersive technology allows individuals of all ages to engage with and appreciate cultural heritage [20]. IoT, cloud computing platforms, and big data support decision making for tourism managers, offering personalized travel recommendations and tailored destination suggestions through platforms like TripAdvisor. VR experiences enhance the exploration of open spaces and historical sites, providing immersive navigation from architectural details to the broader environmental scale. For instance, the Monza Park building's holographic vision and VR experience promote healthy living and sustainability for local residents [67].

6. Intelligence and Digitization of Education

Sustainable development is gaining a widely attention in engineering education, particularly in countries such as India [45]. An interactive intelligent learning environment system that combines VR and AR to provide advanced solutions for smart cities has been proposed which uses VR/AR glasses to enhance the experience of the students when interacting with intelligent digital devices in online courses [46]. Additionally, the National University of Singapore developed a mobile ecosystem for BIM-based intelligent building facility management, enhancing students' learning experience through AR and VR [31]. A multiuser shared virtual environment framework has been introduced for facility management, promoting communication efficiency and sustainable goals [4]. Immersive technology enhances architectural education and caters to digital interaction preferences [26]. However, AR applications improve academic performance but may have limitations in functionality and interactivity [30].

#### 4.1.2. Development Trends of Immersive Technology and BIM in Sustainable Smart Cities

The results of Section 3 (see Figures 4–9) suggest that from the year 2014 to 2023, the collaborative application of immersion technology and BIM in the context of sustainable smart city construction has gradually attracted attention, and the research context of immersive technology and BIM in the construction of sustainable smart cities is gradually becoming clear. Initially, studies began exploring the potential of AR technology and its application in urban planning and architectural design for sustainable smart cities. As technology progressed, VR technology has garnered significant attention and has been extensively studied and applied in sustainable smart city construction. In recent years, there has been a growing focus on MR, leading to the investigation of applications and potential in the construction of sustainable smart cities.

Moreover, the results of Section 3 (see Table 3 and Figure 11) indicate that the collaborative application of immersive technology, e.g., AR, VR, MR, and BIM in the construction of sustainable smart cities may become the focus of future research. AR enables the overlay of virtual information onto real urban environments, providing urban planners and decision makers with intuitive visualizations and simulations of cities. It is employed to demonstrate the effects of sustainable building design solutions, empowering decision makers to assess and comprehend their environmental impacts and promote sustainable construction. VR offers immersive experiences for urban planners and designers to explore and envision the sustainable development of future cities. MR combines virtual content with real urban environments, delivering a comprehensive presentation of information and interactive experiences to decision makers. It is utilized to visualize the layout and improvement of urban infrastructure while providing real-time environmental data and decision support, enhancing decision-making processes in sustainable smart city construction.

The results of Section 3.5 (see Tables 2 and 3) suggest that AR and VR are earlier directions in immersive technology that have been widely used, which have the potential to contribute to smart cities in sustainable education, green building, sustainable building design, and facility management. In public services, immersive technology has also been seen in various studies and applications in sustainable smart tourism, sustainable smart city planning, and smart transportation, but less attention has been paid to sustainable healthcare. AR was first applied in engineering teaching in the year 2014, cultural heritage preservation in the years 2016 and 2020, smart city public services and serious gaming from the year 2019 to 2020, and construction industry and engineering education systems since the year 2021. In contrast, the applications of MR in smart cities are still in the early stages and are considered relatively immature. Since the year 2020, XR technology has been utilized in sustainable community planning, design, building construction, intelligent construction, and landscape management, as well as engineering teaching and design since the year 2021. However, the implementation of various new technologies in immersive technology is still in its exploratory stage, characterized by short durations, one-sidedness, and fragmented efforts.

Interestingly, the overall number of studies in immersive technology shows a fluctuating upward trend in a 3-to-5-year cycle, which indicates that the research interest and investment in the field gradually increase in a specific period till their peak and then gradually decrease. This cyclical change may be influenced by several factors, such as technological advancement, market demand, and academic development. As such, a number of emerging technologies in immersive technology will continue to emerge in the future, which will drive the development of sustainable smart cities.

### 4.2. Challenges and Limitations

#### 4.2.1. Challenges in Implementing Immersive Technology for Sustainable Smart Cities

The results in Sections 3.5 and 3.6 highlight that there are insufficient in-depth investigations into the use of AR-based educational methods and experiences. It is recommended to evaluate applications using objective metrics, structured constructs, and validated scales. Some AR applications lack high-level functional features and interactivity, emphasizing the need for improved functionality and interactivity to unleash the full potential of AR. However, AR users may still experience nausea, claustrophobia, and motion sickness to some extent. The low adoption of VR technology in the engineering industry, where accuracy and precision are crucial, needs further development of refined hardware and software solutions to deliver immersive, holistic, tangible, realistic, touchable, and perceptible technological experiences. Improving the display fidelity of VR headsets remains a challenge for widespread use. Future research could focus on simulating vibrant stadium experiences, offering control over viewing perspectives, enhancing accessibility of information and services in virtual environments, and adding social functionality for realistic interactions between viewers. In addition, MR is a relatively new research direction in immersive technology with less related research compared with VR and AR. Devices such as Microsoft HoloLens, Magic Leap, and Third Eye are known to support pure immersive MR experiences. Future research incorporating cloud computing, 5G technologies, and AI will drive the use of MR applications in large-scale architectural projects. Addressing technological issues such as localization, display improvements, integrated interactions, increased data storage, and collaboration will enhance the maturity of MR applications in the AEC industry.

The results in Sections 3.5 and 3.6 suggest that research on immersive technology and BIM in sustainable smart city construction remains one-sided and fragmented, lacking a systematic and mature system and in-depth insights. Additionally, there is a lack of comprehensive assessment of the environmental impacts, resource utilization, and economic benefits of immersive technology and BIM in the lifecycle of sustainable smart cities, which may lead to the inability of decision makers to comprehensively measure the sustainability and long-term impacts of the projects during planning and implementation. It also may lead to one-sided and uncoordinated implementation of the technology. Therefore, there is a need to further investigate and utilize the synergistic application of immersive technology and BIM for building and infrastructure optimization, energy efficiency improvement, and user experience enhancement.

#### 4.2.2. Challenges in Improving BIM in Sustainable Smart Cities

The results in Section 3.6 indicate that there are some problems and limitations of immersive technology and BIM in sustainable smart city application research. The integration of project stakeholders using BIM may lead to the elimination of checks and balances, potentially overlooking or delaying the detection of problems [10]. Existing studies on BIM have gaps, including the lack of analysis and comparison of BIM standards between countries, assessment of BIM adoption in Europe, and the varying quality of BIM training and educational resources [10]. BIM development faces challenges such as real-time synchronization of building changes and low interoperability across platforms, necessitating process redesign and digital transformation in construction projects and companies [57]. On the other hand, immersive technology research primarily focuses on the design stage of construction projects, with limited exploration in construction planning and monitoring [32]. Comprehensive research is lacking in analyzing the latest applications and developments of BIM technology in the construction industry, as well as related policy formulation, dissemination, and barriers from the perspective of construction sustainability and digitization [61,68]. Insufficient interactivity between software and unified BIM standards hinders information sharing and collaboration [68].

Moreover, the results in Section 3.5 show that integrating XR technologies, such as VR, with dynamic LCA methods provides visual feedback for the early design of sustainable communities. VR enhances communication among stakeholders and helps overcome traditional interdisciplinary barriers by improving image quality, performance, and user input. This enables end devices to interact with emissions data, facilitating communication among different stakeholders and advancing the development of sustainable communities. For instance, ZEN-VR is a VR application that visualizes key performance indicators of zero-emission communities by integrating lifecycle assessments of 11 projects, which enhances stakeholder engagement and incorporates knowledge of greenhouse gas emissions and other sustainable KPIs into the design, planning, operation, and monitoring of user-centered buildings and smart cities [25]. In addition, it is possible to compare and analyze various alternatives and predict the energy efficiency of a building at the initial planning and design stage, which can be achieved by evaluating the energy performance of the building envelope and predicting processes and costs in advance [12].

#### 4.2.3. Limitations

This paper is limited to using publications from the WoS core database, excluding articles and journals from noncore databases. This selective approach aims to ensure that the data sources are higher quality studies, but it may also lead to the omission of some interesting studies on related topics which assist future researchers in considering using different databases (i.e., Scopus) to further complement and segment immersive technology, to more comprehensively investigate the application of emerging technologies such as MR, digital twin, and algorithmic reality in smart city construction, and to validate the potential of immersive technology and BIM through empirical research to address the challenges of sustainable smart city development to support sustainable development.

## 5. Conclusions

This paper aims to explore studies emanating from the literature on immersive technology and BIM within the context of sustainable smart cities from quantitative and qualitative perspectives and addresses four research objectives: the current research status, interrelationships, emerging hotspots, and future perspectives. The main contributions of this paper are as follows:

1. In terms of research methodology and context, this paper employs a triangulation research method combining a quantitative method via bibliometric analysis and a qualitative method via content analysis to investigate the relationship between immersive technology and BIM in the context of sustainable development. It is found that immersive technology and BIM have sustained potential in addressing sustainable urban development via various fields of sustainable smart cities, including transportation systems and public services, energy conservation and sustainability, medical care, cultural heritage and tourism, and education, which is applied to the whole process of the lifecycle of architecture and engineering, provides a comprehensive perspective and foundation on urban planning and decision making, and promotes the design, construction, and management of sustainable smart cities.
2. In terms of research technique, although the bibliometric analysis method is used to reveal the current state of research and application areas of the content of the immersive technology and BIM for sustainable smart cities, it only provides a rough measure due to the complexity of the scientific development. Hence, this paper adopts the visual bibliometric map tool VOSviewer and Citespace to assist the analysis in order to minimize the impact of this limitation on the research, to make the research more rigorous, and to suggest future research with a reliable methodological reference.
3. In terms of research approach, this paper utilizes software tools in a multidimensional and systematic perspective by generating two overlay knowledge maps i.e., overlay knowledge mapping and time period knowledge mapping (knowledge top view and side view) with various perspectives such as specific knowledge network cluster, citation burst, and other detailed highlighted knowledge maps, to form a knowledge universe map at a “macro-knowledge” level stage followed by a “micro-knowledge”

level stage comprising a standard knowledge system, such as lifecycle assessment, to systematically generate knowledge and establish relationships (Figure 1), which provids a way for future research.

This study is limited to the WoSCC database, which may have omitted relevant studies, and there is a lack of implementations for practical, real-world applications and pilot projects that integrate these technologies into smart city infrastructure, operations, and citizen services. Most existing research has been conducted in controlled experimental environments. Future research needs to accumulate practical experience through the actual application of these technologies in real-world smart city settings. It is also important to expand data sources to more comprehensively cover the applications of MR, digital twins, and algorithmic reality in smart city initiatives.

**Author Contributions:** Conceptualization, Z.L., Y.H., P.D. and M.O.; methodology, Z.L., Y.H., P.D. and M.O.; software, Z.L. and Y.H.; validation, Z.L., Y.H., P.D. and M.O.; formal analysis, Z.L. and Y.H.; investigation, Z.L. and Y.H.; resources, Z.L. and Y.H.; data curation, Z.L. and Y.H.; writing—original draft preparation, Z.L. and Y.H.; writing—review and editing, Z.L., Y.H., P.D. and M.O.; visualization, Z.L. and Y.H.; supervision, Z.L.; project administration, Z.L.; funding acquisition, Z.L. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Publicly available datasets were analyzed in this study. These data can be found here: https://access.clarivate.com/login?app=wos&alternative=true&shibShireURL=https:%2F%2Fwww.webofknowledge.com%2F%3Fauth%3DShibboleth&shibReturnURL=https:%2F%2Fwww.webofknowl-edge.com%2F%3FDestApp%3DUA%26action%3Dtransfer%26mode%3DNextgen%26path%3D%252Fwos&referrer=mode%3DNextgen%26path%3D%252Fwos%26DestApp%3DUA%26action%3Dtransfer&roaming=true (accessed on 6 December 2023).

**Acknowledgments:** The authors would like to thank all the people who support this research. Z.L. would like to thank the True2life, Mansfield, England, for building his initial dream on online virtual reality with building information modeling (BIM) in a number of projects that assist him with one-man-band ability to develop a immersive technologies-driven BIM project for the Hong Kong Polytechnic University enabling him to conduct BIM for address sustainability research in Loughborough University, England, which inspire Z.L. to conduct this research to show the knowledge universe to immersive technology and BIM for sustainability in the new context of smart cities.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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