# Exploring the Current Landscape of Image-Based BIM Technologies in Smart Building Deconstruction

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# Exploring the Current Landscape of Image-BIM Technologies in Smart Building Deconstruction


## Abstract

The increasing interest in building deconstruction as a sustainable way to divert demolition waste and promote material reuse in line with circular economy principles is the focus of this research. Specifically, it investigates how Image-BIM integration can help with smart building deconstruction by using advanced technology to automatically extract information from existing structures. To map the available research, a systematic literature review and bibliometric analysis were carried out following PRISMA guidelines, and 86 relevant publications were selected for synthesis. Frequency analysis was used to determine publication trends over time, sources, and nations. The study also mapped authors, influential works, conceptual topics, and intellectual bases utilizing bibliometric networks via VOSviewer. The findings showed increasing stakeholder involvement and research outputs globally since 2015. Key authors and highly cited papers were identified that have helped the field evolve from early feasibility studies to industry-integrated demonstrations. However, some limitations remain, such as deploying verified models in real demolition scenarios and the limited scope of applications. The study recommends expanding validated use cases and employing digital technologies to achieve sustainability goals. This study sheds light on the evolving landscape of building deconstruction, emphasizing the growth in research and stakeholder involvement while highlighting important gaps and offering recommendations for future progress. It provides valuable insights into the potential of Image-BIM integration in advancing smart building deconstruction processes.



**Keywords:** Building deconstruction, Circular economy, Building Information Modelling (BIM), Sustainability, Image-based modelling, Bibliometric analysis

**Paper Type:** Review Paper

## 1. Introduction

Building construction and deconstruction activities generate significant amounts of waste across the world annually. Statistics indicate that waste from building demolition accounts for 30 to 50 percent of all waste in industrialized countries (Webster, 2007). End-of-life activities generate the most significant amount of waste with a large portion of demolition waste materials being thrown into landfills, causing numerous adverse environmental consequences (Taherkhani, 2014; Taherkhani *et al.*, 2021). With ongoing rapid urbanization and expansion of the construction sector, (Ge *et al.*, 2017) opined those problems pertaining to construction, demolition, and excavation waste (CDEW) are becoming increasingly severe. To effectively tackle construction waste issues, it is necessary to optimize building design, construction processes, and end-of-life scenarios. (Aram *et al.*, 2022; Kibert, 2007). Deconstruction, which refers to the complete or partial disassembly of a building, has emerged as a practical solution that can divert waste away from landfills and facilitate material reuse by closing material loops and transitioning towards circular economy principles (Addis and Jenkins, 2008; Akbarieh *et al.*, 2020). Evidence indicates that an appropriate deconstruction strategy implemented through effective design can remove up to 50% of CDEW from landfills (Akinade *et al.*, 2015). However, deconstruction poses unique challenges due to the complexity, diversity, and uniqueness of building designs and components (Crowther, 2005). Effective planning and execution of building deconstruction requires comprehensive information about the structure, components, and materials (Eckelman *et al.*, 2018).

Building Information Modelling (BIM) has transformed various aspects of the Architecture, Engineering, and Construction (AEC) industry due to its numerous advantages across the project life cycle such as cost estimation, project coordination, facility management, and demolition analysis (Andriamamonjy *et al.*, 2019; Charef *et al.*, 2018; Tingley and Davison, 2015). According to (Akhimien *et al.*, 2021), the European Commission has recommended using BIM for pre-construction auditing to effectively assess the reuse and recycling potential of materials. Recent studies indicate BIM can facilitate sustainable deconstruction by enabling digital planning, execution as well as sustainability assessment of end-of-life scenarios as part of an integrated life cycle approach (Chong *et al.*, 2017; Volk *et al.*, 2018). However, research utilizing BIM capabilities specifically for deconstruction purposes is still limited (Akanbi *et al.*, 2019). Prior reviews have also not comprehensively analyzed the integration of building deconstruction and BIM (Akbarieh *et al.*, 2020; Nikmehr *et al.*, 2021). Recent advances in computer vision and image processing technologies have enabled new opportunities through image-based extraction and reconstruction of building information (Hu *et al.*, 2022; Zakerhosseini *et al.*, 2023). Such image-BIM technologies allow the automatic generation of BIM models directly from images of existing structures, eliminating the need for manual data collection (Manca *et al.*, 2020; Sözer *et al.*, 2020). Despite the potential benefits, limited efforts have focused on utilizing image-BIM approaches to support smart building deconstruction processes. A recent review identified this gap and called for more research on digitalizing deconstruction practices through emerging technologies such as image-based modeling (Obi *et al.*, 2021).

Considering the above context, by synthesizing scattered literature through scientific mapping and quantitative evaluation, this study aims to provide a holistic understanding of the current status and future prospects for smart building deconstruction based on image-BIM integration. Specifically, the objectives are to:

- Map the current research landscape, themes, and trends in this area;
- Identify key gaps and challenges limiting further development; and
- Recommend potential future research directions.

## Summary of Literature Reviews of Image-BIM Study Applications

BIM provides a platform for integrating image and sensor data with structured deconstruction information (Valinejadshoubi et al., 2022). However, interoperability remains a challenge due to the lack of standardized nomenclature and protocols for exchanging such data across project team applications (Shehzad et al., 2021). Augmented/virtual reality applications are being developed to overlay deconstruction schedules, material take-offs, and hazardous material locations onto the visual context for training and on-site guidance (Jerald, 2015). Automated disassembly sequence generation from BIM and IoT data is another active area (Rausch et al., 2019). Planning methodologies have been proposed for maximizing materials recovery and minimization of environmental impacts (Goldstein et al., 2011). Technologies also play a role in safety planning through automated hazard detection (Zhang et al., 2017) and worker training simulations.

This review of literature forms the basis for reviewing the current status of research and practice at the intersection of these domains, with a focus on image-based BIM technologies for smart and sustainable building deconstruction. The review identifies key gaps and outlines future research directions in this emerging field. Table I**Error! Reference source not found.** provides a comparative synthesis of implemented economic benefits and persisting gaps/challenges across the BIM-deconstruction case studies.

*Table I : BIM-deconstruction case studies, implemented benefits and challenges*

| Year | Author(s) | Study | Implemented Economic Benefits | Key Gaps/Challenges |
|---|---|---|---|---|
| **2015** | Megahed | Towards a theoretical framework for HBIM approach in historic preservation and management. | HBIM digitization streamlines preservation projects and cuts the costs of documentation errors. | The framework requires field implementation validation for precision historic planning integration complexity addresses. |
| **2017** | Zhang, Cao & Zhao | Applying sensor-based technology to improve construction safety management. | Sensor monitoring improves hazard identification cutting risks and associated costs. | Construction complexities challenge comprehensive safety oversight despite technologies, necessitating further refinement. |
| **2018** | Ghisellini, Ripa & Ulgiati | Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review | Potential material recovery estimated to calculate revenue gains from reuse/recycling. Reduced labor costs for documentation. | In the first pilot study, uncertainties remained about scale-up and applicability to real complex demolition sites. |
| **2018** | Gálvez-Martos, Styles, Schoenberger & Zeschmar-Lahl | Construction and demolition waste best management practice in Europe | Waste volumes are estimated to help improve management and reduce disposal costs. | The heterogeneous landscape of waste management practices across EU member states makes standardized implementation challenging |
| **2018** | Wong, J. K., Ge & He | Digitization in facilities management: A literature review and | Digital technology assimilation into facility management practices trims maintenance faults while maximizing | Limited reviews preclude comprehensive insights needed guiding research |

| | | | | |
|---|---|---|---|---|
| | | future research directions | resource utilization for expense reduction. | cohesion across technologies. |
| **2018** | Volk, Luu, Mueller-Roemer, Sevilmis & Schultmann | Deconstruction project planning of existing buildings based on automated acquisition and reconstruction of building information | Mobile scanning aids planning and cuts retrofit/deconstruction risks and costs. | Automated processing requires further testing and parameter optimization for real-world precision project integration. |
| **2021** | Xue, Hou & Zeng | Review of image-based 3D reconstruction of building for automated construction progress monitoring. | 3D reconstruction linking photos to integrated BIM schedules facilitates overseeing work and comparing intended to actual situations, where divergence detection may diminish unpredictable expenses through impending hazard guidance. | Though many techniques emerged, relationships between them remain unclear as works fail to relate methods systematically, challenging comprehension for researchers opting for applicable tools despite this effort to pursue mapping knowledge gaps and associating perspectives. |
| **2022** | Valinejadshoubi, MMoselhi & Bagchi, | Integrating BIM into sensor-based facilities management operations. | Integrating BIM with sensors data facilitates maintenance cuts disruptions impacting monitoring services costs. | Workflow requires expanded integration of additional sensor types and machine learning for autonomous fault detection rather than relying on manual reporting. |

## 2. Methodology

This study adopts a systematic review approach guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page *et al.*, 2021). A bibliometric analysis is also conducted to map and analyze the emerging research landscape. PRISMA is an evidence-based minimum set of items for reporting systematic reviews and meta-analyses. It aims to help authors improve the reporting of systematic reviews and meta-analyses (Page *et al.*, 2021). The PRISMA checklist is followed to ensure all relevant aspects are covered in this review. The bibliometric analysis methods used in this study are based on established techniques for mapping scientific literature, and research trends, as demonstrated in previous studies (Chen, 2017; Donthu *et al.*, 2021; Han *et al.*, 2020). Bibliometric indicators such as publication counts, citation frequencies, and co-occurrence networks provide both quantitative and qualitative insights into research trends, intellectual bases, and emerging fronts (Li *et al.*, 2017; Zhao, 2017). VOSviewer, a recognized bibliometric software, is used to conduct the analysis and create visualization maps (Jan van Eck and Waltman, 2018; Markscheffel and Schröter, 2021). To address the objectives mentioned in section 1, the review involves the following systematic methodology:

### 2.1. Literature Search and Selection

Scopus was used to find relevant literature. Scopus is one of the most comprehensive citation databases for engineering and construction bibliometric analysis(Burnham, 2006; Echchakoui, 2020). Architecture, building technology, and smart construction are also covered in detail (Locatelli *et al.*, 2021)The initial search keywords were image-based BIM, image-to-BIM, image BIM, deconstruction, dismantling, demolition, and building or structures or facilities. The review included English documents published between January 2015 and December 2022. Due to limited research before then, the start year was 2015. Unpublished manuscripts were rejected for quality. This review included only English-language publications due to the potential for inaccuracies and inconsistencies in translating non-English texts, which could affect the reliability, and validity of data extraction, and analysis. While this approach ensures methodological consistency, it may exclude valuable insights from non-English sources, which we acknowledge as a limitation.

After eliminating 154 duplicates, 374 documents remained for screening. The following qualifying criteria were independently assessed for titles, abstracts, and full texts:

- Research on image-based BIM methods for building deconstruction, demolition, and disassembly.
- Research on using image data/processing technologies (photogrammetry, computer vision, augmented reality) to extract structural information for end-of-life building assessment or planning.
- Reviewed articles, books, and book chapters on smart technologies for digital deconstruction were included.

The final review included eighty-six publications that met all criteria.

## 2.2. Data Extraction and Analysis

A standardized form was designed in Microsoft Excel to extract relevant data from the selected studies. The following key aspects were recorded:

- Bibliometric details: author/s, year, document type, source title.
- Contextual descriptors: study objectives, image techniques used, case study details.
- Key findings: frameworks/tools developed, limitations addressed, recommendations provided.
- Citation metrics: number of citations for articles published until mid-2022 using Scopus.

The extracted data underwent descriptive statistical analysis using SPSS statistical software. Frequency distributions helped understand publication trends across years and sources. Citation analysis was also performed to determine the most influential articles.

CVS files were generated for selected Scopus studies for bibliometric mapping. R was used to clean and integrate the datasets, removing duplicates with "Bibmerge". VOSviewer received the final CVS file with 86 unique publications. Normalising minimum occurrences to 1 for all related publications set bibliometric network thresholds. Based on six bibliometric indicators—authors, keywords, sources, organizations, countries, and cited references—VOSviewer's overlay visualization and clustering algorithms created maps. Network visualization revealed field contributors, conceptual domains, emerging fronts, and citation dynamics. Mapping was augmented by descriptive text analysis. Future sections present a systematic review and bibliometric analysis results to fully address the research questions.

## 2.3. Data Sources and Search Strategy

Database-regulated vocabulary and syntax customized initial search phrases. The first search was on January 16, 2024, and second on March 19, 2024, to include current articles. Manual snowballing searches through references and citations reduced oversight. The initial screening identified specialized journals for later searches. Since 2015, English articles have been selected for their built environment research. 2015 was the "foundation year" for automated 3D reconstruction and digital modeling research, justifying timelines(Hu *et al.*, 2022). This method preserved seminal works and allowed trend analysis. The database accepted only peer-reviewed journal articles, conference papers, and scholarly publications. Secondary sources like unpublished literature, newspaper stories, newsletters, and magazine features were removed for data quality and reliability.

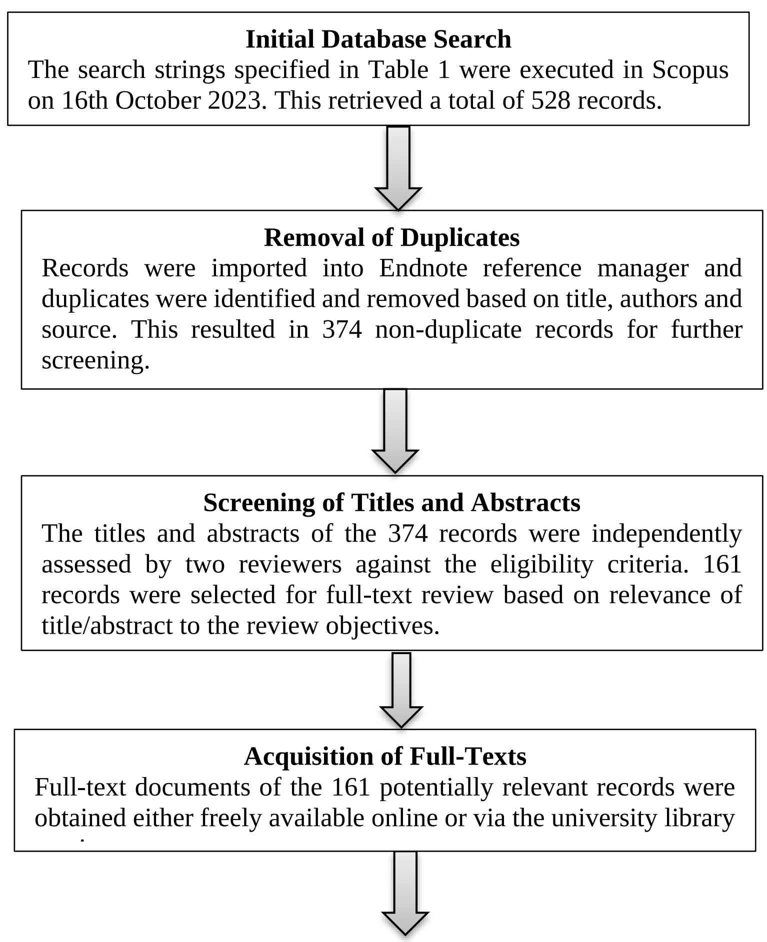
## 2.4. Data Evaluation and Management

The PRISMA flowchart in Figure I shows the screening and filtering workflow. Two independent reviewers assessed titles and abstracts of retrieved publications based on eligibility criteria after deduplication. According to (Perianes-Rodriguez *et al.*, 2016), discussion resolved differences to agree on including or excluding studies. Full texts of potentially eligible documents were then acquired and screened again for methodologies and application contexts that met review objectives. To find missing relevant studies, all source reference lists were hand-searched. The final 86 publications formed the systematic review analysis evidence base. MS Excel, RSS filtering tool, and CVS database file manager recorded and managed publication screening, data extraction, analysis, and bibliometric mapping. Coded identifiers were used to track workflow integrity and reproducibility (Aria and Cuccurullo, 2017).

# 3. Results

## 3.1. Selection Results

This section presents key quantitative insights derived from systematically reviewing and mapping the available published evidence related to digital technologies for smart deconstruction. Both descriptive statistics and bibliometric outcomes were analyzed to understand the evolving landscape of interest areas, contributor dynamics, as well as research networks and directions constituting this domain. The PRISMA flow diagram in Figure I The study selection process employed is summarized. A detailed report of the selection workflow is provided for replication and analysis purposes.



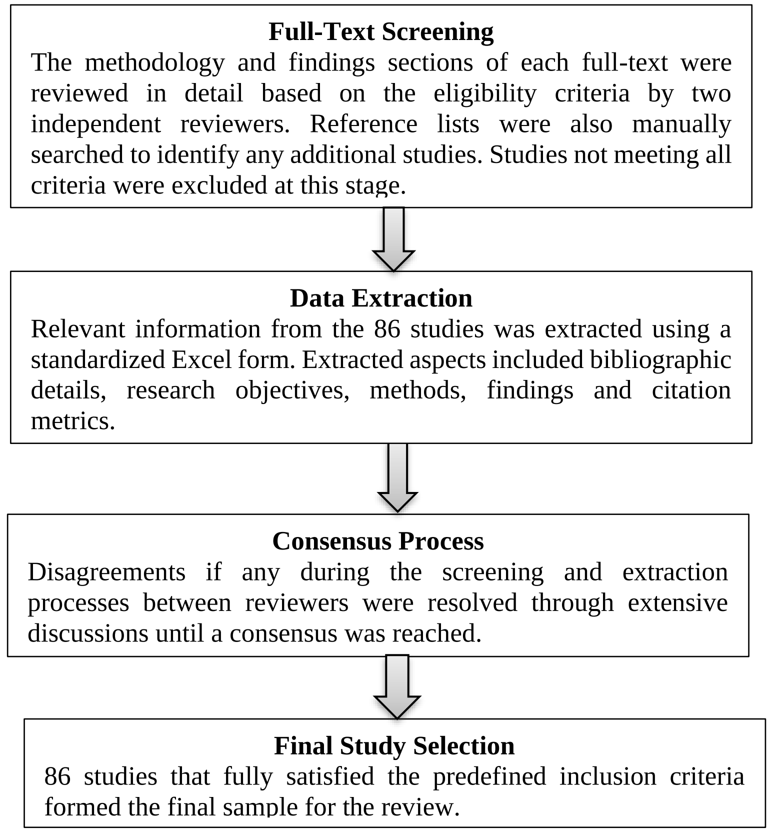



*Figure I: Study selection process*

## 3.2. Publications Source and Type

Journals contributed the majority (83.72%) of included literature, with the most prominent sources being Waste Management & Research, the Journal for a Sustainable Circular Economy (9 articles), and the Journal of Sustainability (8 articles). This affirms the interdisciplinary nature of the research topic drawing perspectives from both engineering informatics and built environment domains. Conferences made up 12.79% of the evidence, a considerable proportion originating from specialized events like AIP Conference Proceedings and Proceedings of the 24th International Symposium on Advancement of Construction Management and Real Estate. Three books constituted the remaining 3.49%, tailored to professionals seeking knowledge consolidation beyond individual studies.

## 3.3. Geographical Distribution

Figure II presents an overlay visualization map based on the country of affiliation recorded for the 86 studies. It highlights 18 countries participating in research endeavors. The United Kingdom emerged as the dominant contributor with 21 publications (22.11%), followed by China publishing 12 articles (12.63%) and Australia publishing 11 (11.58%). Papers from Spain received the maximum average citations of 139, followed by Australia (73.72), China (44.91), and the United Kingdom (31.62) per article. This emphasizes comparative influence and outreach achieved by research despite the count variations.

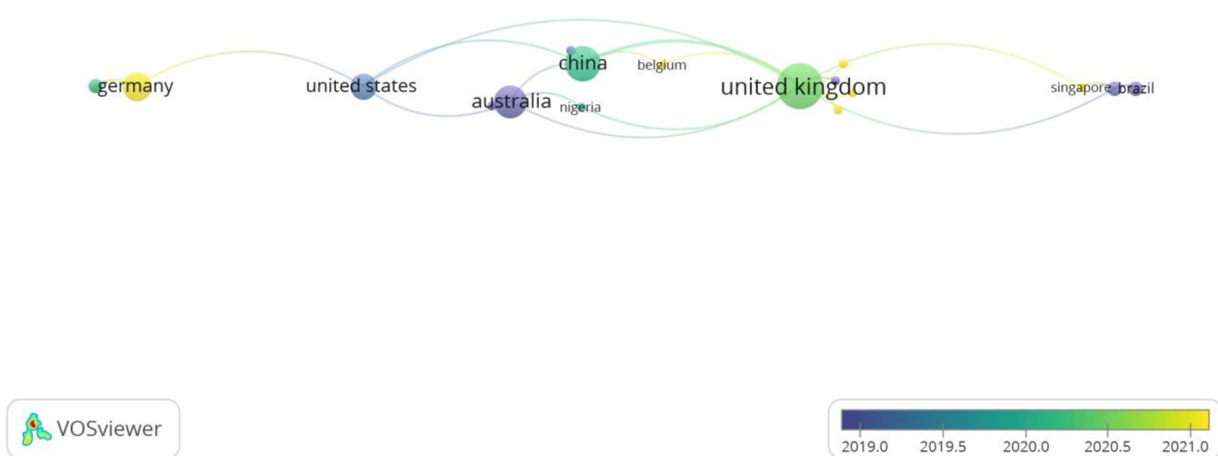



*Figure II: Geographical Distribution Chart*

### 3.4. Institutional Collaboration

The organization collaboration network derived from VOSviewer clustering in Figure III identified 79 institutions actively conducting research in this area, evidencing increased cross-institutional research consortiums and knowledge exchange in recent years compared to the individual efforts observed earlier. The University of South Australia topped the list with the highest number of collaborative articles (6), followed by Deakin University Australia (4).

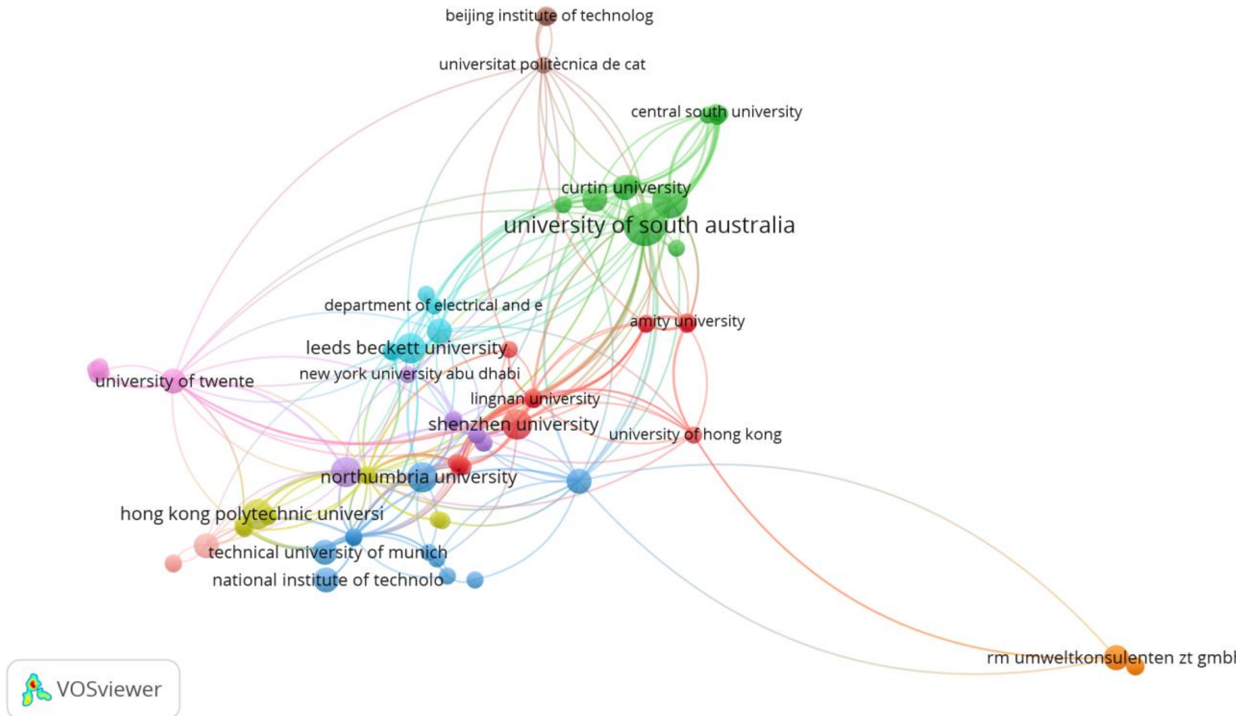



*Figure III: Institutional collaboration network*

## 3.5. Authorship Landscape Analysis

A total of 143 authors contributed to the 86 articles constituting this study's evidence bases for analysis. Table II ranks the top 10 authors based on their overall research productivity, calculated as the number of quality publications and total citations received until mid-2022. Chileshe, Nicholas, and Rameezdeen, Raufdeen emerged as the foremost authors, with five publications each and 25 and 14 total citations, respectively. The next leading contributor was Haas, Carl, who published three articles. Their inclusion in multi-authored works complements the distributed trend of research teams over standalone efforts observed across outputs investigated.

*Table II: Overall Research Productivity by Authors*

| Author | Publications | Citations |
|---|---|---|
| Chileshe, Nicholas | 5 | 25 |
| Rameezdeen, Raufdeen | 5 | 14 |
| Haas, Carl | 3 | 3 |
| Charef, Rabia | 2 | 9 |
| Yu, Bo | 2 | 6 |
| Hosseini, M. Reza | 2 | 2 |
| Chen, Zhe | 2 | 3 |
| Rakhshan, Kambiz | 2 | 61 |
| Morel, Jean-Claude | 2 | 1 |
| Zhao, Yiyu | 2 | 61 |

## 4. Bibliometric Analysis Results

Table III describes VOSviewer's bibliometric analysis and publishing pattern mapping method. To define the intellectual structure, authors, keywords, sources, organizations, nations, and cited references were used to create networks. The full counting method was used to evaluate the 86 publications. Bibliometric variables, including citations, collaboration density, and average publication year, helped prioritize high-impact organizations. Visualizing element connections revealed dataset conceptual links.

*Table III: Methodology employed for conducting bibliometric analysis*

| **Indicators for network generation** | **Details** |
| --- | --- |
| Authors | Co-authorship links between authors of publications |
| Keywords | Co-occurrence of keywords across publications |
| Sources | Links between sources of publications |
| Organizations | Institutional collaboration links |
| Countries | Inter-country collaborative links |
| Cited references | References cited across publications |
| Input publications | 86 publications selected from systematic review |
| Counting method | Full counting of links between bibliometric elements |
| Important metrics | Citations, collaboration density, average publication year |
| Visualization | Connections between elements to identify conceptual relationships |
| Objective | Comprehensively delineate intellectual structure and identify high impact entities |
| Software | VOSviewer for bibliometric network analysis and mapping |

### 4.1. Authors Co-citation Network

Figure IIII Demonstrates the co-citation network of authors constructed based on the criterion that an author should have minimum 40 citations or more within the mapped publication set(Ding *et al.*, 2009). The network highlights 16 globally influential authors at the forefront of research progress based on peer acknowledgements. Oyedele, Lukumon O. occupies the dominant node position with 134 total citations confirming his seminal thought leadership. Direct links between leading authors demonstrate conceptual alignment enhancing integrity of the evolving research domain.

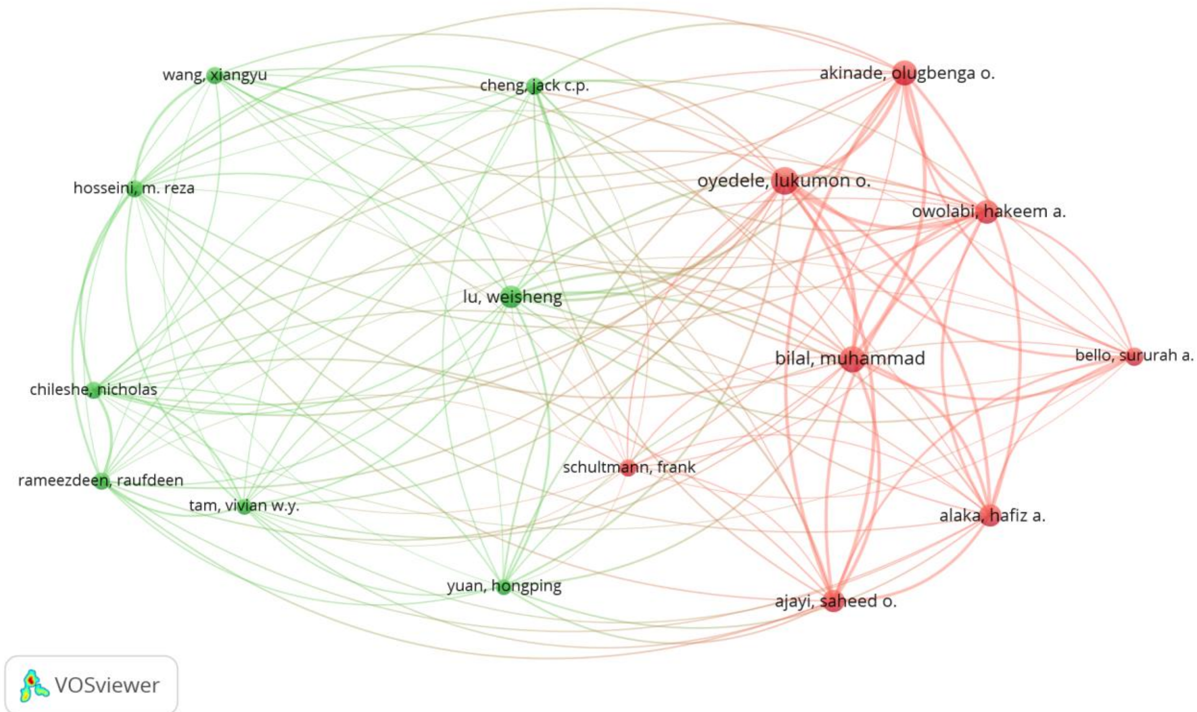



*Figure IIII: Co-citation Network of Authors*

## 4.2. Country Co-citation Network

The country co-citation network in Figure V delineates research collaborations through cross-country acknowledgments among publications. It recognizes top seventeen nations with a minimum twenty cross citations or joint publications. United Kingdom emerged as the pivotal collaborating hub based on their total link strength of forty-five from VOSviewer clustering, while Australia and China consolidated their leadership through extensive international engagement with link strengths of 34 and 28, respectively, showcasing future research potential.

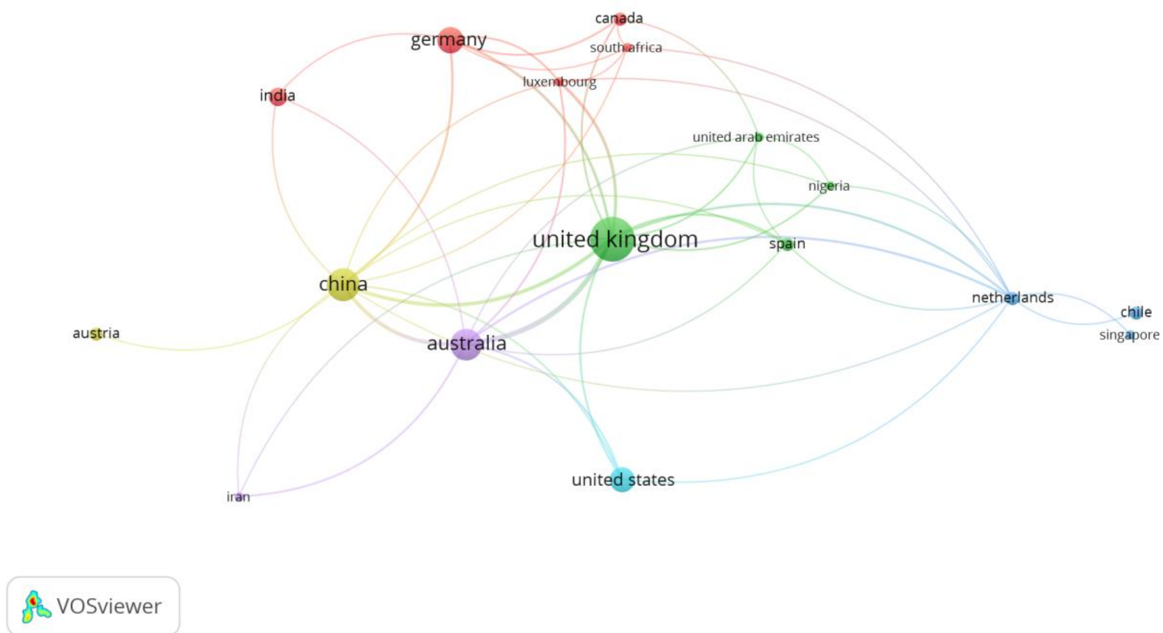



*Figure V: Country Co-citation Network*

## 4.3. Citation Analysis

Citation analysis of eighty-six publications identified highly significant outputs showing research impact over time. From 2015 to 2022, 2,497 citations occurred. Figure IV shows that publication citations have increased over time, peaking in 2018 (678). With 639 and 413 citations, 2020 and 2021 works also garnered attention. As the area evolves, research production and knowledge development increase, as does worldwide recognition and knowledge absorption. Since 2020, Ruiz's Journal of Cleaner Production paper has had 238 citations, topping the list. Its pioneering work is highlighted here. Review studies summarizing earlier advances and case application papers maximizing practitioner dissemination are also helpful. As indicated, Sustainability, Journal of Cleaner Production, Waste Management & Research, Journal for a Sustainable Circular Economy, and Automation in Construction published many influential works advancing BIM, computer vision, and construction research lifecycles. Their pioneering work supports integrated studies.

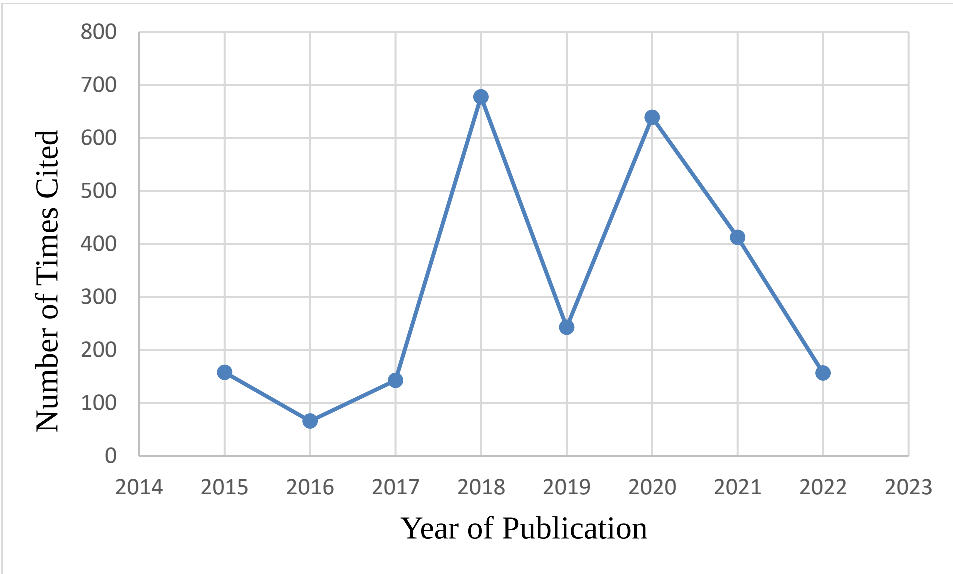



*Figure IV: Annual citations trend for publications*

## 4.4. Highly Cited References Network

Figure V Visualizes the network of cited references across the selected 86 publications developed through VOSviewer. It maps the intellectual bases acknowledged by each study to shape the emerging knowledge domain through concepts, frameworks, and prior cases built upon.

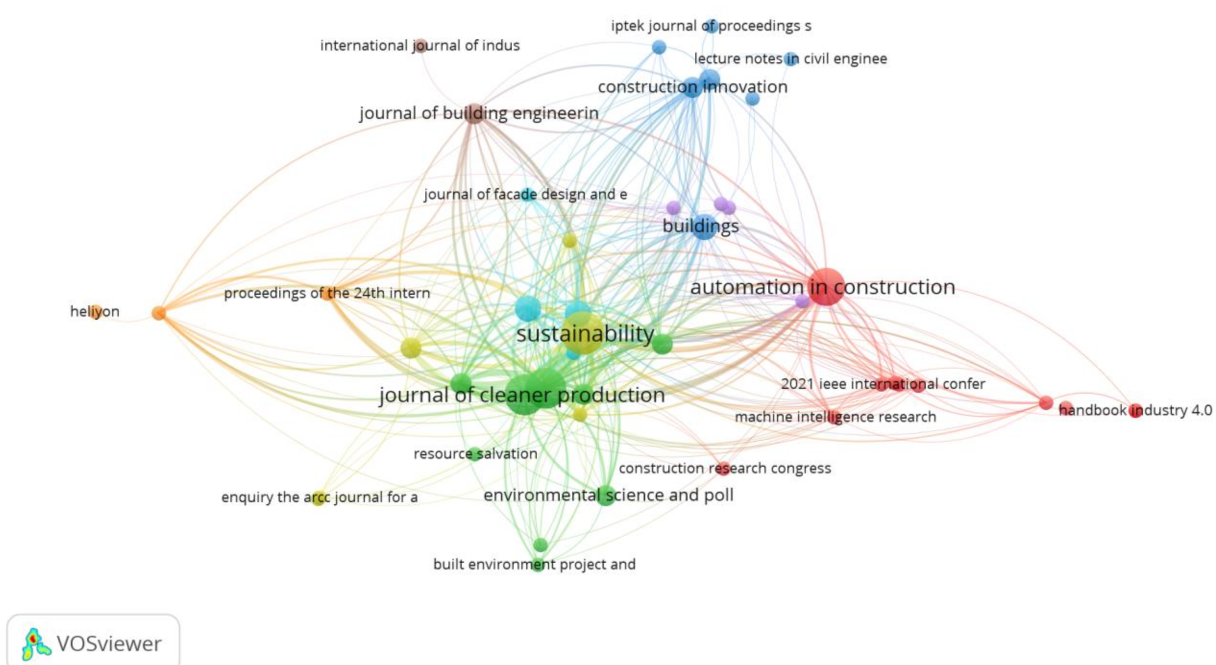



*Figure V: Network of Cited References*

## 4.5. Bibliographic Coupling Network of Publications

Figure VIII demonstrates the bibliographic coupling connections between publications derived based on their common cited references identified through VOSviewer without recurrence filtering. It clusters publications endorsing similar premises through similar peer acknowledgments in backgrounds. Publications centrally placed signify fundamental papers conceptualizing key notions that laterally related works proceeded upon to expand methodologies or validate in new scenarios. Observed density highlights collectively advancing knowledge frontier, yet dispersion indexes diversifying thinking into emerging problem areas like structural demolition planning subtle from original motivations.

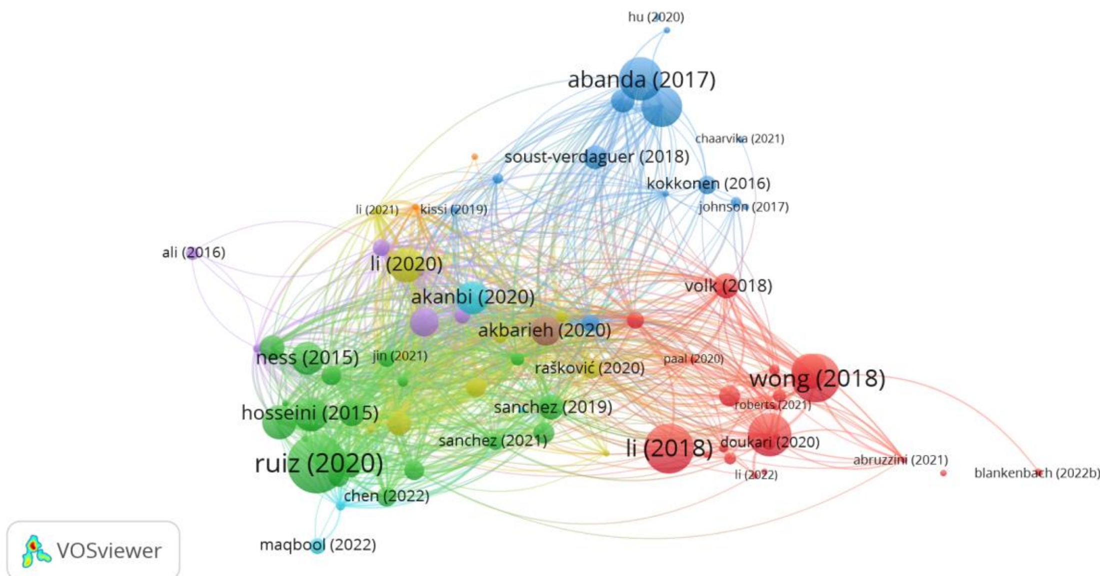



*Figure VIII: Bibliographic Coupling Network*

Bibliometric networks and descriptive statistics mapping the intellectual landscape confirmed an evolving multidisciplinary research consortium globally engaged in solving vital industry and sustainability challenges through disruptive modeling solutions. Discussion qualitatively interprets these outcomes.

# 5. Discussion

The results obtained from systematically reviewing and mapping the available literature provide valuable insights into the current state and gaps shaping research at the intersection of image-BIM technologies and smart building deconstruction. This section qualitatively analyses key findings to address the study's specific objectives.

## 5.1. Research Trends and Productivity

The analysis of research trends and productivity in this cross-disciplinary domain highlights a progressive growth in scholarly attention since 2015. This growth coincides with significant advancements in digital modeling capabilities, which have revolutionized the field. The increasing number of publications each year confirms the expanding knowledge frontiers and the growing global interest in this study area.

A closer examination reveals that journals remain the primary platforms for disseminating research findings, playing a crucial role in the academic community. However, conferences also contribute significantly by enabling the rapid dissemination of research results and providing immediate feedback on prototypes and early-stage research. These conferences facilitate dynamic exchanges and foster a collaborative environment for researchers to present their work, receive constructive critiques, and refine their methodologies.

Research in this domain is characterized by multi-national partnerships rather than isolated efforts. These collaborations underscore the strategic importance of optimized demolition practices in the transition toward sustainability. The focus on sustainable practices reflects a global commitment to environmental preservation and resource efficiency, highlighting the critical role of interdisciplinary research in addressing complex challenges.

The most productive authors in this field predominantly investigate construction, engineering, and architecture challenges. This reflects the intermingling of different application viewpoints and underscores the interdisciplinary nature of the research. By integrating perspectives from various disciplines, researchers can develop more comprehensive and innovative solutions to the challenges faced in the field.

Top publishing nations, which spearhead technological innovations, play a pivotal role in advancing research. These innovations are subsequently localized through international engagements, facilitating the global dissemination and adoption of new technologies. The collaborative nature of these efforts ensures that advancements are not confined to specific regions but are shared and implemented worldwide.

Bibliometric maps provide a visual representation of research dynamics over the past decade. They highlight the evolution of author collaboration networks, evidencing a shift from solitary works to distributed multi-institutional initiatives. This rise in productive teams, as opposed to lone authors, supports the trend towards open collaborations. Such collaborations are essential for advancing knowledge frontiers more rapidly as they leverage multiple institutions' diverse expertise and resources.

In summary, the research trends and productivity in this domain demonstrate a vibrant and growing field driven by technological advancements and a commitment to sustainability. The collaborative efforts, both within and across national boundaries, underscore the importance of interdisciplinary research and the collective pursuit of innovative solutions. As the field continues to evolve, it is expected that these trends will persist, further expanding the frontiers of knowledge and contributing to the development of sustainable practices in demolition and construction.

## 5.2. Knowledge Gaps and Recommendations

Despite the significant advancements made in the field, several impediments require focused attention. One of the primary challenges is that validated models are often developed and tested in controlled laboratory environments, which leaves uncertainties when these models are deployed in actual, complex demolition sites. These scale uncertainties need to be resolved to ensure the models' effectiveness in real-world applications. Furthermore, replicating these models across diverse geographical conditions is essential to determine their generalizability and broader applicability.

Current applications tend to center predominantly on independent structural inspections, often overlooking the sociotechnical complexities at project interfaces. These include managerial, regulatory, and worker engagement dimensions that are crucial for comprehensive project success. Therefore, to truly optimize deconstruction processes, there is a pressing need to develop enriched digital twins. These advanced models should integrate multi-stakeholder coordination dynamics, facilitating a more holistic approach to project management.

In addition to technological advancements, addressing socio-technical factors such as regulatory frameworks, and stakeholder dynamics is critical for the successful implementation of image-BIM technologies in building deconstruction. For instance, regulatory variations across jurisdictions often hinder the uniform application of BIM-driven processes. Developing adaptable compliance frameworks could facilitate more widespread adoption.

Moreover, effective stakeholder engagement is essential to align project objectives with the diverse priorities of contractors, policymakers, and end-users. Establishing collaborative platforms that integrate these perspectives could optimize project outcomes and ensure regulatory alignment.

Future research directions should focus on expanding the valid use cases that demonstrate the socioeconomic and environmental sustainability payoffs realized from integrating image-based Building Information Modelling (BIM) in various deconstruction contexts. This includes standardizing industrial pathways that assist practitioners in making informed technology adoption decisions, which is crucial for scalable circular transformations in the industry.

Prospects for the future also include conceptualizing deconstruction automation through the application of computer vision technologies. Integrating robotics into the deconstruction process can significantly enhance worker safety, particularly when inspecting hazardous environments. Additionally, synthesizing heterogeneous data sources will leverage multimodal sensing capabilities, bringing together several types of information gathered from various devices. This integration will improve the overall understanding of deconstruction processes.

Another critical area of focus is developing semantic ontologies that capture tacit procedural knowledge. These ontologies facilitate the automation of building deconstruction processes and tasks by organizing expert knowledge into systematic frameworks. As highlighted by Dimyadi et al. (2016), such frameworks allow automation systems to follow complex procedural steps effectively.

Strengthening academia-industry linkages is vital for translating laboratory models into practical field tools that maximize circular outcomes. Joint efforts to identify localized problems and develop customized solutions will reconcile innovation goals with contextual appropriateness, ensuring that advancements are practical and relevant in different settings.

Implementing demonstrable economic benefits, such as the use of reclaimed materials, minimized waste, and automated planning via BIM, has been shown to yield higher profits through reduced costs and increased recycling incomes in various case studies. These tangible benefits encourage the uptake of advanced technologies and promote a more sustainable approach to deconstruction practices.

The integration of digital twins, and robotics into sustainable deconstruction practices offers transformative potential, yet their large-scale implementation faces significant hurdles. Resource-intensive deployment and limited field testing highlight the need for phased adoption strategies. For example, pilot programs in partnership with industry stakeholders could serve as proof-of-concept initiatives, demonstrating feasibility, and cost-efficiency. Collaborative efforts between policymakers, and industry leaders are crucial to subsidize initial implementation costs, and create incentives for adopting these advanced technologies.

Policy frameworks play a pivotal role in operationalizing these recommendations. Aligning regulatory standards with technological capabilities could accelerate adoption. For instance, mandating the use of digital twins for large-scale projects or offering tax benefits for robotics integration in hazardous environments could provide the necessary impetus for industry-wide shifts. Additionally, developing guidelines for resource allocation and training programs would address the skill gap, ensuring the workforce is prepared to handle advanced tools.

In practice, projects such as the Circular Construction in Regenerative Cities (CIRCuIT) initiative in Copenhagen and the Deconstruction of the Silo Building in Zurich have demonstrated the utility of BIM in mapping building components for recovery. However, these examples reveal challenges such as limited interoperability and insufficient adoption of image-based modeling in demolition planning, reflecting the broader gaps identified in this review.

In summary, addressing the current knowledge gaps and implementing the recommended strategies will significantly enhance the effectiveness and sustainability of deconstruction practices. By focusing on real-world applicability, integrating advanced technologies, and fostering academia-industry solid collaborations, the field can continue to evolve and contribute to a more sustainable and efficient construction industry.

## 6. Conclusion

This study provides a comprehensive overview of the landscape of Image-BIM integration in smart building deconstruction, addressing sustainability challenges in the construction industry. Key conclusions can be drawn from the systematic literature review and bibliometric analysis:

- Global Research Trends and Productivity:
  - Growing Interest: The research landscape has witnessed a steady increase in interest since 2015, indicating a global recognition of the importance of smart building deconstruction for sustainable practices.
  - Interdisciplinary Collaboration: Collaboration is increasingly evident, with multi-national research partnerships highlighting the interdisciplinary nature of this field. Notable contributions come from diverse geographic regions, with the United Kingdom leading in terms of publications.
- Institutional and Author Contributions:
  - Collaborative Networks: Institutional collaboration networks reveal an increasing trend in multi-institutional initiatives, demonstrating a shift from individual efforts to collaborative endeavors.
  - Influential Authors: The top authors, such as Oyedele and Rameezdeen, emerge as thought leaders, contributing significantly to the advancement of the field. Their influence is reflected in high citation counts.
- Knowledge Gaps and Recommendations:
  - Validation Challenges: The study identifies challenges in deploying validated models in real demolition scenarios, emphasizing the need for addressing uncertainties and ensuring scalability.
  - Limited Application Scope: While advancements are noted, there is a notable gap in addressing socio-technical complexities, urging the need for enriched digital twins to comprehensively optimize building deconstruction.
- Holistic Understanding:
  - Intellectual Landscape: The bibliometric analysis provides a visual representation of influential authors, key publications, and conceptual topics, offering a holistic understanding of the evolving intellectual structure of this cross-disciplinary domain.
- Future Research Directions and Study Limitations:
  - Expanded Use Cases: Recommendations underscore the importance of expanding validated use cases, especially in demonstrating socio-economic and environmental sustainability outcomes.
  - Automation Opportunities: Future research should explore automation opportunities, integrating computer vision and robotics to enhance worker safety and automate various aspects of building deconstruction.
  - Standardization and Collaboration: Standardizing industrial pathways and strengthening academia-industry linkages are essential for maximizing the benefits of Image-BIM integration in diverse construction environments.

This work's limitations include potential publication bias, as it relies on literature indexed in the Scopus database, and the exclusion of non-English literature may limit the comprehensiveness of the review.

While this study highlights the immense potential of digital twins and robotics in sustainable deconstruction, their practical adoption hinges on overcoming current challenges, such as resource demands, and the lack of large-scale validation. Realizing these recommendations requires targeted policy interventions, collaborative industry efforts, and significant technological advances. By addressing these gaps, stakeholders can transform ambitious concepts into actionable solutions, advancing both sustainability and innovation in the construction sector.

In conclusion, this study not only maps the current state of Image-BIM technologies in smart building deconstruction but also outlines crucial challenges and provides strategic recommendations for future research. The findings contribute to advancing sustainable practices in the construction industry by leveraging cutting-edge technologies and fostering global collaboration.

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