

Adapting Content Generation Knowledge to Extended Reality Based Training in Construction: A Systematic Literature Review

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ABSTRACT: Extended Reality (XR) based training applications designed for the construction environment is rapidly gaining popularity, but creating high-quality content remains a significant challenge. Traditional content generation methods, such as manual 3D modeling, paper-based checklist creation, the creation of static training simulations, reliance on pre-recorded video and 2D diagrams for instruction, and manual annotation of 3D models for training purposes, are time-consuming, require specialized skills, and are often cost-prohibitive, limiting scalability and accessibility. While other industries have successfully implemented automation and artificial intelligence (AI) for content creation, the construction field continues to rely heavily on manual processes. By learning from advancements and best practices in other fields, the construction industry can overcome these challenges and unlock the full potential of XR for training its workforce. This systematic review analyzes and synthesizes the current literature on content generation techniques for XR-based training. It examines different content generation methods, identifies some benefits and challenges, and explores their potential suitability for various training domains and objectives. The review explores content generation methods, XR technology platforms, interaction types, and learning environments, with a focus on their potential to inform best practices for construction. Following PRISMA guidelines, the review included studies from top-quantile peer-reviewed journals and conferences over the past 20 years, identifying 97 direct relevant studies from Scopus, ACM library, and Web of Science. The review indicates that while 3D modeling remains dominant in XR training content creation, AI-powered generation is still emerging with limited applications specifically for training content. Initial findings suggest potential benefits such as increased learner engagement and reduced development time, but challenges in accuracy and ethical considerations persist. The insights gained can inform the development of guidelines and best practices for creating high-quality XR training content tailored to the construction environment.

1. INTRODUCTION

The shortage of skilled construction labors has been continued for years in different countries and areas (Brucker Juricic et al., 2021; Ho, 2016; Maqbool et al., 2024; Zaki et al., 2012). Meanwhile, extended reality (XR) training, including virtual reality (VR), augmented reality (AR) and mixed reality (MR) technologies have emerged as powerful approaches that helped address the skilled labor shortage. XR technologies are especially useful for training in highly practical fields where hands-on experiences are critical, such as medical, manufacturing and construction. Within years of experimenting and improvement, XR training has been proved on its effectiveness and the head-mounted display (HMD) headsets have been recognized as highly engaged and flexible training mediums. For example, a systematic literature review highlighted that XR has been successfully used for surgical skills training and other simulation training that led to increased confidence of trainees and prepared them for real-world scenarios (Co et al., 2023). Another review has discussed the monitored increased time taken for completion in monitoring assembly line and job shops tasks in the manufacturing factors (Doolani et al.,

2020). Likewise, in the construction industry, a content review has shown how XR enhance trainees' responses to the high-risk tasks, learning equipment operations, performing ergonomics or postural training, and so on (Jin et al., 2024).

While the potential of XR training has been explored across different disciplines, every training application and its tasks need to be well designed. However, challenges remain in XR training content development. These include the time-consuming nature of content creation, the high costs associated with development, the specialized skills required for effective implementation. In contrast, other fields have successfully applied advanced content generation practices and techniques, demonstrating the potential of adapting their experiences to the construction XR training. For example, A surgical training toolkit offers educators to drive the creation of learning scenario, which allows customization of specific procedural steps with reduced programming and technical modelling knowledge required (Scott et al., 2008). Another authoring platform for distance learning enabled object manipulation within the VR spaces with built-in artificial intelligence (AI) support (Koyama et al., 2022). With an interest in understanding the status of content generation in XR training across various domains, including construction, a systematic literature review has been conducted to gather valuable insights. Two research questions were established:

RQ1: What are the most promising content generation techniques and applications for XR training in all domains?

RQ2: What are the key considerations and best practices for implementing these techniques in construction XR training?

Thematic analysis was conducted to answer the two research questions, which can be found in section 3 and 4. The findings reveal that key practices and techniques in the included studies consist of approximately 34% focusing on authoring tools, while 11% of the studies developed and tested AI-supported content generation platforms. Additionally, about 10% employed procedural content generation, and 5.2% utilized co-creation methods to generate content, alongside various other knowledge and modeling techniques. This review also identifies and discusses challenges such as the need for automation and real-time feedback in XR content generation, the complexity of technical skill requirements, and ethical considerations surrounding advanced technologies.

2. METHODOLOGY

This section outlines the systematic approach used to identify, select, and analyze relevant studies. It encompasses the search strategy and database selection (Section 2.1), the inclusion and exclusion criteria applied during the screening process (Section 2.2), and the data extraction and analysis methods employed (Section 2.3). The overall study selection process is illustrated in the PRISMA flow diagram (Figure 1), which details the number of records at each stage of the review. The following subsections provide a comprehensive description of each methodological step.

2.1 Search Strategy and Database Selection

A systematic literature review was conducted following the PRISMA guidelines. The search strategy aimed to identify relevant studies focusing on content generation in extended reality (XR) training. The searches were conducted on October 28, 2024. The following databases were selected for the search:

- Scopus
- Web of Science (WoS)
- ACM Digital Library - Guide to Computing Literature

The search terms included combinations of synonyms of keywords: "content generation", "training", "education", 'extended reality".

The general search query employed the following terms and Boolean operators: ("content generation" OR "content development" OR "content creation" OR "content production") AND (train OR education OR instruction OR learning) AND ("extended reality" OR "immersive technology" OR "mixed reality" OR "virtual reality" OR "augmented reality" OR "augmented virtually"). Database-specific syntax variations, as detailed in Table 1, were applied to adapt this query for each database.*

Table 1: Database-Specific Syntax Variations for Search Queries

Database	Specific Syntax Variations	Example of Query Snippet
WoS	TS (Topic Search) prefix used for all terms.	TS=("content generation" OR "content development"...)
Scopus	TITLE-ABS-KEY prefix used for all terms.	TITLE-ABS-KEY ("content generation" OR "content development"...)
ACM Digital Library	Title, Abstract, Keyword search fields specified.	Title:(("content generation" OR "content development"...)) OR Abstract:(...) OR Keyword:(...)

2.2 Inclusion/Exclusion Criteria and Quality Assessment

The study selection process for this systematic review followed a multi-stage approach. Initially, we conducted searches across the Scopus, Web of Science, and ACM Digital Library databases. We utilized the databases' built-in functions to filter results according to the following inclusion criteria: publication between 2005 and 2025, peer-reviewed status, and publication in the English language. Following the completion of the database searches, all identified records were imported into a reference management software, where duplicate entries were automatically removed. The subsequent screening process involved several stages of exclusion to refine the selection. First, we screened the titles and abstracts of the remaining records. At this stage, we excluded studies published in journals not ranked within the top two quartiles (Q1-Q2) according to the SCImago Journal & Country Rank (SJR) indicator, and studies published in conferences not ranked within A1-B2 according to the Excellence in Research in Australia (ERA) and Qualis Conference Ranking. Full-text articles were retrieved for the studies that passed the title and abstract screening. During the full-text retrieval process, we excluded studies for which full-text access was not obtainable. Finally, we conducted a full-text examination of the remaining articles. At this stage, studies that were not relevant to at least one of our research questions were excluded. The searches yielded the results as in Figure 1.

Inclusion criteria for the studies were as follows:

- Studies published between 2005 and 2025
- Peer-reviewed articles
- Studies written in English

Exclusion criteria included:

- Studies published in journals not ranked within Q1-Q2 according to the SCImago Journal & Country Rank (SJR) indicator or studies published in conferences not ranked within A1-B2, according to the Excellence in Research in Australia (ERA) and Qualis Ranking (601 excluded)
- Studies lacking full-text access (13 excluded)
- Studies not directly relevant to the at least one research question (74 excluded)

2.3 Data Extraction and Analysis

Data extraction was performed using a standardized form that captured key information, including:

- Authors and year of publication
- Study design and methodology
- Domain(s) of study
- Main findings and challenges

Qualitative and quantitative data were analysed using thematic analysis, identifying key themes and patterns in the data. Quantitative data were synthesized using descriptive statistics. The initial coding scheme was developed through a combination of deductive and inductive approaches. Deductively, we derived initial codes from our research questions and the key concepts identified in the literature review (e.g., 'Immersive Learning,' 'Safety Training'). Inductively, we allowed codes to emerge from the data as we reviewed the selected studies. For example, the code 'Personalization' emerged from studies that emphasized tailored learning experiences. The initial codes were then refined through iterative reviews of a subset of the papers. For instance, 'Immersive Learning' was further divided into 'Visual Immersion' and 'Interactive Immersion' to capture the nuances of XR experiences. Related codes were then grouped into higher-level themes based on their conceptual similarity. For example, 'Visual Immersion,' 'Interactive Immersion,' and 'Multimodal Content' were clustered under the theme 'User

Engagement and Experience.' The weighting of themes was primarily based on the frequency of their occurrence across the reviewed studies. Specifically, the number of times each code was applied was counted, and these counts were aggregated at the theme level. The final set of studies included in the review was summarized in a PRISMA flow diagram (figure 1), detailing the number of records identified, screened, assessed for eligibility, and ultimately included in the review.

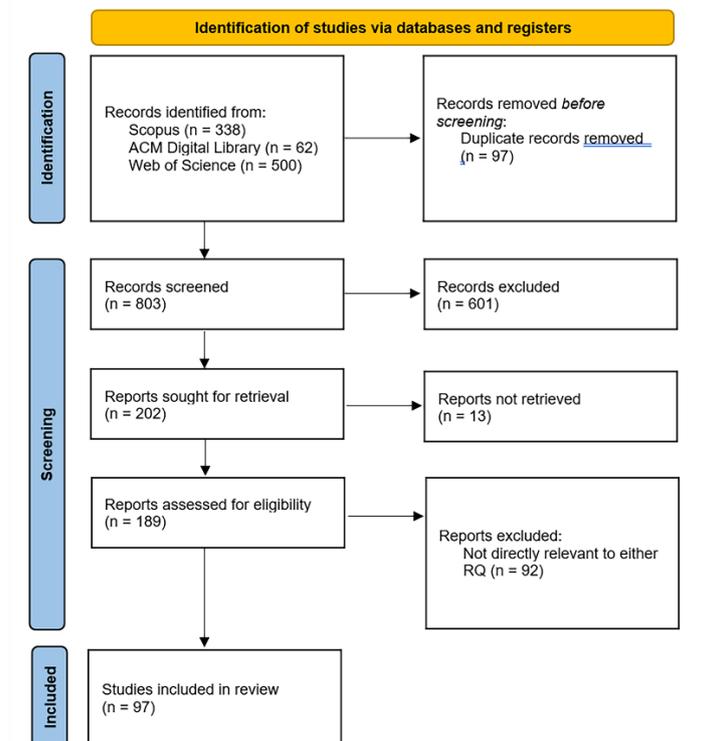


Figure 1: A PRISMA Flowchart

3. RESULTS

3.1 Overview of Content Generation Techniques and Their Applications

This section presents the thematic analysis of content generation techniques categorized into two primary domains: Software/Modelling Techniques and Knowledge Transfer Methods. The findings from the systematic literature review have been organized into several tables that summarize key aspects of the studies reviewed.

Table 2 details the software and modelling techniques utilized in the studies. It includes categories such as authoring tools, procedural content generation, and AI-supported tools, reflecting the diversity of technological approaches employed for content generation.

Table 2: Software and Modelling Techniques

Content Generation Technique	Frequency (n/N)	Percentage (%)	Citations
Authoring Tool	33/97	34.0	(Belda-Medina, 2022; Blattgerste et al., 2023; Brancaccio et al., 2023; Bricard & Lavric, 2022; Brůža et al., 2021; Camba et al., 2016; Coelho et al., 2024; Dimoulas, 2022; Engelke et al., 2013; Ferreira et al., 2021; Gabriel et al., 2024; Gao et al., 2023; Horst et al., 2024; Im et al., 2021; Ipsita et al., 2021; Lorenz et al., 2020; Maik et al., 2022; Muser et al., 2023; Naef et al., 2023; Papagiannakis et al., 2018; Puggioni et al., 2021; Sankaran et al., 2019; Sauer et al., 2006; Schoenauer et al., 2023; Scott et al., 2008; Strugala et al., 2020; Walczak et al.,

			2006; Wang et al., 2022; Wolfartsberger et al., 2020; Xiberta et al., 2022; Zikas et al., 2020)
Procedural Content Generation	12/97	12.4	(Agarwal & Shridevi, 2023; Ferreira et al., 2021; Georgiou & Demiris, 2017; Huber et al., 2021; Kern et al., 2019; Mahmoudi-Nejad, 2021; Saad et al., 2023; Scott et al., 2008; Singh et al., 2024)
Physical Subject Capturing	10/97	10.3	(Alqarni et al., 2024; Brůža et al., 2021; Kavanagh et al., 2016; Kong et al., 2022; Park, 2023; Puggioni et al., 2021; Shadiev et al., 2024; Southgate et al., 2022; Vellingiri et al., 2023; Wallgrün et al., 2024)
AI-Supported Tool	11/97	11.3	(Huber et al., 2021; Ipsita et al., 2021; Koyama et al., 2022; Liu et al., 2022; Ng et al., 2023; Oliveira et al., 2018; Park, 2023; Park et al., 2019; Saad et al., 2023; van Paridon et al., 2021; Zwolinski & Kaminska, 2024)

Table 3 focuses on knowledge transfer methods, including expert knowledge transferring, designer knowledge transferring/co-creation, and requirement engineering. This table underscores the importance of collaborative and expert-driven approaches in effectively generating training content.

Table 3: Knowledge Transfer Methods

Content Generation Technique	Frequency (n/N)	Percentage (%)	Citations
Expert Knowledge Transferring	12/97	12.4	(Arboleda et al., 2023; Blattgerste et al., 2023; Brancaccio et al., 2023; Hahn et al., 2019; Im et al., 2021; Lawson et al., 2020; Lorenz et al., 2020; Miyata et al., 2009; Scott et al., 2008; van Lopik et al., 2020; Wolfartsberger et al., 2020; Xiberta et al., 2022)
Designer Knowledge Transferring	10/97	10.3	(Belda-Medina, 2022; Belda-Medina & Ramon Calvo-Ferrer, 2022; Caspar, 2021; Hammang et al., 2018; Im et al., 2021; Kong et al., 2022; Lucas, 2020; McDonnell et al., 2023; Munoz et al., 2022; Rafi et al., 2008; Southgate et al., 2022; Wu et al., 2023; Zarzycki, 2014)
Co-create	5/97	5.2	(Liu et al., 2022, McCaw et al., 2022, Munoz et al., 2022, Kang et al., 2020)
User Generated Content	6/97	6.1	(Dimoulas, 2022; Ipsita et al., 2021; Koyama et al., 2022; Scott et al., 2008; Wang et al., 2022; Zikas et al., 2020)

By analysing these tables, we gain a comprehensive understanding of both the technological and methodological facets of XR training content generation. The predominance of authoring tools indicates a strong reliance on established software solutions, while the emerging use of AI-supported tools suggests a trend towards adaptive and intelligent content generation methods. Additionally, the emphasis on knowledge transfer methods highlights the critical role of collaboration and expertise in developing effective training solutions.

3.2 Clustered Practices Influencing Content Effectiveness in XR Training

The treemap (Figure 2) illustrates the clustered factors that positively influenced XR training, highlighting various practices and their occurrences within research. The size of each section in the treemap is proportional to the weight of the corresponding theme, visually representing the relative importance of each factor in influencing XR training effectiveness. The most prominent cluster, "User Engagement and Experience," stands out with 94 occurrences, emphasizing its critical role in enhancing training effectiveness. Following closely is "Instructional Design" with 48 occurrences and "Collaboration and Knowledge Sharing" with 45, suggesting that thoughtful instructional strategies and collaborative approaches are vital for successful XR training. Other noteworthy clusters include "Visual Communication" (35), "AI-driven" (31), and "Personalization" (19), indicating that tailored and innovative

content delivery methods significantly contribute to learner engagement. Additionally, ethical considerations and authentic content are acknowledged, with 18 and 11 occurrences respectively, underscoring the importance of integrity and realism in training environments. Overall, the treemap effectively encapsulates the multifaceted factors shaping XR training practices.

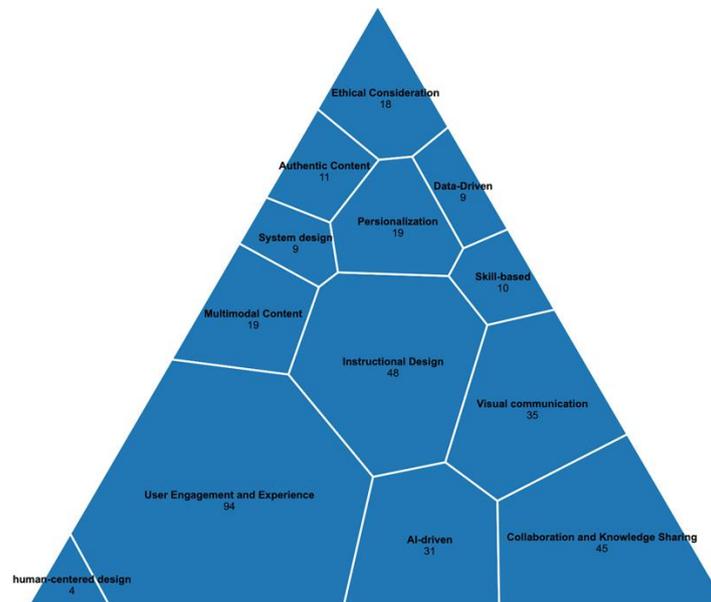


Figure 2: A Treemap of Clustered Factors that Positively Influenced the XR Training

4. DISCUSSIONS

4.1 Practical Implications for XR Training Design and Development in Construction

The thematic analysis revealed several key factors that significantly influence the design and development of effective XR training programs for the construction industry. As visualized in the treemap (Figure 2), "User Engagement and Experience" emerged as the most dominant theme, with a weight of 94, indicating its critical role in successful XR training. This high weight underscores the importance of creating immersive and interactive training environments that capture and maintain learner attention (Doolani et al., 2020). Construction training, often dealing with complex procedures and safety protocols, benefits significantly from engaging content that fosters active participation (Coelho et al., 2024). Closely following in importance is "Instructional Design," with a weight of 48. This highlights the necessity of structuring XR training programs with clear learning objectives, effective pedagogical strategies, and well-organized content (Blattgerste et al., 2023). In the context of construction, where practical skills are paramount, instructional design must prioritize hands-on learning and real-world scenarios (Lucas, 2020). "Collaboration and Knowledge Sharing" (45) also plays a substantial role. Construction sites are inherently collaborative environments, and XR training that promotes teamwork and knowledge exchange can enhance on-site efficiency and safety (Brancaccio et al., 2023). The ability to simulate collaborative tasks and share best practices through XR can be particularly beneficial (Schoenauer et al., 2023). The integration of "AI-driven" techniques (31) offers significant potential for enhancing XR training. AI can personalize learning experiences, adapt content to individual learner needs, and provide real-time feedback (Zwolinski & Kaminska, 2024). In construction, where workers have diverse skill levels and learning styles, AI-driven personalization can optimize training outcomes (Georgiou & Demiris, 2017). Furthermore, the themes of "Personalization" (19) and "Multimodal Content" (19) contribute to enhanced user engagement. Tailoring training content to individual learner preferences and incorporating diverse media formats can improve comprehension and retention (Belda-Medina & Ramon Calvo-Ferrer, 2022). "Ethical Considerations" (18) and "Authentic Content" (11) are also crucial. XR training should reflect real-world construction scenarios and adhere to ethical guidelines, ensuring that learners are prepared for the challenges they will face on-site (Southgate et al., 2022). The relatively lower weight of "Human-centered design" (4) suggests a potential area for improvement. Future XR training programs should prioritize user-centered design principles to ensure that content is intuitive, accessible, and aligned with the needs of construction workers (van Lopik et al., 2020).

While all themes identified in the thematic analysis are represented in Figure 2, the discussion focuses on 'User Engagement and Experience' and 'Instructional Design' due to their high relative weights and their direct implications for the practical design of XR training programs in construction.

4.1.1 Application of Content Generation Techniques and Influencing Factors

The identified content generation techniques and influencing factors can significantly enhance the design and development of XR training programs for construction workers. Techniques such as immersive simulations, interactive 3D models, and augmented reality overlays can be tailored to meet the specific needs of construction training (Strugala et al., 2020). By leveraging user engagement and experience, as highlighted in the treemap, training programs can be designed to foster active participation, ensuring that workers are not only passive recipients of information but also engaged learners (Coelho et al., 2024). Incorporating ethical considerations and authentic content further ensures that training is not only effective but also respects the realities and challenges faced in the construction environment (Southgate et al., 2022).

4.1.2 Specific Examples for Common Training Needs

For safety training, XR programs can simulate hazardous scenarios that workers may encounter on-site, allowing them to practice safety protocols in a controlled and risk-free environment. For instance, virtual reality (VR) can be used to recreate situations such as working at heights or operating heavy machinery, where workers can learn to identify risks and respond appropriately (Gao et al., 2023). In terms of equipment operation, interactive 3D models can be utilized to familiarize workers with machinery before they operate it in real life. By using augmented reality (AR), workers can receive real-time guidance and overlays that demonstrate the correct usage and maintenance of equipment (Lorenz et al., 2020). For construction processes, XR training can illustrate complex workflows, such as the sequencing of tasks in a building project. This approach can help workers understand their roles within the larger context of the construction site, enhancing efficiency and collaboration (Lucas, 2020).

4.2 Addressing Challenges and Future Research Directions

While the systematic literature review (SLR) provides valuable insights into XR training in construction, it has certain limitations. The scope of included studies may not cover all relevant literature, potentially overlooking emerging technologies or techniques. Additionally, the variation in methodologies and contexts of the studies reviewed may limit the generalizability of the findings. Implementing content generation techniques in XR training presents several challenges. Firstly, the high costs associated with developing and maintaining XR content can be a barrier for many construction companies (van Lopik et al., 2020). Secondly, there may be a lack of technical skills among trainers to effectively integrate XR technologies into their training programs (Maqbool et al., 2024). Lastly, resistance to change from traditional training methods may hinder the adoption of innovative XR solutions, creating a need for change management strategies (Ho, 2016). Future research should focus on longitudinal studies to evaluate the long-term effectiveness of XR training in construction. Additionally, exploring the integration of artificial intelligence (AI) to personalize training experiences could yield promising results (Zwolinski & Kaminska, 2024). Research might also investigate the potential for hybrid training models, combining traditional methods with XR, to address the challenges of implementation and maximize training effectiveness (Lawson et al., 2020).

Specifically, the application of AI-driven content generation in construction XR training requires careful consideration of the industry's unique characteristics. Unlike more structured training environments found in fields such as multidisciplinary education and media production, construction sites are dynamic and often unpredictable, with evolving safety hazards and logistical complexities. Therefore, the development of XR content must account for these real-world variables, requiring robust data collection and adaptable modelling techniques (Agarwal & Shridevi, 2023). Furthermore, the integration of 3D modelling tools must be tailored to handle the large-scale, complex structures common in construction projects, ensuring that training simulations accurately reflect on-site conditions (Strugala et al., 2020). By drawing parallels with successful implementations in other complex, data-rich fields, we can identify best practices for adapting these techniques to the construction industry.

5. CONCLUSION

In conclusion, the integration of content generation techniques in XR training in the construction industry presents significant opportunities for enhancing worker safety, efficiency, and skill acquisition. Future directions should emphasize the exploration of emerging technologies, such as AI and machine learning, to further tailor training experiences to individual needs. Additionally, industry opportunities lie in the potential for collaboration between construction firms and technology developers to create tailored XR solutions that address specific challenges in the field. As the construction industry continues to evolve, the adoption of XR training will not only improve workforce competency but also contribute to safer and more productive work environments. Engaging in ongoing research and development in this area will be crucial for staying at the forefront of training innovation in construction.

ACKNOWLEDGMENTS

The authors would like to express their sincere acknowledgement to the Discovery Grants Program (RGPIN-2023-04239) from the Natural Sciences and Engineering Research Council of Canada (NSERC).

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