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Adoption of Emerging Technologies in the U.S. Construction Industry: A Focus on UASs and AI

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The current research examined the implementation and impact of the emerging technologies that are being used in the construction industry, mainly focusing on technologies such as Unmanned Aircraft Systems (UASs), Artificial Intelligence (AI), and Robotics. The primary goal of this research is to investigate the utilization of emerging technologies that are being implemented by construction firms based on diverse background information such as the company type, size, and geographical location. Moreover, this research discovers the perceptions of construction firms regarding the benefits and challenges associated with adopting these emerging technologies. Additionally, this study identifies the strategies that could help facilitate the broader adoption of emerging technologies. This study adopted a quantitative research approach; a survey was distributed to the construction industry professionals to collect the data, and descriptive analysis was performed. By identifying the current utilization levels, benefits, and challenges to adoption, this research provides practical guidance for adopting emerging technologies in the construction industry and enables greater integration, innovation, and impact the improves overall jobsite productivity.

Keywords: Emerging technologies, UASs, robotics, AI, benefits, challenges.

Introduction

Emerging technologies such as Artificial Intelligence (AI), Robotics, Unmanned Aircraft Systems (UASs), and others are bringing significant positive change to the construction industry by improving productivity, safety, quality, and efficiency. These technologies can be helpful in every stage of the construction process, they can be used in quick data retrieval, providing visual information, monitoring equipment, construction performance in real-time, and performance optimization. Consequently, they facilitate the digitization of physical assets, and enhance seamless communication, and virtual collaborations, which leads to a substantial increase in construction productivity and efficiency in construction practices (Kissi et al., 2023). According to (Chen et al., 2022) despite an annual revenue of around $10 trillion globally, the construction industry is still struggling with low productivity. Therefore, the evolution of emerging technologies is crucial for an industry that has traditionally lacked digitalization and resisted change (Abioye et al., 2021). The 2023 FMI (Fails Management Institute) Labor productivity study states that 3 out of 4 internal factors affecting productivity are related to planning, communication, and collaboration. Emerging technologies have the potential to improve all these factors considerably, however, the industry has not fully adopted them emerging technologies (Kissi et al., 2023). It is important to understand the challenges to full adoption as it helps in a seamless adoption of technologies in the future that could improve the productivity of the construction industry. Therefore, this study aims to answer the following three research questions:

1. What is the current state of utilization of emerging technologies (i.e., UAS, AI, and Robotics) of the construction firms based on the company background (i.e., type, size, and geographical location)?
2. What are the benefits perceived by the construction firms implementing emerging technologies?
3. What are the challenges to adoption of the emerging technologies as perceived by the construction firms?

By answering these questions, the current study seeks to provide a comprehensive understanding of the perspectives of various industry practitioners regarding the implementation of emerging technologies.

UASs in Construction

Over the past few years, the construction industry has undergone a significant evolution driven by the technological process. Drones have emerged as pivotal innovations, reshaping the planning, execution, and maintenance of construction projects. With advanced sensors, cameras, and GPS technology, drones provide unmatched abilities to capture live data, create precise 3D models, and perform remote inspections, revolutionizing traditional practices in the industry (Shakhatreh et al., 2019). Traditional inspection methods often require skilled workers and engineers to climb structures to collect data, which can be slow, dangerous, and risky. UASs allow the deployment of various detection and surveying tools to assess the health of infrastructure more safely and efficiently (Mattar and Kalai 2018). By using the diverse types of UASs, construction industry professionals can vastly improve their workflow efficiency, enhance project coordination, and effectively avoid risks. (Shanti et al., 2022). The flight duration and carrying capacity of UASs are often limited, which can require multiple UASs to transport materials for construction tasks **(**Otto et al., 2018**).** Additionally, UAS operation requires specialized training, which can impact productivity levels due to the learning curve involved. The Federal Aviation Administration (FAA) imposes regulations that restrict UAS use, such as mandating that UASs operate within the visual line of sight of the operator. Furthermore, adverse weather conditions such as heavy rain, snowfall, or strong winds can hinder UAS operations. Both drone operators and the public need to understand these legal regulations and operational limitations to ensure the safe and effective use of UASs. Awareness of UAS capabilities and limitations enables users to select the appropriate drones for their assigned tasks (Syd Ali 2019).

Leveraging AI and Robotics for Enhanced Productivity

Artificial Intelligence (AI) refers to advanced algorithms and machine learning systems that optimize, automate, and enhance processes such as design, project management, safety, and quality control (Pan and Zhang 2021). Robotics refers to automated machines, and systems designed to perform physical tasks such as bricklaying, welding, material handling, and site inspection, or bots automating processes often enhancing efficiency, precision, and safety (Pan and Zhang 2021). In the context of this research data collection, AI and Robotics are tied up together because most firms use them both, and also robots deployed in the construction industry utilize AI concepts.

In the Architecture, Engineering, and Construction (AEC) industries, AI is turning into the next big thing. To solve real-world problems, AI gives a more automated and reliable approach rather than the traditional methods (Hu et al., 2022). These valuable characteristics of AI make it a valuable tool for facing the problems often encountered in construction projects. The integration of AI into construction projects is expected to bring out lasting benefits in automation, risk management, enhanced efficiency, productivity, and safety within the construction industry (Pan and Zhang 2021). The adoption of robotics in the construction industry if compared to other industries is significantly slow. The main factors contributing to this slow adoption are the fragmented nature of the construction industry, high upfront costs, complex work environments, and issues related to data acquisition and retention (Regona et al., 2022). While the challenges remain, addressing these barriers could transform the industry, facilitating streamlined processes, lower labor costs, and greater project consistency (Pan and Zhang 2021). According to the study conducted by Emaminejad & Akhavian in 2022, building trust and acceptance between AI systems and end-users is a critical step toward promoting the adoption and utilization of these technologies in the AEC industry.

Methodology

In this research, a survey questionnaire-based methodology is utilized to investigate the adoption of emerging technologies, the benefits and challenges faced, and the potential remedies associated with the construction industry in the United States. The methodology includes (1) Literature review; (2) Questionnaire Survey; and (3) Data analysis. The data for the literature review was collected from multiple research databases and journal sources such as Web of Science, Journal of Construction Management and Research, Journal of Management in Engineering, and others by using keywords such as "Emerging Technologies, AI, Robotics, and UASs in Construction". Initially, 90 papers were downloaded spanning between the years 2014 to 2023. After careful evaluation, the authors screened the papers eliminated 50 papers, and finalized 40 papers to be considered for this study based on the aptness of the papers for the research goal. A thorough literature review was conducted to know the applications, benefits, and challenges associated with implementing these emerging technologies namely AI, Robotics, and UASs in the construction Industry. Survey question types include single-choice, multiple-choice, and text entry.

Survey Design

Based on the information collected from the literature, the online survey was designed to collect data from industry practitioners. The survey questionnaire included three types of questions: multiple choice, multiple selection, and open-ended text-based entry. The survey also included demographic questions and perception questions. A pilot study was conducted, and improvements were made to the questionnaire survey before sharing it with the potential participants. Nine major benefits and Ten major challenges associated with implementing the emerging technologies included in Qi et al, (2020) were used in the survey questionnaire of this study. The benefits and challenges are slightly reworded and rearranged to suit the implementation of UASs, AI, and Robotics at the construction firms. Along with this, seven strategies associated with emerging technologies adoption that identified in the literature review were added to the survey (See Table 1).

Table 1. Benefits, Challenges, and Strategic variables used in the questionnaire survey

Label	Benefits	Label	Challenges	Label	Strategies
B1	Improved quality	C1	High capital costs	S1	Conducted employee training and skill development programs
B2	Reduced construction cost	C2	Continuous demand for upgrading hardware and software.	S2	Developed user-friendly interfaces and training materials
B3	Reduced construction time	C3	Lack of software or hardware compatibility, applicability, and practicability.	S3	Increased communication and transparency regarding technology adoption
B4	Reduced labor	C4	Lack of skilled workers and experienced professionals	S4	Engaged in open dialogues and feedback sessions with employees
B5	Improved flexibility	C5	Cultural resistance to change	S5	Foster a culture of innovation and continuous learning
B6	Environmentally friendly practices	C6	Information security limitations and cybersecurity risk	S6	Conduct regular progress assessments and evaluations
B7	Improved safety	C7	Difficulty in measuring profit and assessing investments	S7	Conduct surveys to gauge employee sentiment and concerns
B8	Better information sharing and collection	C8	Lack of standards, laws, and regulations		
B9	Improved productivity	C9	Lack of software or hardware reliability		
		C10	Lack of technical training and high cost of education		

All the Benefits, challenges, and strategies were converted to variables to make it easier to represent those in the bar graphs.

Pilot Study

After developing the survey, it was sent to known 4 project managers in the construction industry and a construction management professor who has significant knowledge and experience in working with these emerging technologies to verify the survey design, format, flow, and content and to identify errors, if any. From the feedback received, necessary changes were made to the survey by either rewording the questions or adding new questions. Following these adjustments, the survey was distributed through Qualtrics using the snowball sampling method, wherein the authors reached out to a few known construction professionals initially extending an invitation to complete the survey.

Furthermore, the survey participants were asked to forward the information of their colleagues that could be a good fit. Then authors invited the suggested colleagues to participate in the study.

Survey Distribution and Data Collection

The snowball sampling method was utilized for this study to gather survey responses. Initially, the researchers gathered information about construction professionals through professional platforms like LinkedIn and approached (through email) about 300 professionals to complete the survey. The participants were selected from different domains based on their experience working as construction managers, VDC managers, and Innovation Managers in different construction firms. The rationale for choosing these specific participants is their expertise in utilizing these technologies or working on projects where they are used. The survey was distributed to the participants through an email hyperlink to access the survey. The respondents were also requested to share the survey link with other professionals with experience using UASs, AI, or Robotics as a part of their daily job tasks. The survey was open for 35 days (March 1st, 2024, to April 4th, 2024).

Data Analysis

A total of 89 responses were recorded, out of which 35 were omitted due to incomplete responses and participant misfit. Consequently, only 54 responses (18% response rate) were deemed valid and included in the final data analysis. A descriptive statistical approach was adopted for this research.

Results And Discussions

In this study, the data was gathered from a diverse group of respondents with varying years of experience in the field. Among the 54 participants, 81% have an experience of more than 5 years in the construction industry, with 20% having an experience of more than 20 years. As a part of this study, the firms with annual revenue of USD 200 million or more are categorized as large, USD 36-200 million as medium, and less than USD 35 million as small companies. From the survey, 69% of the participants work for large companies, 20% of respondents are employed by medium-sized construction firms, and 11% work for smaller organizations. With respect to geographical participation, the Northeast has 20%, the Southwest, and Southeast regions each had 19% responses, the Midwest has 18%, and the West region had the highest number of responses at 24%.

Technology usage vs region

For this study, the U.S. geographical locations have been categorized into five regions: West (WA, OR, CA, NV, ID, MT, WY, UT, CO), Midwest (ND, SD, NE, KS, MN, IA, MO, WI, IL, MI, IN, OH), Northeast (PA, NJ, DE, MD, NY, CT, RI, MA, VT, NH, ME), Southwest (AZ, NM, TX, OK), and Southeast (AR, LA, MS, TN, KY, WV, VA, NC, SC, AL, GA, FL). UASs has the highest adoption rate across all the regions, with the West leading with 50% of the respondents confirming it. Not only UASs but also the adoption rate of AI and Robotics is higher in the West at 35.2%, this suggests that the construction firms in the western region are aggressive in implementing emerging technologies for various applications (Refer Figure 1).

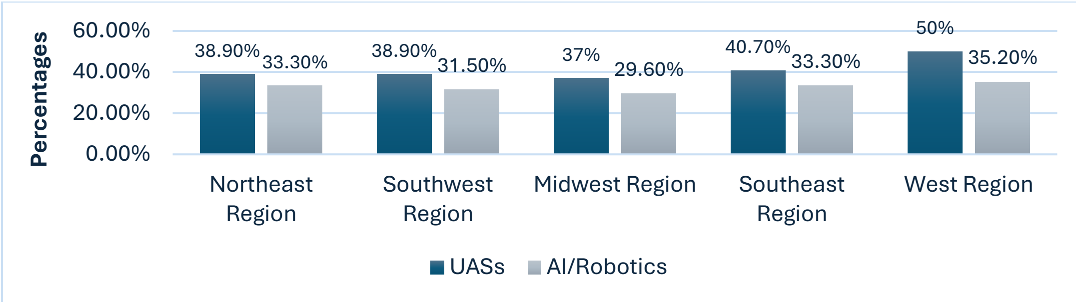

Figure 1. Technology usage Vs region

Technology utilization vs Type of construction:

The analysis of the emerging technology adoption across the various types of projects has shown a significant difference in how these technologies have been integrated into construction projects across different sectors (see Figure 2). The commercial and healthcare sectors are the top 2 sectors that utilize these technologies most effectively compared to others, which suggests that the focus on these technologies is more for larger scale or complex projects or depends on the project needs, such as using them for client engagements where detailed visualization is needed for better communication and understanding. The residential sector showed the lowest adoption rate for both UASs and AI/Robotics.

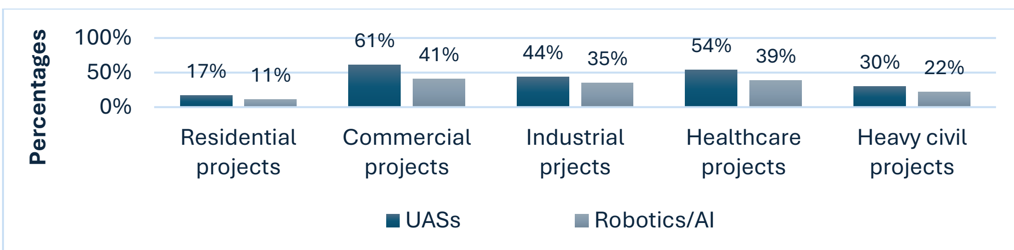

Figure 2. Technology usage Vs type of construction

Technology utilization vs size of the company:

The analysis of technology adoption among the different sizes of companies informs that (see Figure 3) larger companies have the highest adoption across all the technologies compared to medium and small-size companies. The significantly higher percentages for large companies could be attributed to their access to resources and capacity to invest and implement emerging technologies. This indicates the potential barriers that small and medium-sized companies face, which include the high capital costs, and the difficulty in the resource allocation to implement these technologies.

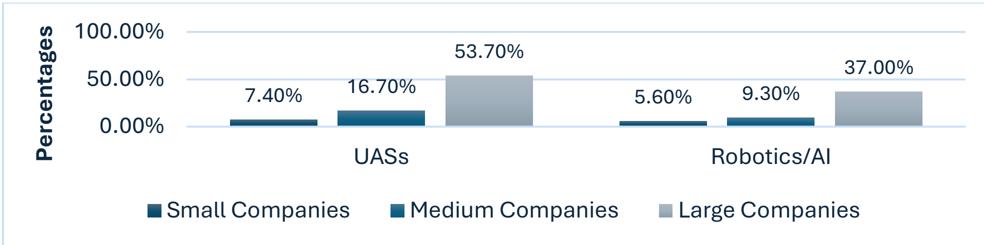

Figure 3. Technology usage Vs size of the construction

Benefits:

The integration of emerging technologies in the construction industry provides various benefits (see Table 1). AI/Robotics was chosen by 51.85% of the total participants, with 79% of AI/Robotics respondents recognizing its impact on improving quality, which reflects the industry's focus on precision and reliability. Surprisingly no respondents selected AI/Robotics for reducing costs, due to high implementation upfront cost, 64% noted its benefit in reducing labor, and 46% of them recognized its role in enhancing safety and flexibility, showing its potential to create safer and more adaptable work environments.

A total of 77.78% of the survey respondents confirmed the utilization of UASs in their construction. The most significant benefit recognized by 90% of the UAS respondents is better information sharing and collection, followed by 62% acknowledging their contribution to improving quality. UASs were also noted for reducing construction time by 43%, showcasing their effectiveness in critical tasks like surveying and site inspections. Moreover, half of the respondents recognized its safety benefits, with UASs playing a key role in real-time hazard monitoring (Refer Figure 4). Collectively, these technologies are pivotal in advancing efficiency, precision, and safety in construction projects.

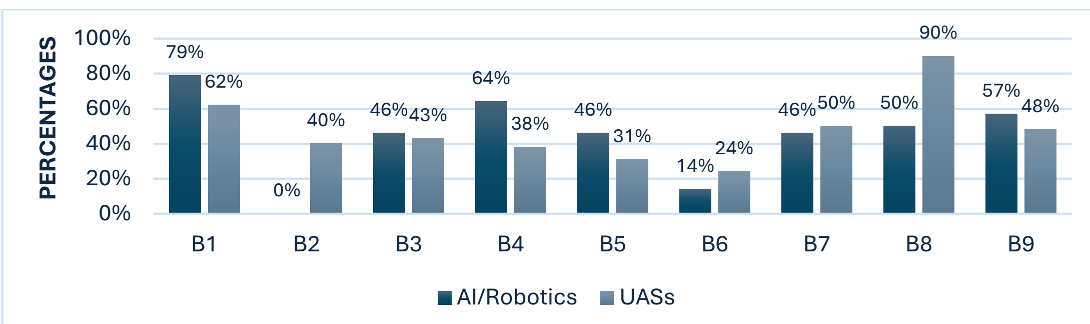

Figure 4. Benefits of utilizing AI/Robotics and UASs in construction operations

Challenges:

The implementation of emerging technologies in the construction industry poses a variety of challenges (see Table 1). While integrating the UASs, 60% of the respondents identified compatibility issues highlighting difficulties integrating UASs with existing systems and workflows. The continuous need for upgrading both the UAS's hardware and software was selected by 14% emphasizing frequent updates needed to maintain operational efficiency and compatibility, and 69% selected the lack of skilled workforce because of the shortage of personnel with the necessary expertise to effectively use and operate UASs. 55% of the respondents indicated that it was difficult to

measure the return on investment with implementing UASs. None of the participants selected the lack of technical training and high cost of education as a challenge for integrating UASs.
While implementing AI/Robotics, 68% selected high capital costs as a major hurdle, 57% selected they had challenges with lack of software and hardware compatibilities, 21% selected the lack of skilled workforce because of the shortage of personnel with the necessary expertise to effectively use and integrate AI/Robots.

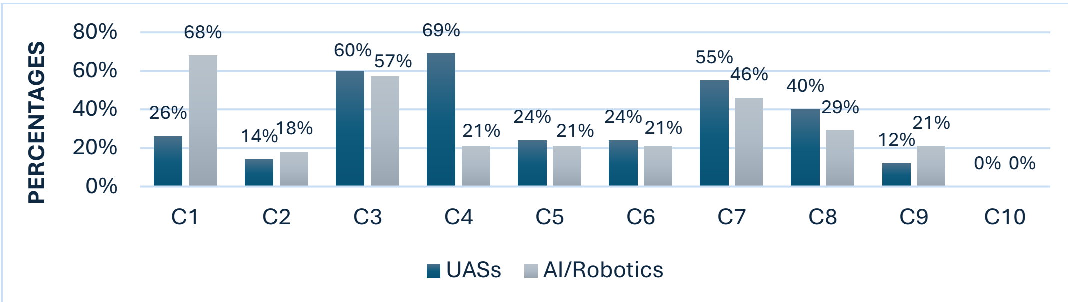

Figure 5. Challenges while implementing AI/Robotics and UASs in construction operations

Cultural resistance

The survey data highlights cultural resistance among employees to implementing these technologies in construction. Out of 54 responses, 51.85% confirmed the utilization of AI/robotics, while 77.78% confirmed the utilization of UASs. When asked about employee resistance to implementation (Refer Figure 6), AI/robotics faced an even split of resistance among employees, 50% each. For UASs, a majority of 67% reported no resistance to adoption, while 31% were not open to adopting UASs in their operations. Referring to the challenges (see Figure 5), resistance was significantly declined after the implementation for both technologies. Resistance to AI/robotics dropped from 50% to 25%, while for UASs, it decreased from 31% to 12%. This indicates that, after implementation, most of the workforce has adapted to these technologies, enhancing construction operations' effectiveness and efficiency. With minimal effort and training, the utilization of these technologies can be significantly increased to achieve higher returns.

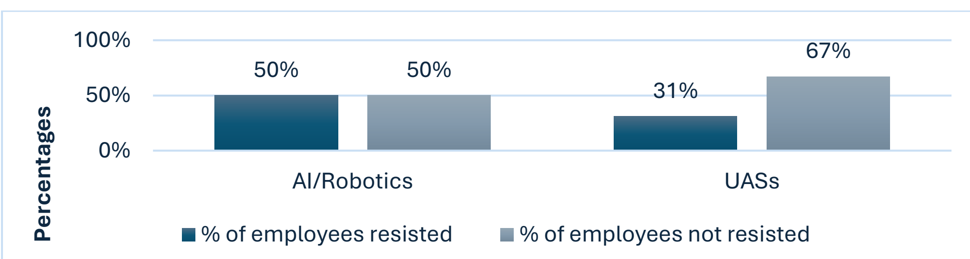

Figure 6. Cultural resistance before implementing AI/Robotics and UASs

Strategies for effective adoption

To improve better adoption of the UASs (Refer Figure 7), the respondents indicated that the most effective strategy is engaging employees in open dialogue and feedback sessions about implementing UASs (24%) as this provides an opportunity to foster collaborative spaces for the workforce to discuss and align UAS integration with their roles. Additionally, 19% of respondents indicated that employee training and cultivating a culture of innovation as an important strategy to further UAS adoption. With regards to AI and Robotics, the respondents indicated that facilitating open dialogue (29%), promoting a culture of continuous learning (29%), and increased communication and transparency (21%) as important strategies to further AI and Robotics adoption. This indicates the significance of creating workplace environments that not only inform the workforce about emerging technologies but also actively involves them in the adoption process by considering their difficulties, making them feel heard, and providing solutions.

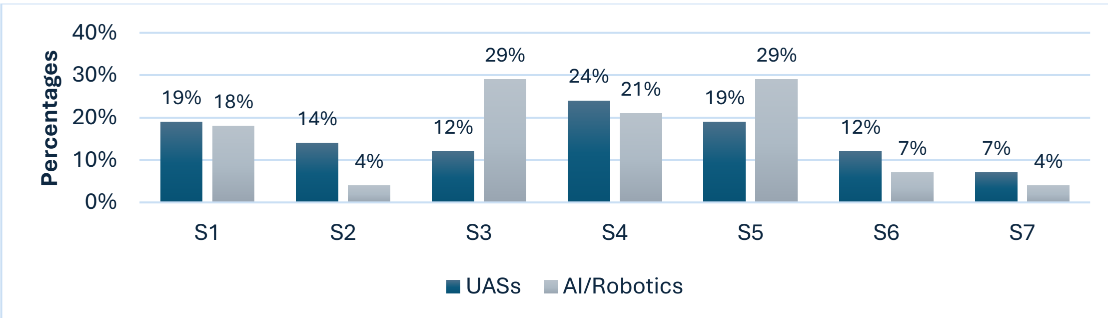

Figure 7. Strategies for effective adoption

Conclusion

This study provides an in-depth analysis of the current utilization level of UASs, and AI/Robotics and their adoption patterns, challenges, and strategies related to their integration within the construction industry. The adoption of these emerging technologies varies significantly based on the company's background such as size, type, and geographical location. The large firms utilize these technologies most as they have access to enough resources, particularly those located in technology-advanced areas like the west and southeast regions of the United States. In terms of the type of construction, both commercial and healthcare have been adopting these technologies the most compared to the residential and heavy civil sectors. The top 3 benefits of implementing UASs include better information sharing, improved quality, and improved safety, meanwhile, for AI/Robotics the most recognized benefits were improved quality, reduced labor, and improved productivity.

The challenges to wider adoption of UASs and AI/Robotics include a shortage of skilled personnel for UAS operation, and the high initial costs associated with AI/Robotics. Furthermore, difficulties in measuring return on investment (ROI) pose a significant barrier, especially for smaller companies with limited resources. Cultural resistance within construction firms also hinders the initial adoption of these technologies, although survey data indicate that resistance diminishes significantly post-implementation as employees adapt to and accept these innovations. To improve the wider adoption of these technologies, strategies such as targeted employee training programs and skills development initiatives are essential. Construction firms also found that open dialogues and feedback sessions help address employee concerns and foster a culture of acceptance. This cultivates a culture of innovation, alongside a clear technology adoption roadmap tailored to organizational needs, which is critical for overcoming adoption challenges and ensuring these technologies reach their full potential.

The study’s limitations include limited sampling and a quantitative approach alone. Regional imbalance in the study’s participation could be a limitation that could’ve influenced the findings. Future studies must adopt a mixed methods approach and balanced regional particpation to comprehensively investigate the qualitative perspectives of industry practitioners regarding the strategies to address challenges to wider adoption of the emerging technologies. By understanding the challenges and strategies to wider adoption, construction professionals and industry leaders can fully leverage the potential of these emerging technologies to transform construction practices.

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