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Digital Challenges and Opportunities of Addressing On-Site Productivity and Safety on Construction Job Sites: An International Perspective

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DIGITAL CHALLENGES AND OPPORTUNITIES OF ADDRESSING ON-SITE PRODUCTIVITY AND SAFETY ON CONSTRUCTION JOB SITES: AN INTERNATIONAL PERSPECTIVE

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Abstract

The slow pace of digital transformation in construction remains an impediment to the industry's evolution. Despite rapid developments in digital technologies, the vast bulk of data generated on construction job sites remains underutilised due to the limited use of real-time data capture. The diffusion of digital solutions in construction depends on successfully capturing critical real-time data that can inform and contribute to more productive work patterns and safer job sites. Nevertheless, the construction industry's fragmented nature has segregated the digital solutions offered by technology providers from the volatile challenges facing on-site construction practitioners.

This paper will present the early development of a nationally-funded Irish case study deploying a combined camera and sensors solution that enables measurable productivity and safety measures through passive data capture. Semi-structured interviews were conducted with highly experienced international construction practitioners to present the functions of the novel technology and explore the contemporary issues influencing on-site productivity and safety. Moreover, the qualitative data were subjected to thematic analysis to explore the extent of integration between the practical applications of the visualisation technology and the current demands of construction project managers.

Findings from this study revealed a recognisable disparity between the motivations and perceptions of the technology-developing firms compared to the demands and priorities of construction practitioners. The study aims to narrow the technology gap by understanding the business case for real-time data capture technology deployment on construction job sites. It also presents a successful example of the necessary collaboration between technology developers, building firms, research institutions, and public organisations towards digital adoption in construction.

Keywords: safety, Innovation, artificial intelligence, collaboration.

1. BACKGROUND

The construction industry is vital for national economic and social development since it provides essential infrastructure and buildings for human activities [9]. Expenditures in construction represent between 9% to 15% of GDP in most countries [10]. Nevertheless, the economic, competitive, and regulatory business environment presents numerous challenges to firms operating within this industry. Contracting firms face increasing pressures to improve their operational efficiency and effectiveness to combat the competitive threats to their survival. However, the construction industry is beset with inefficiencies related to on-site productivity and workplace safety [10].

The International Labour Organisation classified the construction industry as a primary contributor to work-related fatalities globally [31]. The number of fatal accidents in construction remains relatively high compared to other industries [22]. This phenomenon has been observed across the US, China, the UK, South Korea, and Singapore [21; 31; 44]. Moreover, the productivity gap between construction and other industries is a global challenge to the building sector [4; 37]. In the Irish context, there was slight growth in labour productivity between 2000 and 2016, and the productivity measured in Ireland stands 24% below the EU average [15].

Young et al. (2021) and Huang et al. (2021) argued that the primary reasons for the poor safety environment and productivity gap in construction are the modest intensity of innovation and continued reliance on traditional information systems. The scope of traditional information systems in construction management is often limited to recording basic information related to project design, schedules, costs, and resources [24]. On the other hand, the vast volumes of data generated in projects' planning, design, construction, operation, and maintenance phases remain underutilised [43].

The application of Artificial Intelligence (AI) and its subfields in progress tracking, health and safety monitoring, cost estimation, supply chain and logistics process improvements, and risk prediction have been associated with; increased operational productivity and efficiency, reduction of cost and time of building activities, better adherence to project schedules, higher quality of construction outputs and accompanying documentation, safer work environment, and improved design of buildings [1; 2]. Concerning safety management, previous studies revealed that on-site accidents were reasoned by the lack of proactive and preventive measures, such as risk source identification and control [29]. Therefore, adopting visual and analytical AI technologies, such as computer vision and machine learning, can potentially improve construction safety management practices [22]. It has been claimed that these technologies could facilitate hazard identification, support accident prevention, and improve safety training [18; 22].

Despite the crucial importance of digital transformation for construction firms to address the persistent and concurrent challenges above, the construction industry remains one of the least digitised industries [1]. The inception of construction digital solutions dates back to the 1960s through automated systems and robotics [10]. Over these decades, digitalisation has proven its capability to revolutionise the building process and provide numerous benefits to the Architecture, Engineering and Construction (AEC) sector [12]. Likewise, the unique nature of construction, being highly labour-intensive and the highest consumer of raw materials, mandates crucial endeavours towards adhering to the Industry 4.0 strategy, which promotes the importance of digitising and automating the business environment [27; 30]. Nevertheless, the uptake of digital solutions across the global construction industry faces several impediments, such as; cultural barriers, high initial costs, security, and skills shortages [1].

He et al. (2017) and Turk (2021) observed a gap between the rate of technology adoption among construction firms and the advances in technological solutions developed by innovation firms and research communities. Furthermore, they sought to explain the reasons behind this considerable gap between the construction and technology industries:

- Construction projects are unique, and their building processes broadly vary between projects according to various reasons (e.g., adopted building codes, client requirements, and regional laws). Hence, building projects often lack repetition, which is well suited for AI and information technology (IT) solutions;
- Tight schedules offer construction practitioners a limited opportunity to try new technologies;
- Skills shortage and complexity of attracting technology specialists into construction firms;
- The slow pace of change in the construction industry reasons by the absence of leadership and drive;
- The poor appetite of construction firms to invest in research and development (R&D);
- The complexity of exchanging data between different technology solutions.

2. TECHNOLOGY GAP

Among the key issues that have proven obstructive in unlocking the digitalisation potential in construction is the disparity between the construction problems and the solutions offered by technology providers. Oesterreich and Teuteberg (2019) referred to this barrier as the technology dimension. Perceived usefulness and ease of use were found to be the dominant factors for technology diffusion [26]. Lack of coordination between the two sides: problems that aggravate the construction processes and digital solutions provided by the technology startups contribute to further productivity loss [13].

A major cause of the technology gap is that project stakeholders interpret construction automation and digitalisation differently [8]. For example, building designers focus on digitalising planning and design activities, but contractors may understand it as using robotics to implement onsite tasks. In other industries, market disruption counted on the fact that digital technologies moved faster because of modular or compartmentalised adoption [13]. However, the dynamic and complex nature of construction projects encourages the fragmentation of the building process [26]. Despite this fragmented state, digital technology providers and researchers often focus on a singular objective or process. As a result, interoperability problems among different platforms create barriers to digital adoption on construction sites [38]. Likewise, digital solutions designed to address specific problems rarely provide significant value due to the interconnectedness of operational tasks [28].

Another significant reason for the technology gap is the cost of adopting new technologies. At an industry level, Low-profit margins prevent large contractors from the expansion into digitalisation [36]. Likewise, the immense initial capital investments to develop, deploy, and train employees inhibit organisational profitability from digitalization [38]. At a project level, tight schedules and cost pressures prevent the experimentation of new technologies.

Finally, the lack of standards prevents the mass adoption of digitalisation in construction [26]. The push for digitalisation has come from various avenues, including research institutions, technology startups, and R&D departments of global conglomerates. However, the inherent motivations from these quarters lack an overall collaborative vision to create complete digital transitions of construction processes [32]. As a result, the study in hand aims to address the technology gap issue by integrating the functions and applications of a construction technology under development with the contemporary construction industry demands.

3. CASE STUDY

The proposed A-EYE Technology is an early-stage research project funded by the Irish government and aligned with Ireland's Industry 4.0 Strategy 2020-2025 [15]. The project is developed with a collaborative vision to address the productivity, sustainability and communication challenges facing building contractors. The disruptive A-EYE solution is the result of integrating the pioneer innovation of two Irish construction innovation firms specialising in computer vision, artificial intelligence, machine learning, sensors technology, and project planning. Technological University (TU) joined the project consortium as the research performing organization (RPO) responsible for user-experience research management and dissemination of findings.

3.1. Project Scope

The A-EYE technology is developed to help address the productivity, sustainability, and communication challenges facing construction firms in the current complex business environment. This disruptive innovation aims to create a construction visualisation platform that enables measurable productivity advantages through passive data capture and real-time delivery of mission-critical information in an accessible form. A-EYE seeks to provide easy access to visualised data and documented proof of events in pursuit of efficient team-wide collaboration on construction sites.

A-EYE's control tower, supported by high-resolution cameras and tracking sensors, is uniquely positioned to provide complete project visibility and enables the most transparent visual communication between stakeholders. The following figure displays the intended application of the A-EYE visualisation platform to monitor and track construction activities, labour, and machinery to update project progress, detect irregularities, automate schedule amendments, and cut down on waste.

Most existing data organising, project scheduling, and reality capture technologies operate individually and mandate human intervention to connect these systems through manual data input. However, A-EYE's point of differentiation lies in the automated integration of reality capture and scheduling processes on construction sites. The following table summarises the functions and applications of A-EYE to address the prevalent worldwide on-site construction challenges.

Application	Anticipated benefits of A-EYE
Real-time scheduling and resources control	Adopting A-EYE technology on construction sites can help monitor concurrent activities and track labour and plant to detect irregularities, automate schedule updates, and reduce resource waste.
Real-time BIM	Integrating real-time data with a project's BIM allows for automating the model update process to reduce buildings' initial and lifecycle costs.
Budgets and billing	A-EYE aims to match the billing process with actual on-site progress by detecting materials' delivery time, quantities, and equipment up-time to resolve supplier disputes and cut unnecessary costs transparently.
Safety monitoring	Analysing video footage using A-EYE technology can provide real-time alerts in the event of safety violations. Signals can be delivered in case of equipment operating procedures violations, and personal protective equipment is not used on-site to prevent safety hazards due to labour faults or exposure to heavy machinery.
Performance Analytics and Estimation	One of the A-EYE's main objectives is to develop robust construction productivity measures using real-time and visual data. Measured productivity will include partial productivity (e.g., labour and machinery) and overall productivity of the construction process. Developing reliable productivity measurements in construction can create an accurate industry benchmark and improve future decision-making [39].

Table 1: A-EYE Technology Applications

4. METHODOLOGY

4.1. Research Method

Opinions, experiences, and predictions of people can be elicited by conducting qualitative studies [6; 33]. Qualitative research recognises the personal experiences of research participants, as well as the association between personal consciousness and external objects [3]. Hence, a qualitative research approach was adopted in this exploratory study to understand the range of perspectives international senior construction managers and technology developers hold about on-site productivity and safety management challenges [14; 23].

Qualitative research methods emphasise the comprehensive investigation of textual data gathered in a conversational format through interviews [25]. Semi-structured interviews were used to gather data since they provide an in-depth understanding of the phenomena under investigation and assist in the portrayal of multiple views [16; 34]. Firstly, the representative of the A-EYE technology-developing startups was interviewed to understand: the disruptive technology functions and practical applications, the technology's key points of differentiation, his perception of the current construction productivity and safety challenges, and how the disruptive technology aims to tackle these challenges. Afterwards, a series of semi-structured interviews were conducted with international construction managers to explore the extent of alignment between A-EYE and the digital demands of site practitioners.

The disruptive technology applications under investigation were initially presented to the participants. Moreover, interviews sought to explore the contemporary safety and productivity challenges in the global construction industry, how digital solutions can help address these issues, the shortcomings of the prevalent digital construction tools, and how this technology under development can improve on-site productivity and safety management.

4.2. Research Sample

Purposive non-probability sampling was deployed in this study since it is considered the most practical technique for exploratory studies [34]. The sampling frame included the representative of the A-EYE developing team in addition to five international construction companies. The construction industry is highly fragmented, and projects often involve a wide array of stakeholders [40]. Therefore, representing the construction industry diversity was deemed critical due to the small sample sizes associated with qualitative studies.

The chosen study sample included large construction contractors, global construction materials suppliers, and multinational technology development firms. Likewise, the selection criteria considered the geographical diversity of target firms. Participating companies were based in the United States, Ireland, the United Kingdom, Sweden, Poland, and Saudi Arabia. The unit of observation, target personnel, was defined as senior construction managers of contracting companies, R&D directors of materials producers, and directors of construction innovation firms. The following table provides a summary of the participants' profiles. Interviewees were assigned pseudonyms, ranging from A to F, to maintain their confidentiality. Also, firm size was measured according to the number of full-time employees as per the EU criteria [11].

Participant	Region	Position	Business Area	Firm Size	Practical Experience (years)
A	Ireland	Co-founder & Managing Director	A-EYE developing firm	Medium	>20
B	Saudi Arabia	Director of Digital Delivery	Construction contracting	Large	>30
C	Sweden	Managing Director	Construction contracting	Large	>30
D	Poland	Head of Innovation	Materials supplier	Large	>30
E	USA	Director of Operations	Construction contracting	Large	>30
F	Ireland	Director of Global Partnerships	Technology developing firm	Medium	>20

Table 2: Research Interviewees' Profiles

4.3. Data Collection Procedures

The ethical validity of the research procedures adopted in this study was carefully considered to ensure the findings' credibility [34]. The conduct of this study carefully considered the following ethical considerations: integrity, confidentiality, informed consent, and the privacy of research participants [35]. Ethical approval was gained from the TU Dublin research committee. The committee assessed the data collection process and procedures and confirmed their ethical validity.

Before the commencement of interviews, the consent of participants was gained through a formal letter of invitation. They were informed of the study's purpose. Also, participants were allowed to withdraw from the research at any stage to minimise potential response bias [23]. The research design ensured the participants' anonymity and the collected data's confidentiality. Each interview lasted approximately 45 minutes and was audio-recorded with the participants' consent. Audio records were later transcribed verbatim to facilitate the data analysis.

4.4. Interview Questions

Two interview sheets were designed to provide a comprehensive understanding of the disruptive technology under development and the on-site productivity and safety challenges under investigation (Appendix B). Questions were compiled based on a desktop study to review the latest peer-reviewed publications on construction productivity, safety management, and challenges to digital transformation in the building sector [e.g., 5; 20; 39; 41].

4.5. Data Analysis Method

Thematic analysis was adopted to examine the data gathered during the fieldwork phase. It is a widely used approach to identify, analyse, and report themes within qualitative data [17]. The thematic analysis provides a rich and detailed, yet complex, account of the interview data by examining narrative materials from life stories and breaking the text into relatively small units [7].

The thematic analysis process has followed the six-step approach articulated by Braun and Clarke (2006) due to its clarity and flexibility. The six steps can be summarised as follows: familiarising yourself with your data; generating initial codes; searching for themes; reviewing potential themes; defining and naming themes; and producing the report. The six-step approach guided the transcription, coding, analysis, and reporting of the gathered qualitative data. Data analysis was conducted using NVivo 12 software for data management [23]. A deductive thematic analysis approach was adopted since themes were identified during the desktop study phase. Interview transcripts were initially coded and then grouped into the following themes: AI benefits, safety management, construction productivity, barriers to AI adoption, and A-EYE Technology opportunities.

5. FINDINGS AND ANALYSIS

The step-by-step approach starts with familiarising with the transcribed interviews. Transcripts were reviewed several times, and initial ideas were highlighted to become fully immersed in the dataset. Likewise, any terms referring to a participant's identity or company were anonymised for confidentiality.

5.1. Data Coding

Data were coded to structure the transcribed discourse. The initial codes organised the data according to the general topics raised, which then yielded a starting point to develop relevant themes. A large number of codes (n=78) emerged; some included only one phrase, and others contained several sentences.

5.2. Establishing Themes

Themes emerged from the abovementioned initial codes by merging related codes into subordinate categories. The primary purpose of this phase was to explore the patterns and relationships between highlighted codes throughout the entire dataset [7]. The established themes were directly related to the study's aim and objectives and were developed by interpreting the underlying roots of codes. Five main themes were established and supported by coded data. All predetermined themes revolved around exploring the extent of integration between the functions of A-EYE Technology and the contemporary challenges on building sites. The following table presents an overview of the identified themes and a few relevant code examples.

No.	Theme	Relevant Codes
1	AI benefits	•National digital twin programme •Automating materials delivery orders •Addressing labour shortage
2	Safety management	•Zero incidents target •Strategic importance of AI •Safety standards differences between countries
3	Construction Productivity	•Skills shortage •Managing multiple projects •Lack of collaboration
4	Barriers to AI adoption	•Resistance of subcontractors •National restrictions on data storage •Resistance of unions
5	A-EYE opportunities	•Safety as a primary application •Creating a safety culture •Automating operational process workflow

Table 3: The Five Main Themes

5.2.1. AI Benefits

Participants generally agreed on the substantial importance of AI and its subfields in various stages and areas of the building process. Apart from the various benefits of AI applications in tracking on-site progress, safety, productivity, and output quality, Participant B ascertained that the strategic importance of AI stems from managing and aligning multiple sites concurrently. Another participant, operating in the materials supply field, stressed the numerous benefits of using AI technologies to automate the purchasing order process. "*It will be phenomenal in the sense of consistency and stopping errors from occurring and just having a better quality and faster information*." – Participant D.

Construction visualisation technologies were also considered essential to communicate and collaborate with stakeholders since the Covid-19 pandemic and the remote working trend's emergence. Likewise, Participant F noted that new construction acts in several countries to support and mandate digital transformation present a substantial opportunity for diffusing information and communication technologies (ICT).

On the other hand, Participant B highlighted several potential limitations to using AI on construction sites. First, he stated that the importance of these technologies stems from managing and coordinating multiple projects and numerous activities. However, these technologies become less feasible if their scope becomes limited to smaller projects and specific disciplines. This raised limitation is consistent with the arguments of Oraee et al. (2019) and Turk (2021), who claimed that the interconnectedness of construction activities and interoperability problems among digital platforms are primary reasons for the technology gap. Also, Participant B added that construction managers must define the purposes of gathering and analysing data to benefit from the abundant data provided by these technologies. "*Capturing data correctly and using it correctly are two different things. A lot of people start going out collecting data, but they don't actually know what questions they are trying to answer*." – Participant B.

Another interviewee warned the A-EYE development team about the anticipated rivalry in this market segment due to the existence of multiple proficient competitors. However, there remains room for A-EYE to provide unique value since the digital construction field remains in its preliminary stages. "*There are a lot of people doing this kind of technology. But we need to be casting our mind, in a wider format to ask what we don't have now, that could be potentially useful in the future*." Participant E.

5.2.2. Safety Management

Interviewees working for construction contracting firms agreed that AI technologies could significantly improve construction site safety culture and standards. *"From a safety perspective, it's a positive if they know that things are being watched. It keeps us on our toes and keeps them doing everything safely."* – Participant E. Differences between safety standards worldwide were considered a significant challenge to companies operating globally and cooperating with international clients. Hence, the advent of AI applications for monitoring staff compliance with safety rules and detecting potential hazards can leverage the strategic endeavours of multinational contractors to internationalise their operations. *"Health and safety is a huge element of these projects. We are running stats now with the number of zero incidents, of seven million hours have been worked on the projects across our campuses here, you know so there is a huge, huge emphasis."* – C.

5.2.3. Construction Productivity

Interviewees provided valuable input to explain critical reasons behind project delays, cost overruns, and unnecessary waste. A significant issue was the modest exploitation of technological solutions in use, such as BIM. Limited attention to early identification of design clashes resulted in excessive time and financial waste. However, several participants confirmed that the successful adoption of ICT facilitated team-wide collaboration and early detection of potential issues.

It was found that a primary challenge to exploiting ICT lies in the varying digital capabilities between construction stakeholders (e.g., architects, general contractors, and subcontractors). Participant D noted that the digital proficiency of stakeholders plays a vital role in supporting coordination and collaboration throughout a project lifecycle. Another participant highlighted the complexity of integrating information emerging from different stakeholders with varying levels of digital capabilities. *"Basically, everyone that has an input to the project. So, you spend a lot of time physically chasing down information to load. But even that depends on the standard of information"* – Participant C. Moreover, the lag between site activity and project control reporting was found to be a primary source of time waste among projects. The impact of this lag could be potentially reduced by adopting AI and ICT technologies that support visual communication between project teams.

5.2.4. Barriers to AI adoption

Despite the substantial benefits of AI adoption on building sites, interviewees reported numerous barriers to digital transformation in the construction industry. The modest tendency of contracting firms to invest in modern technologies stands as a barrier to the diffusion of digital tools. "*The biggest challenge really is the human challenge. If you're talking to a general contractor about this solution, they'll go, 'wow, that is brilliant, fantastic, really great.' But if you ask them to purchase it, they are like, ' hang on. Have you seen my margins?'*." – Participant F.

Another issue that obstructs the utilisation of AI technologies on construction sites is resistance to change by construction staff. This barrier has been reported by several interviewees who clarified that on-site staff resist computer vision technologies to avoid accountability. Although A-EYE Technology complies with the EU's General Data Protection Regulations (GDPR) since it does not intend to identify individuals on construction sites, the diffusion of computer vision technologies regularly faces ethical and legal hurdles. "*The challenge with these technologies, as I already mentioned, there's a large resistance to the technology because of the potential exposure of people*." – Participant B.

The same participant proceeded to explain that subcontracting firms are likely to resist the application of AI-driven construction cameras: "*You got to be very, very careful about these cameras, as I can tell you that most contractors, they will set the cameras up and they will use them against their own supply chain*." – Participant B. Finally, other participants stated that public authorities and labour unions often obstruct utilising such technologies on site: "*The union trust did not want them on the site because for any kind of claims or financial injuries or delays on their part. They didn't want that oversight*." – Participant E.

Ease of use remains a critical issue facing contracting firms aiming to adopt on-site cameras. While fixed cameras can fail to provide complete visibility of construction activities, using portable cameras is also challenging since their continuous manoeuvring is hectic and time-consuming. Likewise, the complexity of transferring data between different software solutions utilised on a construction project is a challenging task. "*Not every company uses the same platform even within a single project*." – Participant E. Another issue highlighted by a director of a contracting firm was the difficulty of sharing data with stakeholders due to restrictions set by the clients who insist on their ownership of a project's data.

5.2.5. A-EYE Technology Opportunities

There are numerous opportunities for A-EYE Technology to exploit. Existing digital solutions fall short in addressing a multitude of challenges to improving safety management and raising construction productivity. The 'safety management' theme appeared only once during the analysis of the transcript of Participant A, the A-EYE representative. He stated that A-EYE can improve on-site safety management and hazard prevention. Nevertheless, Interviewees argued that the safety monitoring function of A-EYE can be a breakthrough in the safety management discipline. "*The positives you can draw from it from a safety perspective is huge*." – Participant E. They ascertained the enormous potential for commercialising the A-EYE safety functions. "*Such a technology to creating a greater safety culture through the use of cameras would be welcome with open arms*." – Participant C.

On the other hand, several participants recommended amending A-EYE applications to match the prevalent industry challenges and achieve maximum commercialisation potential. For instance, the focus on automating the BIM update process was criticised by an interviewee who claimed that it does not have commercial benefits. Instead, he advocated that automating the construction workflow by supporting the collaboration between project teams can raise on-site productivity. "*Being able to map out the entire process, not just the physical installation of the system, that's where the data starts getting interesting because that's where you start to find all the lags and delays*." – Participant B.

Regarding process automation, it was found that automating the purchasing order process with the support of visual communication can enhance production efficiency, reduce errors, improve logistics efficiency, and raise client satisfaction. Another interviewee suggested that the A-EYE solution should be supported with mobile camera options with built-in chargers to facilitate capturing visual data in restricted areas. Finally, a senior director of a construction innovation firm insisted that relying on quantitative studies is essential to facilitate A-EYE commercialisation. "*We are going through a process now where we are saying that we must quantify and put the numbers in front of people*." – Participant F

5.2.6 Summary

In summary, the prevalent business environment provides AI technologies, such as A-EYE, with enormous opportunities to deliver unique value. The study findings ascertained that A-EYE is a promising disruptive innovation that can change the safety culture and raise construction productivity. Nevertheless, there are necessary amendments to the A-EYE technology on three levels: strategic priorities, system design, and industrial research process to ensure consistent alignment with market challenges and demands.

Regarding the strategic priorities of A-EYE technology, it was advised that the safety monitoring A-EYE function should represent a unique selling proposition. The A-EYE safety monitoring application was determined to possess significant potential since most competing AI technologies fall short of significantly improving the on-site safety management process. Likewise, it was advised that the focus of A-EYE should divert from automating the building information model and scheduling of activities into automating the construction workflow. Using A-EYE computer vision to leverage on-site collaboration between the design, construction management, quantity surveying, and quality control teams can cut time waste and reduce the volume of repeat work. Moreover, A-EYE can support the continuous engagement of clients throughout the project development and implementation phases to maintain client satisfaction. Finally, workflow automation and continuous engagement using computer vision should expand to include materials suppliers to cut unnecessary waste associated with orders errors and delays.

Concerning the system design, the A-EYE cameras system was recommended to include portable cameras to capture necessary visual data in confined workspaces. Additionally, A-EYE needs to have the capability of sharing data with other technological solutions due to the plethora of digital tools used on a project by different stakeholders. Finally, the importance of conducting quantitative research studies to objectively evaluate A-EYE's performance on construction sites was deemed essential to support the technology's future commercialisation.

6. CONCLUSION

Construction firms are facing a myriad of challenges that are hampering their performance and threatening their business survival. Poor safety management practices and modest construction productivity rates are primary impediments to the successful delivery of construction projects. Nevertheless, the advent of the digital transformation era presents a substantial opportunity for building firms to overcome these challenges. Digital solutions have proven considerable effectiveness in improving the safety culture on construction sites and raising productivity by supporting collaboration between project teams and coordination between intersecting activities.

The construction industry remains lagging behind other industries for realising the digital potential. The unique nature of construction projects exacerbates the complexity of utilising modern technological tools on building sites. Likewise, digital solutions developers may lack an understanding of the unique problems facing construction teams on building sites. Hence, the successful delivery of disruptive digital solutions requires close consideration of the construction industry's challenges. The systematic coordination between technology developers, construction researchers, and practitioners remains essential to address the prevalent technology gap segregating innovation and building firms.

In pursuit of continuous technological advancement, this study sought to explore the extent of integration between the A-EYE functions and the contemporary demands of worldwide construction practitioners. The research findings ascertained the substantial importance of the proposed A-EYE functions, such as safety management, monitoring and tracking, and real-time BIM. However, interviewees advised several amendments to the A-EYE applications, system design, and industrial research process to align the technology with the industry's needs and challenges. The feedback from senior practitioners operating in various construction industry segments presents a valuable opportunity for A-EYE's evolution to achieve successful diffusion and commercialization. The Irish A-EYE collaborative research project presents a successful example of the advised collaboration between technology developers, construction firms, research institutions, and public organisations to support the building sector's transition towards digital transformation.

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