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Abstract – The evolution of 3D visualisation and the Internet of Things (IoT) presents a substantial opportunity for integrating real-time data with Building Information Models (BIM) to improve its functionality and construction workflow efficiency. Integrating real-time data with BIM can enhance the digital representation of construction buildings' physical and functional characteristics and provide recordable status of on-site operations. Nevertheless, the integration between Visualisation and IoT technologies with BIM remains in its preliminary stages and faces a myriad of technical and operational challenges. Furthermore, developing advanced solutions to facilitate this complex integration requires a considerable understanding of the viability and feasibility of merging BIM and real-time data sources.

This paper presents the early development of a nationally-funded Irish case study deploying a combined camera and tracking solutions that enable the integration of BIM and real-time data through passive data capture. It aims to explore the potential benefits, challenges, and perspectives of integrating the disruptive A-EYE solution for real-time data BIM in Irish construction projects. Semi-structured interviews were conducted with the BIM specialists of an Irish construction company to investigate the data-related challenges to As-built BIM updating. The qualitative data were subjected to thematic analysis to explore their predispositions, expectations, demands, and motivations for utilising real-time data in updating BIM. The research results demonstrated a favourable perspective regarding integrating real-time data sources with BIM, enhancing the efficiency and quality of the As-built BIM development process.

Keywords – data capture, BIM, visualisation, automation, construction

I Research Background

Building Information Modelling (BIM) has become an established process for enhancing construction project delivery practices [1]. It is regarded as the digital representation of a building's physical and functional characteristics and encompasses creating, sharing, exchanging, and managing information throughout a project lifecycle [2]. Properly developed and managed, BIM can provide a wealth of descriptive, geometric, positional, and operable data about individual building components.

Initially, BIM was implemented to solve collaboration problems among stakeholders during the design phase of building projects [3]. Nevertheless, owing to the escalating adoption rates of BIM in advanced economies, it is progressively regarded as the principal technology driving the digitalisation of the construction sector [4]. The increasing use of BIM as a central digital element for data management in construction projects has spurred the emergence of numerous related BIM applications [5]. As a result, the scope of BIM has extended beyond the design phase, encompassing various aspects throughout the lifecycle of building projects, as illustrated in Figure 1.

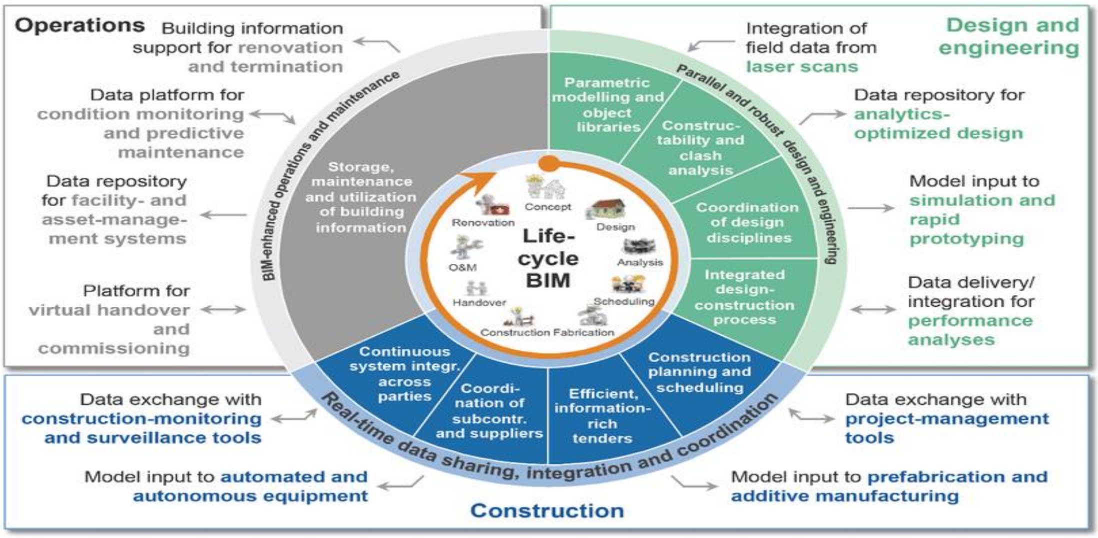

Fig 1. Applications of BIM across the construction value chain (Boston Consulting Group; Shaping the Future of Construction: A Breakthrough in Mindset and Technology)

The adoption of BIM is commonly associated with a range of perceived advantages. These include the enhancement of project outcomes, the facilitation of decision-making, the promotion of collaboration among project stakeholders, the augmentation of operational efficiency, and the reduction of both building and operational costs. Lu et al. (2014) reported a 6.92% decrease in costs achieved through adopting BIM across the architectural, engineering, and construction phases. Similarly, Staub-French and Khanzode (2007) documented a 25% productivity enhancement in productivity achieved through BIM-enabled coordination and constructability reviews, pre-emptively identifying the majority of design conflicts before the construction phase.

The BIM process's efficacy, on the other hand, heavily depends on the quality and timeliness of data acquired from construction projects. Precise, up-to-date, and timely data are vital in developing an accurate digital representation of buildings, creating and adjusting project plans effectively, supporting team-wide collaboration, and enhancing cost control. However, capturing up-to-date and accurate data from on-site projects poses a challenge for BIM technology [4].

In response to this issue, researchers are increasingly interested in investigating the integration of BIM with advanced data capture and visualisation technologies, such as cameras, laser scanners, and sensors [8, 9]. It was discovered that incorporating data generated by these technologies into BIM can improve progress monitoring, facilitate conflict resolution, enable the reuse of project knowledge, and enhance data representation [3].

Despite the considerable potential of employing modern data capture technologies for precise and real-time data input into BIM, their widespread adoption in the building industry has been hindered by several challenges. Firstly, there is a shortage of digitally accessible data to support a seamless transition from visual tools to BIM [10]. Visual data obtained from construction sites using cameras is often not adequately converted into digitised formats, obstructing smooth integration within the BIM process. Likewise, costs associated with acquiring and operating these data capture tools impede contractors from investing in this technology without assured returns [3]. Consequently, most construction firms rely on manual and conventional data-capturing and recording approaches.

In summary, integrating BIM and advanced data capture tools presents many opportunities for the construction industry. Among the key benefits are enhanced collaboration, improved design and visualisation, clash detection, and stakeholder engagement. However, challenges such as data interpolation, training requirements, cost considerations, and security management must be addressed to leverage the potential of this integration. By overcoming these challenges, contracting companies can unlock innovation and drive improved project outcomes in building projects.

This publication aims to explore the potential benefits, challenges, and perspectives of integrating real-time data from the IoT and 3D visualisation technologies with BIM in the construction industry. The paper focuses on a case study from Ireland that utilises camera and tracking solutions for passive data capture, aiming to understand how real-time data can enhance the efficiency and quality of the As-built BIM development process. The aim is to contribute insights into the viability and feasibility of merging BIM and real-time data sources, ultimately advancing the integration of these technologies in construction workflows.

The following case study presents the early stages of an Irish government-funded A-EYE project. This disruptive technology seeks 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. The technology aims to integrate captured on-site real-time with the BIM process to raise the digital representation accuracy in building projects, enhance team-wide collaboration, improve cost estimation and control, reduce conflicts and rework, and facilitate clash detection.

II Case Study

a) A-EYE Technology

The A-EYE Technology is aligned with Ireland's Industry 4.0 Strategy 2020-2025 [11]. The collaborative project envisions addressing the on-site productivity, sustainability and communication challenges facing construction firms. A-EYE's control tower, supported by high-resolution cameras and tracking devices, is uniquely positioned to provide complete project visibility and enables the most transparent visual communication between stakeholders. Two Irish construction technology firms developed the integrated solution to capture passive real-time visual and numerical data to monitor and track construction activities, detect irregularities, and reduce waste. Moreover, Technological University (TU) joined the project consortium to act as the research performing organisation (RPO) responsible for user-experience research management and dissemination of findings.

The following table summarises the functions and applications of A-EYE to address the prevalent worldwide on-site construction challenges.

Table 1: A-EYE Technology Applications

Application	Anticipated benefits of A-EYE
Real-time scheduling and resource 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.

b) Technical Evaluation

The technical evaluation of A-EYE is being undertaken by piloting the technology on an active Irish construction project to investigate the productivity, sustainability, and communication advantages of this disruptive solution. The research fieldwork plan includes studying the predispositions, expectations, demands, and motivations for integrating A-EYE solution with the BIM process on building projects.

III Methodology

a) Research Method

A qualitative research approach was adopted in this exploratory study to understand the range of perspectives held by construction practitioners involved in the BIM process of an Irish residential project under development. Qualitative research methods prioritise thoroughly examining textual data acquired through conversational formats such as interviews [12]. Particularly advantageous for exploratory inquiries, interviews facilitate a profound comprehension of the phenomena under investigation by capturing multifaceted perspectives [13].

Four semi-structured interviews were used to gather textual data that provided an in-depth understanding of the phenomena under investigation. The study sample consisted of construction professionals actively involved in the Irish construction project where A-EYE technology is being piloted and tested. Target participants held principal roles in the project's BIM process. Interviewees were assigned pseudonyms, ranging from A to E, to maintain their confidentiality.

Table 2: Interviewees' Profiles

Participant	Position	Practical Experience (years)
A	Construction Director	>20
B	Structural Engineer	>5
C	Quality Engineer	>10
D	Quantity Surveyor	>15

A-EYE functions and applications were initially presented to the study participants. Moreover, the fieldwork sought to explore:

- Current data capture, handling, and analysis challenges on Irish construction projects.
- Constraints associated with the used data management methods for developing BIM as built.
- Opportunities for integrating A-EYE solution with existing BIM workflows.
- Challenges associated with capturing and transitioning live project data using A-EYE to update BIM.

b) Data Collection Procedures

The ethical validity of the research procedures adopted in this study was carefully considered to ensure the findings' credibility [13]. The conduct of this study carefully considered the following ethical considerations: integrity, confidentiality, informed consent, and the privacy of research participants [14]. Ethical approval was gained from the TU Dublin research committee after they assessed the data collection process and procedures and confirmed their ethical validity.

Before the commencement of the interviews, participants were informed of the study's purpose through a formal invitation letter. Likewise, interviewees had the right to withdraw from the research at any stage without an obligation to provide a specific explanation. The data collection process ensured the anonymity of participants and the confidentiality of gathered data. Each interview lasted approximately 45 minutes and was audio-recorded with the participant's consent. Audio records were later transcribed verbatim to facilitate the analysis of data.

c) 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 in qualitative data [15]. The thematic analysis provides a detailed account of verbal data by examining narrative materials from life stories and breaking the text into relatively small units [16].

The thematic analysis followed the six-step approach articulated by [16] 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.

IV FINDING AND ANALYSIS

The data analysis process started by reviewing transcripts and highlighting initial ideas. Likewise, any terms referring to a participant's identity or company were redacted.

a) Data Coding

Data were coded to structure the transcribed discourse. The initial codes organised the data according to the fieldwork objectives, which yielded a starting point for developing relevant themes. A considerable number of codes (n=67) emerged; some included only one phrase, and others contained several sentences.

b) Themes

Themes emerged from 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. The established themes were directly related to the study's objectives and were developed by interpreting the underlying roots of codes. Four main themes were established and supported by coded data. The core themes of this research revolve around examining data capture approaches utilised in the BIM as-built process and the potential integration of real-time data sources within the BIM workflow.

The following table presents an overview of the identified themes and a few relevant code examples.

Table 3: The Five Main Themes

No.	Theme	Relevant Codes
1	BIM Process	•BIM applications •BIM benefits •BIM limitations
2	Current Methods of Data Capture	•BIM development procedures •Data capture challenges •BIM & skills shortage
3	Inter-team Communication	•Progress communication •Transparency •Limitations of digital tools in use
4	A-EYE Opportunities	•Potential advantages •Commercial benefits •Supporting collaboration
5	A-EYE Challenges	•Staff resistance •Skills deterioration •Learning curve

c) BIM Process

It was deemed crucial to obtain participants' feedback regarding the implementation of BIM in construction projects, the benefits of BIM to the building process, and the limitations of BIM use. Participants confirmed that BIM remains primarily used for visualisation purposes. Nevertheless, detailing (i.e. providing specific information about the components of construction elements) and clash detection (i.e. identifying and resolving conflicts between different building elements) are conducted manually by examining 2D drawings of the building design. Subsequently, the information obtained from the detailing and clash detection stages is communicated with the on-site staff for execution. Likewise, Interviewees emphasised that BIM designs frequently encounter technical challenges during project implementation.

It can be elicited that there is a need for upgrading the BIM maturity level across the Irish construction sector. To fully harness the potential of BIM in the construction sector, it is imperative to broaden its applications to include detailing, surveying, and clash detection. Likewise, the research participants asserted that the scarcity of digital skills and resistance to change continue to act as robust barriers to the widespread adoption of BIM.

Concerning the as-built development, interviewees affirmed that it is a continuous process throughout the project execution phase. The as-built model incorporates precise, accurate, and updated information concerning the structural components, geometric attributes, equipment, materials, and services, as well as operational and maintenance information.

d) Current Methods of Data Capture

Creating a BIM as-built is a complex process that necessitates a substantial amount of comprehensive data. Despite the rapid advancement in technology and automation, it was found that data capture continues to rely heavily on manual methods and the expertise of on-site staff. Engineers and construction managers routinely perform physical inspections of the building and utilise checklists to document essential data for updating BIM as-built. Interviewees described the current methods of data capture as rudimentary, deficient in accuracy, and excessively time-consuming.

Research participants clarified that capturing building data is assisted by a few technological solutions, such as laser scanning and drones. However, Participant B has expressed his dissatisfaction with the level of maturity in applying these advanced solutions in the Irish construction industry by saying, “Those areas are still kind of 10 years lagging behind.”

Another participant expressed disappointment with most technological solutions for progress tracking, “Let’s be honest about it. There have been a lot of different things tried, but none stuck that really we will take this on, and we will move forward.” – Participant A

In this context, participants reported their concerns with these technological solutions primarily for several reasons. Firstly, they pointed out that these solutions were not customised to meet the specific requirements of individual construction firms. Additionally, participants emphasised that the solutions did not adequately address the unique characteristics of building projects. Furthermore, another significant concern raised by participants was the essential requirement for continuous technical support to utilise these solutions effectively.

“It has to be user-friendly on a huge scale and does not take effort. If it takes a huge effort, staff will not use it.” – Participant A

e) Inter-team Communication

Notwithstanding the reported challenges associated with digital solutions for on-site progress monitoring, participants asserted that technology has markedly enhanced communication among diverse project teams. Advanced solutions have demonstrated their effectiveness in enhancing coordination during the design, planning, and procurement stages. Subsequently, during the execution phase, similar solutions are employed to automate communication pertaining to task assignments and inspections. However, the absence of visual evidence of events has led to diminished transparency in communication, primarily attributable to the lack of accountability.

f) A-EYE Opportunities

Respondents expressed a positive perspective on leveraging the capabilities of 3D visualisation and artificial intelligence technologies for the real-time capture of on-site data, monitoring construction progress, and enabling effective communication among stakeholders. Interviewees underscored the significance of visual communication in alleviating conflicts between project teams. Furthermore, A-EYE’s potential impact on productivity improvement was highlighted, with the potential to streamline the data capture and analysis process by reducing associated time and effort. The system’s capacity to facilitate remote working was also noted, enabling efficient management of concurrent projects and reducing overhead expenses and travel time. Additionally, the study participants predicted the possibility of enhancing overall project quality by integrating A-EYE cameras with other inspection solutions.

An interviewee described the immense potential of A-EYE in recouping unperformed working hours, stating, “Probably can turn around and save 20,000 worth of day works by looking through a camera at a certain time.” – Participant D.

g) A-EYE Challenges

Although A-EYE could be effective in automating and enhancing the data capture process for developing BIM as-built, the disruptive technology adoption in Irish construction projects may face several challenges. Firstly, the study participants explained that construction staff may resist camera solutions. “Construction staff do not like to be watched, especially in Ireland." - Participant A

Reluctance to utilise innovative solutions on construction sites can also be reasoned by resistance to change. Staff may prefer relying on traditional methods to avoid uncertainty and time pressure. "If you offer them a tool that can do the job twice as good as what they were doing, but it takes twice as long, they will not use it. - Participant C. Consequently, disruptive solutions must exhibit user-friendliness and the ability to assist staff time optimisation. Ultimately, the technology development team faces a substantial challenge in achieving the precision of A-EYE external fixed-position cameras to capture fine building details.

V CONCLUSION

Data capture is an integral part of the process of BIM as-built development. The pivotal process is marked by its complexity and time-intensive nature. Overreliance on traditional methods for data collection, such as checklists, was found to be a primary reason for data loss, reduced data quality, and time waste. Hence, integrating 3D visualisation and IoT solutions, exemplified by cameras and sensors, into the data capture process presents an unparalleled potential for automating this mechanism, consequently raising its efficiency.

The initial outcomes of the pilot testing involving A-EYE Technology at an Irish construction displayed encouraging results. The research outcomes unveiled the substantial potential of this innovative solution in raising workforce efficiency, enhancing data precision, fostering team collaboration, and bolstering the implementation of remote work protocols. Consequently, the A-EYE 3D visualisation solution holds the potential to enhance the operational efficiency of the BIM as-built development workflow and curb expenditures and time investment associated with data capture. Nevertheless, revolutionary technological resolutions centred around camera systems continue encountering various obstacles that impede widescale adoption. These challenges stem from the potential reluctance of staff to embrace change and the time constraints prevalent within Irish construction sites.

Subsequent investigations will be undertaken after the completion of the pilot phase for the A-EYE solution. The forthcoming research endeavours aim to delve into A-EYE technology's functionality, user-friendliness, and complexity when employed in a real construction environment. The insights derived from these studies will be compared with the initially elicited anticipations and requirements of construction practitioners concerning the A-EYE solution, in order to establish a comprehensive assessment of the technology's viability.

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