INNOVATIVE INTEGRATION OF MODERN TECHNOLOGIES FOR HEALTH AND SAFETY DECISION MAKING IN THE CONSTRUCTION INDUSTRY

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Abstract

Health and Safety (H&S) has been one of the key issues in the design and implementation of projects within the construction sector. At the design stage of a project, usually designers are accused of failing to appreciate most of the construction processes that will optimise safety and minimise cost. Therefore, clients and other stakeholders are apprehensive as to whether the designer's input should be fully integrated through other known ways. Also, within a continuation in the downstream end (i.e., construction and facilities management) professional processes used are not fully appreciated by designers. As such these sets of practitioners need to learn fully from each other and integrate their knowledge and skills to close the existing knowledge gap among practitioners. Modern technological innovations have given us new ways of understanding and finding solutions to such existing problems with most professionals working in a collaborative way. Such collaborative ways can enhance learning and cross pollination of professionals within an organisation and across organisations. However, the evidence through data collection is not captured across projects. This conceptual paper aims to integrate modern Artificial Intelligence (AI) and other software applications (such as BIM, IoT, and Digital Twins) to be used within the construction industry setting to understand and augment the learning of all practitioners. An exploratory qualitative research approach through literature review is used in the development of the conceptual framework for the implementation of H&S management that will inform future detailed developments of this proposed innovative approach.

Keywords: Health and Safety; IoT; AI; BIM, Digital Twins, Innovation, Integration; Construction

1 INTRODUCTION

The construction industry is one of the high-risk sectors because of the workplace related accidents that quite often occur because of the complex and dynamic nature of the construction projects [1]. The industry has historically been associated with a higher risk of workplace injuries and fatalities compared with other industries. According to the Health and Safety Executive in the UK, in 2021/22, the construction sector had the highest rate of fatal injuries to workers, with around a quarter of fatal injuries to workers in 2021/22 being in the sector [2]. In the USA, over the past ten years, the construction industry has contributed about 20% of all fatalities, despite employing only 4% of the workforce [3]. The rate of deaths and fatalities in the construction industry is five times higher than rates in other manufacturing industries [4]. Recent international statistics show that there has been no significant decrease in the number of fatalities and deaths over past five years [5].

Farmer [6] pointed out that poor and low investment in and adoption of innovation has been one of the key issues that has led to mediocre performance of the current construction industry in the UK. The construction industry has widely been criticised for low productivity, inefficiency, and reluctance to adopt to technology [7]. The construction industry has been slower to adopt digital technologies compared with other industries like banking, finance, retail, and healthcare [1], [8]. However, the construction industry has been making progress in recent years, and there are several digital tools and technologies available to help improve efficiency, productivity, and safety on construction sites.

Nowadays, Artificial Intelligence (AI) significantly transforms industries such as communications and trade. Knowledge-based systems, robotics, optimisation computer vision, machine learning and other AI subfields have been successfully applied in manufacturing, aerospace, and allied industries to achieve more profit, efficiency, safety, and security. Although the potential benefits of AI application in the construction industry are well recognised, there are many challenges related to AI which still exist and need to be resolved.

In recent years, there has been a growing recognition of the need for the construction industry to embrace technological innovations to improve its performance. Governments, industrial bodies, and stakeholders have been pushing for greater investment in research and innovation [9].

The COVID-19 pandemic has also highlighted the need for the construction industry to embrace innovation and digital technologies. The pandemic disrupted supply chains, forcing the industry to adopt new ways of working, and accelerating the adoption of technologies such as virtual meetings and remote collaboration tools [10]. While the construction industry in the UK still faces significant challenges in terms of productivity and efficiency, there is growing recognition of the need to invest in and adopt innovative technologies and innovations to improve performance and deliver better outcomes [6].

The rest of the paper is divided into the research methodology, health and safety, the perspective of the construction sector, innovative technologies, integration, and a conceptual model development, before discussion and conclusion.

2 RESEARCH METHODOLOGY

This paper is a conceptual idea that will develop the disparate areas that are required for integration to be made among emerging Information Technology (IT), concerning construction personnel health and safety, well-being, and its management, using the developing power of AI in achieving the end solution. An exploratory qualitative research approach through literature review is used in the development of the conceptual framework for the implementation of H&S management [11], [12]. As such three distinct literature reviews were done, one comprising literature on the emerging technologies, a second on health and safety management, and the last literature is on a *person-environment fit* model that has taken root in the environmental social space. The first concerns the modern IT capabilities, as well as the power of AI. The second concerns health and safety practices, concerns, and challenges within organisations, with links to the theoretical bases of the environmental theory, and its associated applications.

This research used certain search engines and the following databases: ScienceDirect, Emerald Insight, and Web of Science with free-text keywords related to subfields and the construction industry to achieve the focus of the research. These keywords include health, safety, integration, innovative, technologies and BIM.

As the literature review was not a systematic one, the last 15 years (since the emergence of BIM concept in academia) was the baseline since the construction sector has existed for an exceedingly long time. Value judgement was used for the selection of the papers which fit the research themes of historical, conceptual, development, principles, and applicability [13]. These were the dominant themes that were relevant to developing what is now part of the literature review in this paper.

3 HEALTH AND SAFETY FOR CONSTRUCTION INDUSTRY

Health and safety is an especially important functional area in all organisations. When it is effectively managed and health and safety processes are working, an organisation's projected image is valued by competitors, as well as admired by the wider built environment. However, if health and safety is compromised, the connotation it has on the organisation's business functions is usually negative in impact that is far reaching and difficult to rectify or made better within a limited time domain. As such it is imperative that organisations working independently or collaboratively should have a hold on the way they carry out health and safety, whether such an organisation be large or small. Although health and safety measures are widely accomplished within all manufacturing industries, in the construction industry conditions cannot be controlled in terms of a "pure" production process as it is known. As such, health and safety become paramount [14].

Through investments in people, processes, and equipment, clear safety policies, communication, leadership, and commitment to health and safety, a positive collaborative safety culture should be ingrained within the company ethos. Collaboration can be aided using structured processes, techniques, and cutting-edge digital technologies [15].

On the other hand, organisations and their members have a fundamental stake in how well characteristics and (capabilities) of the person and the environment of the organisation fit one another. Organisations wish to select persons who will best meet the demands of the job, adapt to training and

changes in job demands, and remain loyal and committed to the organisation. Achieving these goals in a systematic manner requires a taxonomy of characteristics and (capabilities) of actual and potential organisational members and of the organisational environment and its tasks (e.g. [16] and [17]).

Person-environment (PE) fit model can be created using different theoretical perspectives. One unique feature of the framework is its operationalisation-the assessment of the P and E components along commensurate dimensions [18]. The concept of *PE* reflects the insight that it is not the capabilities of a person or the affordances of the environment as such which determine their quality of life in their environment, it is the relation between capabilities of the person and environment.

Because behaviour is always conducted in an environmental context with its unique affordances and constraints, behavioural competence (performance) must be viewed as an outcome of the person-environment transaction. Nonetheless, the relative strength of personal versus environmental determinant of competent performance may vary. Thus, it is possible to group types of behavioural competence into rough inner determined and outer-determined subgroups [19].

There are several methodological problems that remain to be addressed in PE fit theory. The objective measurement of the person's skills, abilities, and needs and of the environment's demands and resources continues to be elusive. The assessment of subjective measures of P and E also requires more methodological development. Scales need to be developed which demonstrate that the P and E measures are not contaminated by each other. A taxonomy of theory-based dimensions of P and E also needs to be developed [18]. Operationalising the PE framework concerning health and safety issues will involve a lot of data capture and analysis, for which the seamless integration of modern technologies will be highly significant [20].

4 INNOVATIVE TECHNOLOGIES

There are myriads of IT technologies which upon can assist in the way the management of work processes on construction site are achieved. Among such technologies are AI, Internet of Things (IoT), and Digital Twins (DT) that we want to evaluate and focus our discussion upon for the development of a conceptual research approach.

Technology is an innovation if the user has not encountered its benefits and its values. However, innovative technology is not an oxymoron when viewed from the perspective that such disparate technologies, when integrated together for higher values, gives us something that has not yet been considered within their usage values.

Adoption of such innovative technologies such as AI, Building Information Modelling (BIM), IoT, Digital Twins DT, Robotics, Virtual Reality (VR), Augmented Reality (AR), Machine Learning (ML), Wearable Devices, Eye Tracking, Radio Frequency Identification (RFID), and Laster Scanning and LiDAR may have better beneficial values when integrated for better functioning values [21], [22]. However, the focus of this research paper is on digital twins (BIM & IoT), and AI.

4.1 Digital Twins (BIM & IoT)

Sensors as the basic unit of data capture instrument, with the use of cloud as the repository, with the aim of using the data within the IoT domain wherein technologies can be fully automated to achieve some form semblance. Sensors and 'things' cannot fully 'talk' to each other seamlessly without some form of automation powered by AI, which human intervention can 'play' with in real time [23]. Hence, there is a need to appreciate fully how such technology will enhance work processes in construction concerning issues of health and safety.

Digital Twin (DT) is gaining momentum in industries like manufacturing, aerospace, and the mechanical sector. Adoption of DT by many industries, sectors, and services has started to emerge with the recent development of IoT [24] and the development of the fifth generation (5G) technology standard for broadband cellular networks. The main concept of DT and IoT is connecting and collecting data about the physical objects to their virtual counterpart and vice versa. However, in construction there is an inertia as to its relevance and benefits for contemporary projects and products. If we deconstruct DT, and its definition, we are already using all the technologies within the construction industry, as independent standalone innovation. However, the concept behind DT is what we have not yet embraced, which may require human intervene in decision making, as well as automating some of the processes. Though the uptake of DT is slow, one issue is that we still have a silo mentality toward their application in construction. However, considering the facts that the next group of leaders, managers, CEOs movers

and shakers within the construction industry will be 'kids' who have grown up with X-box, Nintendo, and Zelda's, a transformation is emerging, as they would be 'relaxed' with such innovative technologies. If the industry approach be radically improved from what it is now, to something close to what they have encountered as kids in their virtual world with continuous improvement, the need for integration of some of the technologies will follow.

Digital Twin technology has been made possible by advances in computing power, data analytics, and IoT not forgetting BIM. BIM digital twins can be beneficial in improving H&S in construction industry. BIM models created during the design phase of a construction project can be used to create a virtual replica of the building or structure. By using this virtual model, the construction team can identify potential safety hazards and take steps to mitigate them before construction begins. BIM model can be used to simulate construction sequences and identify potential conflicts or hazards, such as workers working at heights or in confined spaces. This can help to reduce the risk of accidents and injuries on the construction site. During the construction phase, BIM models can also be used to monitor and manage H&S. For example, sensors and other IoT devices can be embedded in the construction site to collect data on noise levels, air quality, and other environmental factors which can impact worker safety. This data can be used to identify and address potential risks in real-time. Additionally, BIM models can be used to train workers on safety procedures and protocols before they begin working on the construction site [25]. This can help to ensure that workers are prepared to handle potential safety hazards and reduce the risk of accidents.

4.2 AI

The impact of AI on the construction industry is wide and varied. Mostly what we experience of AI is the first iteration that people tend to attribute to the power of AI. Issues of AI-Bots that are application specific to optimise functions equate with the number of queries that have been given/done within known problem areas that AI can be used. In construction the main areas of AI application include IoT, especially in the downstream end of the construction industry. For example, the optimisation of resources through proper AI efficiency.

Nowadays, AI significantly transforms industries such as communications and trade. It can be defined as the field of computer science and engineering which focuses on creating machines and systems that can perform tasks that typically require human-like intelligence, such as perception, reasoning, learning, and problem-solving [26] . While AI is about creating intelligent machines and systems, it does not aim to replicate human intelligence entirely but rather to augment it by providing tools and technologies that can perform tasks that are beyond human capability or perform them more efficiently and accurately.

Knowledge-based systems, robotics, optimisation computer vision, machine learning and other AI subfields have been successfully applied in many industries to achieve more profit, efficiency, health and safety, and security. For H&S in the construction industry, AI technologies focus on enhancing H&S for site workers, such as a system that alerts site personnel with a message about the possible hazards, thereby minimising risks. With improved efficiencies, the technology can lead to advances in H&S, as the technology with robotics can be used to evaluate sites and complete dangerous tasks for humans [27].

However, the potential benefits of AI application in the construction industry are well recognised but there are many challenges related to AI which are still exist.

5 INTEGRATION

The integration of people, technology, and process is essential in ensuring health and safety in construction sites. This approach involves the uses of a systematic and coordinated way to manage and implement health and safety measures. The following sub-section discusses these key elements in detail.

5.1 People

People are the wellspring of what we do when we have work to achieve and complete the goals that are set out in our project objectives. Without the employees' input in turning disparate resources into the product through the project, it is almost impossible to achieve our goals. Although IT automation has helped in most processes there are still issues of interpretation of the integrated processes for good

decision making. Hence the competencies required for such operative and their leaders need to be sound for value to be created when we do our projects.

Leadership is paramount for an effective and efficient project and its health and safety concerns. Management of health and safety is about the people's knowledge and understanding about their job processes and how they integrate technology with these processes in a safe and structured environment, as well as minimising the health and safety risk associated with their jobs. The leader should be focussed in driving his/her ideas through a well-oiled and robust team of players. Without a transformational leader in charge, who see the benefit of AI as the link in integrating these technologies we would not succeed. For example, the AI-Bots, which are used currently in other industries for queries and answer, can be adapted to meet issues of building regulations, violation of Construction, Design and Management (CDM) regulations, as well as violation of construction site contraventions. Hence the people can be just administrators [28].

5.2 Technology

So many technologies have emerged that are utilised in other industries that have not yet taken root in the construction sector. Some of these technologies include wearable devices that monitor heart rate, respiration, and body temperature, which can help detect early signs of fatigue or exhaustion, as well as alert supervisors to potential safety hazards. Additionally, smart safety vests or helmets equipped with GPS and sensors can help track worker movements and notify them of nearby hazards or unsafe conditions [29]. Such devices can be linked using IoT to a digital model where hazard areas are identified with the use of digital twins. Despite most of these technologies being mature and diffused in other industries, there is an absent of their diffusion within the construction sector. Construction inertia may be due to failure to understand how to get these technologies 'talking' to each other. Therefore, with advancements of technology and the life cycle realisation of the project in one holistic environment, a vast amount of the health and safety data can be generated, collected, and stored directly in a single environment. With the aid of artificial intelligence, this data can help construction site personnel and managers, designers, clients, end-users, and all other stakeholders involved in the design, delivery, and use of a facility in making the right and correct decisions regarding health and safety issues which may arise [7].

5.3 Process

Some of our processes within the built environment need formulation as some may not be '*fit for purpose*' due to changes in the way we design or build things. Perhaps revisiting the development of these processes and finding new ways of approaching the 'old' problem may aid us in coming up with better understanding emerging from the appraisal [30]. In most case, practices developed from the evolving work pattern have existed from the start of the process type. However, over time there may come innovation which requires a rethink of these processes, of which AI is an example. Hence new strategic process must be reformulated incorporating the innovation. For example, the drawing of plans has moved from the basic technical drawing, through 2D CAD, into BIM. Similarly, components manufacturing has moved from the workers in a controlled environment into 3D automated printing. Thus, AI can be another innovation which may be disruptive in nature, hence requiring process rethink. Using a known model in developing this innovative integration of using AI reside in the Lawton *person-fit environment* model approach and within a well-developed application [31], [32].

5.4 Optimisation

Optimisation involves improving the efficiency or effectiveness of a system or process by fine-tuning certain parameters or variables within the system or process as data becomes available over time for every successful completed project [33]. It is critical to ensure the health and safety of the employees and reduce the risk of accidents and injuries on construction sites. It is usual to say that once a problem has been analysed and solution found, there is a need to refine the solution through various optimisation cycles such that it can be practically used within the field of application envisage.

Optimisation is an ongoing process that requires the continuous evaluation and refinement of solutions to ensure they are effective, efficient, and sustainable within the field of application. This involves a commitment to innovation, investment in technology and resources, and a culture of continuous improvement and learning.

6 TOWARDS AN AI DECISION SUPPORT HEALTH & SAFETY MANAGEMENT

Fig. 1 gives a high-level schema of how the integration of technologies can be conducted, considering the known processes, as well as new processes will be used in developing the integrated approach. People are considered as part of the integrated environment, for without the person, this approach cannot function effectively. As such, using the Lawton's [19] *person-environment fit* model, its principles and concepts as the premise, and the starting point for this integrated approach, decisions can safely be made by those working within the construction environment. AI together with IoT will ensure that a commensurate scale is used when developing the organisation *PE* fit required through the mapping done to capture the required data measures.

After data collection using IoT, as well as known conventional data collection methods, the data is cleaned, then standardised and structured for database inclusion. The standardised data will be added to the dataset, with the App and AI running seamlessly for the purpose for which they have been designed or the programmes developed. The AI/ machine learning App would have been trained for pattern recognition, for health and safety hazards, risks, incidents, site safety event types, as well as expert domain construction knowledge. A bit of Lawton's [19] *person-environment* will have also been built into the integrated approach, recognisable within the form of AI decision criteria.

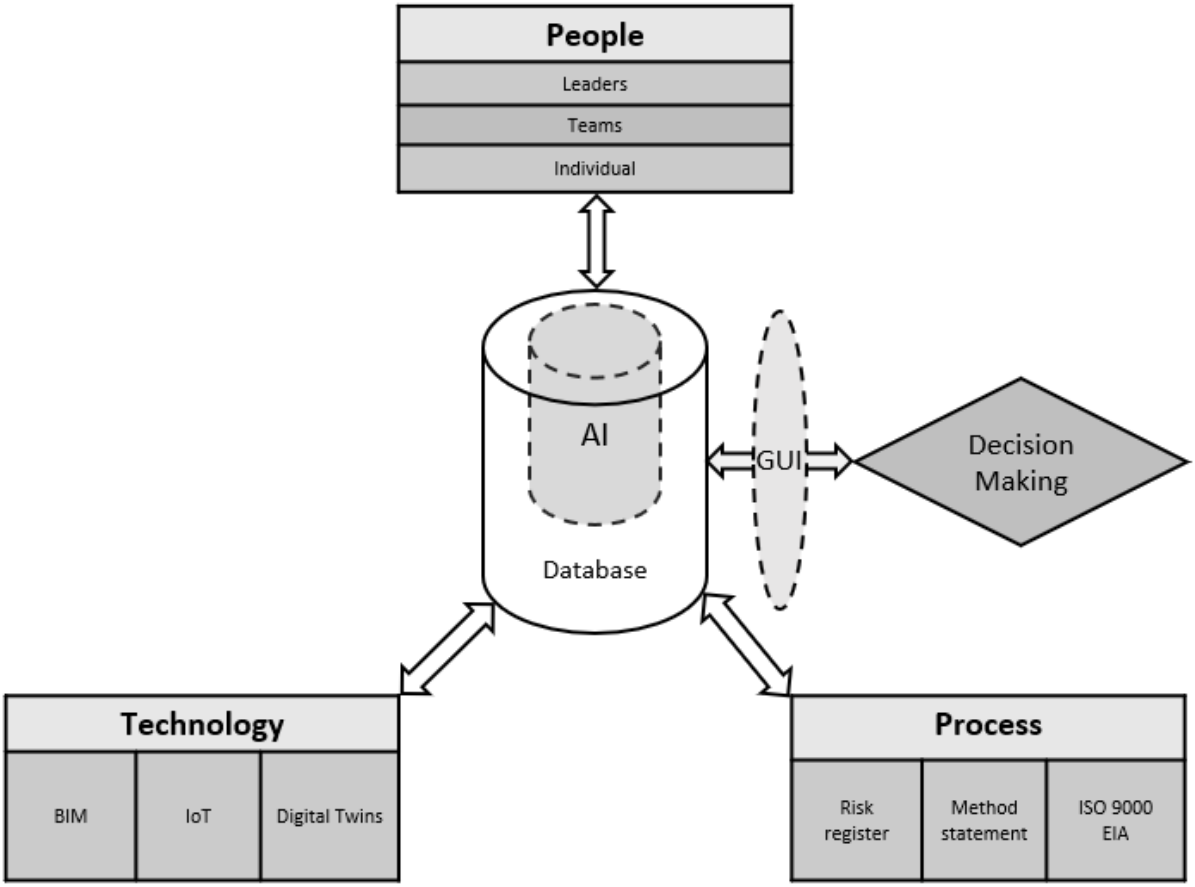

Fig.1: Conceptual representation of digital integration for construction

The AI technology can search the database with a command from the user through the graphical user interface (GUI) for similar issues and analyse each health and safety incidents with all scenarios, with the best possible solution suggested to the decision maker. The speed and accuracy of AI tools for mining data cannot be compared with those of human and other tools. Time in health and safety issues is paramount and key for saving lives and money. AI technology save much of time. With an optimisation algorithm or App as part of the full suite within the framework envisage, the AI machine learning approach would continuously learn by optimising the solution space, with new safety risk challenges, and health and safety issues that are arising as the site work changes, as well as from one site

experience to the next the possibilities are many. AI increases the value of health and safety management by supplying all the possible answers to the raised questions and solving problems that would otherwise require substantial development time [34].

7 DECISION MAKING

For one to be able to make the right decision in real time, there is a need that the operative or the decision maker/team must have competencies in different fields which will aid in making an informed decision [35]. That means the decision made should be credible interpretation of data and text mining, as well as the field of specialism, say project management, health and safety, quantity surveying or environmental engineer. Combining the specialism of the decision maker, as well as the information mining from the disparate technology's issues, better understanding of a phenomenon with specific knowledge can be generated which will be an original creative thought from AI aided approach. Hence, the decision maker will not just be an abductive individual but supported by unambiguous evidence from AI support.

AI can assist to analyse the data collected from sensors, cameras, and other data collectors installed on the construction site to detect potential hazards or risky behaviours of workers. It can also provide real-time alerts and recommendations to the personnel to prevent accidents and injuries. Moreover, AI can assist in predicting and managing risks related to environmental factors such as weather conditions, geological conditions, and natural disasters. This can help the project team to take proactive measures and adjust their plans accordingly to avoid any risks and hazards.

AI assistance will involve gathering measurement in the characteristics (i.e., intrinsic, or extrinsic) of a person through machine learning, by analysing data from social media, online surveys, and other digital platforms. Patterns and trends in data can be identified to measure some of these characteristics.

8 DISCUSSION

Within this paper the concept, principles, and usage of emerging technologies have been developed, although most of such technologies are seen as disparate. A conceptual understanding was generated from Fig. 1, gives an insight into the workings of the proposed model.

The data to be collected comes from the site operatives, designers and stakeholders that will have adverse impact on the site construction process. The data from these operatives are mapped and structured for eventual inclusion into the database. Also, data arising from the changing nature of the BIM artifacts, on construction operations, as well as method statements, and risk registers will be collected into the centralised database. An organisation that has existed from some time will also have historical data as their corporate memory, which is also to be harvested for the dataset that is envisage.

To consolidate all parts of the collected data into a single centralised location and maintain a comprehensive health and safety information (i.e., records, documentation, policies, processes, etc), a mapping process is required between the resultant structured data from the already described processes using the OWL Ontology [36], of which this will be the subject of another paper.

9 CONCLUSION

The premise for this position paper is that processes that are considered independent with the health and safety domain can be improved through the idea of integration of technology, processes, and people. Integration of people has been present all the time but capturing the soft people's issues are not so apparent. In this paper a concept was thought out which would when fully developed give a clear indication about how such concept can be operationalised for the benefit of the construction industry. Therefore, a good deal of research is required for such a position to be attained. One of the biggest and most significant industries in the world is construction, yet compared with other sectors, it has been reluctant to incorporate AI technologies. While there are undoubtedly advantages to employing AI in construction, such as better safety & health, more efficient processes, and lower costs, there is also several difficulties which must be resolved. The requirement for accurate and trustworthy data is one difficulty. Construction AI systems require precise and trustworthy data to function properly. Nevertheless, the data in the construction sector is notoriously complex and disorganised, which can make it challenging to create efficient AI models. Another issue is the lack of qualified personnel who can run and maintain AI systems. The paucity of competent personnel in the construction sector is well

recognised, and it is made much worse by the lack of people who are familiar with AI technologies. It might be challenging to develop efficiently and maintain AI systems without skilled people. Regulatory compliance presents another difficulty. Like any innovative technology, AI systems in construction are subject to several laws and guidelines. Failure to comply may have legal and financial repercussions, and it can be a complicated and time-consuming process. BIM, IoT, and digital twins can enhance health and safety in the construction industry by spotting potential problems, keeping an eye on them in real-time, and supporting workers in their training needs. Although the construction industry can reap substantial advantages from AI, IoT, BIM, and Digital Twins in terms of health and safety, certain hindrances must also be explored and resolved to achieve those benefits. As technology progresses, we can anticipate further breakthroughs in the construction sector that will facilitate digital transformation and enhance future operations.

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