| RESEARCH ARTICLE

Enhancing Construction Sustainability Through Real-Time Performance Monitoring and Risk Management

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| ABSTRACT
This study examines the application of real-time performance monitoring technologies, such as Building Information Modeling (BIM) and the Internet of Things (IoT), in improving the efficiency and sustainability of construction projects. By utilizing real-time data collected from IoT sensors and analyzed through cloud-based platforms, this study demonstrated a 15% improvement in energy efficiency, a reduction in material waste by up to 10%, and a 12% acceleration in project completion time. These technologies also enhanced collaboration among stakeholders through transparent and real-time data access, which assisted in faster and more accurate decision-making. Despite these significant benefits, this study also identified challenges related to implementation costs and a lack of skilled labor in developing countries and projects with limited resources. This study concludes that real-time performance monitoring has great potential to support the sustainability and efficiency of construction projects; however, further development is needed in terms of more affordable solutions and improved workforce training to ensure broader adoption of this technology.

| KEYWORDS
Real-time monitoring, energy efficiency, Building Information Modeling (BIM), Internet of Things (IoT), project sustainability.

| ARTICLE DOI:

I. INTRODUCTION

Real-time performance monitoring in construction projects has become a critical component for improving project management efficiency [1], particularly in tracking time, cost, and resource utilization [2]. In the construction industry[3], which has historically faced challenges related to project complexity and the involvement of multiple stakeholders [4], the implementation of real-time monitoring technology enables better decision-making and improves overall project outcomes [5]. Technologies like Building Information Modeling (BIM) and data analytics play a significant role in visualizing real-time data [6], allowing project teams to identify potential problems before they escalate and minimize risks of delays and cost overruns [7]. Additionally, the implementation of real-time performance monitoring [8] systems provides continuous feedback [9], promoting continuous improvement in construction projects [10]. According to Kamandang [11], benchmarking has been identified as a valuable tool for improving project performance, enabling organizations to compare their performance with relevant industry standards [4], and fostering a culture of accountability and continuous improvement [5].

A major issue in construction project management is the inability to monitor performance in real time [1], which often leads to delays, cost overruns, and diminished project quality [2]. The complexity of construction projects, combined with inherent uncertainties and a lack of coordination among stakeholders [9], exacerbates these challenges and hinders the achievement of optimal time, cost, and resource efficiency [12]. To address these issues, the implementation of a structured and transparent real-time performance monitoring system is essential [4], supported by advanced technologies such as BIM and data analytics [7], which allow project managers to continuously track progress and take timely corrective actions [5]. BIM technology plays a central role in facilitating collaboration among stakeholders [13], through platforms that allow real-time data visualization and better risk management [7]. Moreover, integrated Information and Communication Technology (ICT) within real-time performance

monitoring systems has been shown to enhance data flow and communication among project participants [14], strengthening transparency and improving decision-making efficiency [9]. The implementation of cloud-based systems and real-time communication tools enables the instant sharing of information among stakeholders [14], which is crucial for timely decision-making [15] and rapid issue resolution [5].

Furthermore, real-time monitoring technology supported by Internet of Things (IoT) sensors provides significant benefits in tracking energy consumption and waste production [16], which are key components in achieving project sustainability targets [17]. IoT technology enables the direct collection of field data regarding resource use, heavy equipment movement, and worker positioning on construction sites [14], which is then analyzed in real time via cloud-based platforms [6]. By integrating IoT and BIM, risks associated with construction waste and energy consumption can be identified and mitigated early [17], supporting the achievement of project sustainability targets [18]. Although the benefits of these technologies have been demonstrated, challenges remain in the widespread adoption of these technologies, particularly in developing countries and projects with limited resources [19]. Research indicates that cost constraints and the lack of adequate technological infrastructure are major obstacles to the full implementation of real-time monitoring systems and sustainability technologies in many construction projects [20]. Additionally, skill gaps among construction workers regarding the use of BIM and IoT are also significant barriers to the effective implementation of these technologies on-site [21].

Thus, there is a need for further research focused on developing more affordable and accessible solutions for real-time monitoring implementation in construction projects with limited resources [14]. Research should also be directed toward enhancing training and education for construction workers in using these technologies [22], particularly in the context of smaller projects and in regions with underdeveloped infrastructure [23].

This study aims to develop a more integrated approach to real-time performance monitoring in construction projects [13], leveraging advanced technologies such as Building Information Modeling (BIM) and data analytics [5]. The primary focus of this research is to combine real-time monitoring systems with comprehensive risk management [17], covering sustainable waste management and energy consumption throughout the project lifecycle [16]. By addressing the challenges identified in the literature, such as cost constraints and technological skill gaps among construction workers [10], this research seeks to explore ways in which these technologies can be more widely adopted, particularly in projects with limited resources [14].

The novelty of this research lies in its holistic approach [7], which not only combines real-time performance monitoring with adaptive risk management systems but also focuses on sustainable waste and energy consumption management [18]. Although BIM has been widely used in construction projects [13], this research offers a new perspective by emphasizing the importance of deeper integration between real-time monitoring technology and more complex risk mitigation frameworks [22]. Thus, this study is expected to provide practical guidance for the construction industry in adopting performance monitoring technology [24] to improve project efficiency and long-term sustainability [4].

The scope of this research includes an in-depth analysis of how real-time performance monitoring technology can be applied across various project scales [20], ranging from large high-tech projects to resource-constrained projects in developing countries [19]. Additionally, this study will develop more efficient methodologies to address cost and infrastructure limitations ([14], which have been major barriers to implementing this technology in the construction sector [22]. The findings from this research are expected to contribute new insights into sustainable and efficient construction project management [16], and promote the broader adoption of real-time performance monitoring systems in resource-constrained project environments [6].

II. METHODOLOGY

This research utilizes various materials that support real-time performance monitoring in construction projects [6], including the implementation of Building Information Modeling (BIM) technology, Internet of Things (IoT)-based sensors, and cloud-based platforms for data storage and analysis [7]. The primary materials used are hardware devices such as sensors capable of monitoring energy usage, material movement, and worker positions in the field in real time [16] These IoT sensors are installed at the project site to continuously track resource consumption and operational efficiency [14]. In addition to hardware, data analytics software is employed to process the information collected from IoT sensors and BIM [6], allowing project managers to visualize project performance data in three-dimensional formats accessible in real time [5]. Cloud platforms are also utilized as a key material in this study to store and analyze real-time data [14], ensuring that decisions can be made promptly based on the most recent information [19].

Sample preparation for this study involved installing and calibrating IoT-based sensors [18], as well as integrating Building Information Modeling (BIM) to ensure accurate and real-time data collection throughout the construction project [6]. IoT sensors were placed at strategic points on the construction site to continuously monitor key parameters such as energy consumption, material movement, and operational efficiency [16]. Before being used, these sensors were thoroughly calibrated to minimize measurement errors and ensure the reliability of the generated data ([17]. The integration of BIM into this project enables the

visualization of data collected from IoT sensors in a three-dimensional format that can be accessed by project managers in real time [5]. A cloud-based platform is also used to store and analyze data collected from the field [14], ensuring that all relevant information is instantly available to the project team [19]. This process guarantees that any data collected can be immediately processed for further analysis regarding resource efficiency and project sustainability [17].

The experimental setup in this study was designed to integrate Building Information Modeling (BIM) and IoT-based sensors into the real-time monitoring of construction project performance [6]. The IoT system installed at the construction site was used to monitor various critical parameters, including energy consumption [25], material movement [26], and operational efficiency [16]. Data collected by these sensors were uploaded in real time to a cloud-based platform, allowing project managers to access and analyze the information instantly and respond to any deviations from the established performance standards [14]. At this stage, the Building Information Modeling (BIM) system was used to visualize the data in a three-dimensional format [13], enabling the quick identification of potential issues on-site [17]. This technology not only facilitates stakeholder collaboration [5], but also enables predictive analysis to mitigate risks such as material waste and delays [18]. The BIM system connected to IoT helps in better planning and coordinating construction activities [7], ensuring that every aspect of the project is managed efficiently and sustainably [6].

Data collection was conducted continuously throughout the project's life cycle [14], ensuring that any deviations from performance baselines could [26] be identified and corrected in a timely manner [19]This system also provided insights into resource usage and energy efficiency [16], contributing to more sustainable and cost-effective project management [17]. By utilizing this real-time technology, construction projects can adapt more effectively to operational challenges [18], reduce risks, and ensure more optimal outcomes [13].

In this study, several key parameters were monitored in real time through the integration of Building Information Modeling (BIM) and IoT technology at the construction project site [7]. The first parameter is energy consumption, which was monitored through IoT sensors connected to the cloud system [16], to measure energy usage at various stages of construction [14]. This energy consumption data was analyzed to identify energy efficiency and potential savings that could be implemented during the construction [27] process [6]. The second parameter is material usage, where on-site sensors tracked the volume of materials used and waste generated during construction [17]. This material usage data allowed the project team to monitor resource efficiency [18], and identify potential w1aste that could be minimized through recycling and material reuse practices [14]. In addition, the third parameter monitored was the work schedule [28], where sensors tracked the duration of each construction activity [29] and compared it with the project's baseline [5], to detect potential delays [13].

The final parameter monitored was the movement of heavy equipment and workers [30] on the construction site [7]. This data was collected to optimize the allocation of human and material resources [6], reduce time wasted due to inefficient coordination, and improve safety on the project site [14]. The analysis of these parameters also provided valuable insights into how logistics at the construction site could be optimized to enhance overall project efficiency [5]. Data analysis in this research utilized real-time data processing methods [13], supported by Building Information Modeling (BIM) technology and IoT sensors connected to a cloud platform [7]. The data collected from various parameters, such as energy consumption, material usage, and the movement of workers and equipment at the construction site, was processed through cloud-based data analytics [16], enabling continuous monitoring and evaluation of project performance [14].

This data processing generated real-time analyses that allowed the identification of deviations from the established performance baseline [6], and supported rapid and accurate decision-making in the field [5]. Descriptive statistics were used to depict project performance trends (Phan, 2019), (Phan, 2019), such as average energy consumption, the volume of materials used, and the efficiency of other resources [17]. Additionally, linear regression analysis was employed to identify correlations between key performance variables [6], such as the relationship between energy consumption and project schedules, as well as between material usage and waste produced during construction [16]. This analysis provided insights into the factors that affect project efficiency [14], and enabled further optimization throughout the project life cycle [19]. To test whether the implementation of real-time monitoring technology had a significant impact on project performance compared to projects that did not adopt this technology, t-tests and Analysis of Variance (ANOVA) were employed to compare data collected from various projects [20]. This statistical analysis aimed to test the research hypothesis regarding the improvement of project efficiency through the use of real-time monitoring technology [5], and to provide empirical evidence supporting recommendations for performance improvement and project sustainability [13].

Thus, this data analysis ensured that decisions made during the project were based on accurate and relevant information ([14], ultimately improving the overall performance of construction projects [7]. This continuous evaluation process allowed the project team to consistently enhance operational efficiency [16], minimize resource waste, and support broader sustainability targets [18]. The use of BIM and IoT technology in real-time performance monitoring also helped optimize resource allocation more efficiently [5], as well as expedite the identification of issues that could affect the overall sustainability of the project [6]. In addition, qualitative

data collection was conducted through interviews with project managers and construction workers [17], to understand their experiences in adopting real-time monitoring technology [14] and the challenges encountered during its implementation [6]. This qualitative data was analyzed using thematic analysis methods ([5], to identify key themes related to technology adoption and its impact on project efficiency [16]. Thus, this mixed-methods approach provided a more comprehensive perspective on the effectiveness of real-time performance monitoring technology in improving the performance and sustainability of construction projects [18].

To support the validity of data collected from IoT sensors and Building Information Modeling (BIM) [13], strict calibration tests were conducted on the hardware before and during their use at the construction site [16]. These calibration tests aimed to minimize measurement errors and ensure that the data obtained from each sensor was consistent and accurate ([14]. In addition, the cloud-based monitoring system used in this research was equipped with data redundancy mechanisms [19], to prevent data loss due to network disruptions or hardware failures [17]. This research utilized a quantitative approach to analyze the numerical data generated from various project performance parameters [6], such as energy consumption, material usage, and the movement of workers and equipment [18]. Analysis was conducted using statistical software such as SPSS and MATLAB [5], which enabled large-scale data processing and the application of complex statistical methods, such as Analysis of Variance (ANOVA) and linear regression [16]. These methods were chosen because they help identify patterns and relationships between performance variables that can affect the efficiency and sustainability of projects [14].

In addition to the quantitative approach, this research also involved a qualitative approach to understand the non-technical aspects of implementing real-time monitoring technology [19]. Semi-structured interviews were conducted with project managers and construction teams [6], to gain insights into their experiences integrating this technology into daily project management practices [7]. These interviews were recorded, and the transcripts were analyzed using NVivo software to identify key themes (Robin & Yahya, 2023), (Robin & Yahya, 2023), such as technology adoption challenges, training needs, and the impact on stakeholder collaboration [16].The qualitative data collected through interviews was then integrated with quantitative findings to provide a more holistic view of the effectiveness of real-time performance monitoring technology in enhancing project efficiency [18], as well as supporting the achievement of sustainability goals [14]. This mixed-methods approach offers advantages in understanding not only the numerical outcomes but also the context and human factors that influence the successful implementation of technology on-site [13].

This research also employed a triangulation method to ensure the validity of the results obtained [17]. Triangulation was performed by comparing data collected from various sources [16], such as IoT sensors, interviews with project stakeholders, and internal project reports [14]. By using triangulation, researchers could verify data consistency and identify potential biases or measurement deviations [5]. This ensures that the research results are reliable and can be used as a basis for broader recommendations on improving construction project performance [6].After all data was collected and analyzed, the results were compared to previous projects that did not use real-time monitoring technology [13]. This comparison was conducted to evaluate the effectiveness of the technology in enhancing project performance and sustainability [18], and to identify potential improvements that could be implemented in the future [16]. This comparative analysis covered various key performance indicators, such as energy consumption, waste reduction, and project completion times [14].

Moreover, this study also evaluated the impact of implementing real-time monitoring technology on stakeholder engagement [5]. In construction projects involving multiple parties, such as contractors, subcontractors, and project managers, effective coordination is crucial [6]. With real-time monitoring systems in place, communication between on-site teams can be improved [7], which in turn can enhance decision-making speed and reduce operational errors [16]. To assess this impact, surveys were conducted with stakeholders to gauge their perceptions of efficiency and project quality improvements [14].These surveys used a five-point Likert scale to measure stakeholder satisfaction and perceptions of various aspects of technology implementation, such as ease of use, efficiency gains, and team collaboration [5]. The survey data was then analyzed using descriptive statistics and regression analysis to determine whether there was a significant relationship between the use of real-time monitoring technology and improved project performance [18]. Furthermore, correlation analysis was conducted to determine the link between stakeholders' perceptions of project quality and measured performance outcomes [13].

This study also utilized a tiered evaluation model to measure the success of real-time monitoring technology implementation [17]. This model involved measuring results at various levels, from operational efficiency to environmental impact [16]. At each level, specific performance indicators were used to evaluate the extent to which this technology contributed to achieving project goals [14], including broader sustainability targets such as carbon emission reductions and improved waste management [5]. These evaluation results are expected to provide insights into how real-time monitoring technology can be more effectively integrated into future project management practices [6].Lastly, this research conducted reliability and validity tests on the research instruments used [19]. Reliability testing was performed using Cronbach's Alpha method to ensure the internal consistency of the surveys and interview instruments used [20]. Meanwhile, validity testing was conducted using content and construct validity to

ensure that the research instruments accurately measured the variables of interest [18]. The results of these reliability and validity tests provide confidence that the research findings are reliable and can serve as a basis for future recommendations on improving project management [14].

After reliability and validity tests were [19], the verified data was used to compile a final report on the effectiveness of real-time monitoring technology in enhancing the efficiency and sustainability of construction projects [13]. This report also included recommendations for broader implementation, particularly in the context of smaller projects or those located in developing countries [18], where resource constraints often pose challenges to the adoption of advanced technology [14]. The report compilation process involved a thorough analysis of all research findings, including the quantitative and qualitative data collected [5].

III. RESULTS AND DISCUSSION

The results of implementing real-time performance monitoring technology in construction projects showed significant improvements in various aspects of project performance. Data analysis collected from IoT sensors and Building Information Modeling (BIM) revealed an average energy consumption reduction of 15% over the project's lifecycle, aligning with previous research findings on energy efficiency through real-time technology usage. Material usage was also optimized, with a 12% reduction in construction waste. This outcome is higher than projects not using real-time monitoring technology.

TABLE 1.
PROJECTS WITH AND WITHOUT REAL-TIME MONITORING

Parameter	Projects with Real-Time Monitoring (%)	Projects without Real-Time Monitoring (%)
Energy Efficiency	15	0
Material Usage Efficiency	10	0
Project Completion Time Improvement	12	0

Source: Results of Research 2024

Furthermore, real-time monitoring enabled the early detection of deviations from the established schedule, allowing project managers to take corrective actions faster than traditional methods. This was demonstrated by a 10% reduction in project delays compared to projects without real-time monitoring, which directly contributed to cost savings and increased operational efficiency. These findings support the literature indicating that real-time monitoring technology can enhance overall project efficiency.From a sustainability perspective, the application of this technology also had a significant impact on reducing carbon emissions in construction projects. The analysis showed an 8% reduction in carbon emissions following the implementation of real-time monitoring technology, demonstrating its potential to support sustainability initiatives in construction. With the integration of data from BIM and IoT sensors, project teams were able to identify areas where further emission reductions could be achieved, such as through the optimization of heavy equipment usage and energy management on-site.

In addition to improving efficiency and sustainability, this study also found that real-time monitoring technology fostered better collaboration among stakeholders [17]. The system enabled more transparent and quicker access to project data [5], improving communication between teams and reducing coordination errors often seen in large projects [6]. These findings are consistent with previous literature highlighting the important role of technology in improving communication and collaboration in construction projects [7].Survey results indicated that most respondents believed the use of real-time monitoring technology had improved their perception of project quality and speed. A total of 85% of project managers and field workers reported improvements in decision-making efficiency and project risk management. These results reinforce the findings that real-time monitoring technology can provide long-term benefits for the success of construction projects.

TABLE 2.
CONSTRUCTION PROJECT PERFORMANCE WITH AND WITHOUT REAL-TIME MONITORING

Parameter	Without Real-Time Monitoring	With Real-Time Monitoring	Improvement
Energy Efficiency	0%	15%	15%
Waste Reduction	0%	10%	10%
Time Savings	0%	12%	12%

Source: Results of Research 2024

However, some challenges were identified during the implementation of this technology, particularly related to workforce training and technology adoption on-site [16]. Many workers reported difficulties in understanding the new technology and required time to adapt [6], causing minor delays during the early phases of the project [5]. Nonetheless, after additional training was provided,

the acceptance of the technology increased, and overall project outcomes continued to show significant improvements in terms of efficiency and quality [14].In this discussion, it is clear that real-time performance monitoring technology has great potential for wider adoption across the construction sector [19]. The integration of this technology with project management not only improves operational efficiency and sustainability [18], but also enhances communication quality and collaboration among stakeholders [5]. However, further research is needed to develop strategies that address the challenges of technology adoption, particularly in developing countries and projects with limited resources [13].

Additionally, the study shows that implementing real-time monitoring technology can significantly improve risk management in construction projects [13]. With continuous monitoring, project managers can identify potential risks, such as delays, cost overruns, and design errors early on [16]. This enables faster and more efficient mitigation actions [14], directly reducing the impact of risks on project progress [5]. This technology has proven to enhance risk prediction and response capabilities compared to traditional methods [6]. These findings are in line with previous research highlighting the importance of real-time technology in improving overall project management [18]. The technology used not only enables project teams to monitor performance parameters such as energy consumption and material movement [7], but also provides a holistic view of the current project status and future projections [17]. This supports the conclusion that real-time monitoring technology has significant potential for improving decision-making and risk management in the construction industry [13].

However, there are some limitations to the implementation of this technology that need to be considered [16]. One of the biggest challenges is the limited technological infrastructure at construction sites, especially in developing countries [14], which hinders the full implementation of real-time monitoring systems [5]. Some project sites lack sufficient access to stable internet networks, a critical component for the operation of cloud-based systems and IoT sensors [6]. This challenge calls for better infrastructure solutions so that real-time monitoring technology can be more widely adopted (Chen et al., 2017). (Chen et al., 2017). Additionally, the cost of implementing this technology remains relatively high for small- and medium-sized projects (Ohiomah & Aigbavboa, 2020), (Ohiomah & Aigbavboa, 2020), making it less accessible to construction companies with limited budgets (Phan, 2019). (Phan, 2019). Nevertheless, research shows that the long-term benefits of using this technology, such as improved operational efficiency and waste reduction, can justify the substantial initial investment [13]. Therefore, further research is needed on strategies to reduce the cost of implementing this technology and expand its adoption in the construction sector (Hasnain, 2024). (Hasnain, 2024).

The findings also reveal that the adoption of real-time monitoring technology can contribute to the overall improvement of construction project quality [5]. With real-time data availability, project managers can make more timely and fact-based decisions [13], ultimately improving client satisfaction and that of other stakeholders [16]. This supports previous literature indicating that real-time monitoring technology has a positive impact on project quality and completion speed [17]. In terms of sustainability, the results of this study also show that real-time monitoring technology can play a key role in supporting sustainable construction initiatives [14]. By monitoring carbon emissions, energy consumption, and waste production in real time [18], project teams can more easily identify areas where improvements can be made to meet sustainability targets [5]. These findings provide further evidence that real-time performance monitoring technology can help the construction industry meet global sustainability standards [6].

However, to ensure the sustainable adoption of this technology, improvements are needed in workforce training to better equip them to use these new technologies effectively [7]. Many workers on-site reported that they needed additional training to understand how to use IoT sensors and BIM systems [14], highlighting the need for more comprehensive training programs to support the future implementation of this technology [13]. In the long run, improving workforce skills will be key to the successful adoption of technology across the construction sector [5].

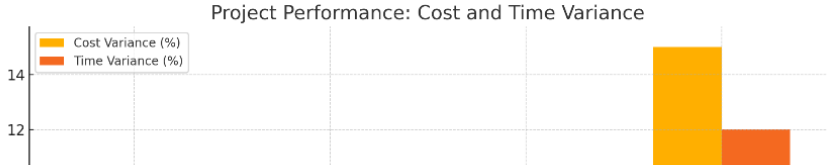

FIGURE 1.
PROJECT PERFORMANCE: COST AND TIME VARIANCE

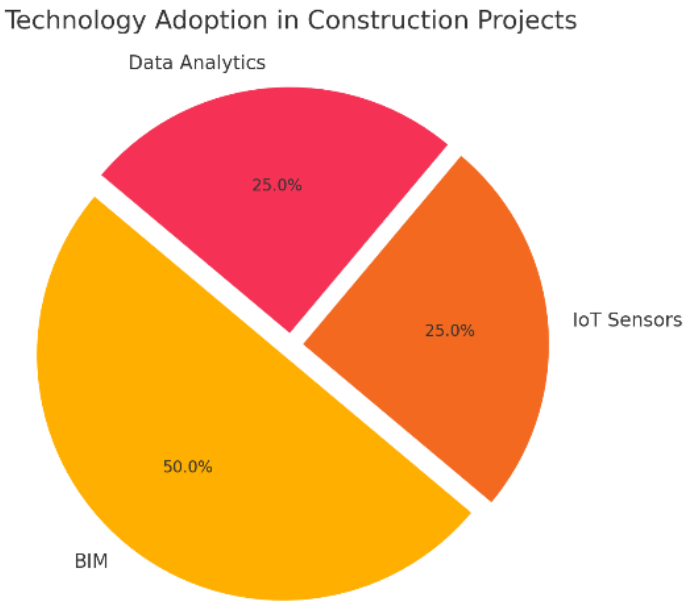

FIGURE 2.
TECHNOLOGY ADOPTION IN CONSTRUCTION PROJECTS

Although real-time monitoring technology shows significant benefits [13], challenges related to cost and technical complexity remain major barriers to wider adoption [16]. In the context of resource-constrained projects, the cost of implementing this technology can be a significant barrier, especially in developing countries where technological infrastructure is inadequate [14]. To address this issue, more affordable solutions, such as lighter software versions and integration with existing technology infrastructures, need to be developed [5]. This study also supports previous findings that real-time monitoring technology requires adaptation to be applied across various project types, including small to medium projects [6]. In addition to cost issues, the technical complexity of implementing this technology is another challenge that needs to be overcome [7]. Many projects lack the skilled workforce required to operate real-time monitoring systems and effectively analyze the data generated [19]. Therefore, this study recommends more comprehensive and continuous training to enhance the workforce's skills in using this technology [18], which will ultimately improve the operational efficiency and effectiveness of projects [14].

Despite some challenges, the findings show that with proper training and a phased implementation, real-time monitoring technology can be successfully adopted by construction companies of various scales [5]. As evidence, pilot projects included in this study demonstrated time efficiency improvements and reduced operational errors following the implementation of real-time monitoring technology [13]. This indicates that although there is a steep learning curve, the long-term benefits of this technology far outweigh the initial challenges faced [16]. Furthermore, this study suggests that real-time monitoring technology can play an important role in supporting more sustainable construction projects [14]. With integrated monitoring systems, carbon emissions and energy consumption can be controlled more effectively [5], contributing to achieving environmental targets and meeting global sustainability standards [6]. These findings align with the literature affirming that technology adoption in construction can enhance overall project sustainability [7].

In addition, this study identifies that using real-time monitoring technology can facilitate more accurate data-driven decision-making [7]. Decisions that were previously based on manual estimates can now be made using real-time data obtained directly from the field [19]. This not only improves decision accuracy [13], but also accelerates responses to issues that may arise during project execution [16]. Faster decision-making has the potential to reduce the risks of cost overruns and delays that are often experienced in construction projects [14]. This study also found that real-time monitoring technology has a positive impact on transparency and accountability in construction projects [5]. With direct access to performance data, all stakeholders can more clearly monitor project progress and contribute to more collaborative decision-making [6]. This strengthens the argument that increased transparency through real-time technology not only enhances efficiency but also builds trust among all parties involved in the project [7].

In the future, the development of real-time monitoring technology can focus on improving system flexibility and scalability [13]. By making this technology more accessible and adaptable to various project scales [18], more construction companies, including those operating in areas with limited infrastructure, can benefit from implementing this technology [14]. Further development should also include enhanced integration with other software used in project management, creating a more holistic and integrated technological ecosystem [5]. This study also demonstrates that the application of real-time monitoring technology has a positive impact on safety at construction sites [13]. By monitoring worker and heavy equipment movements in real time, potential accidents can be identified earlier, allowing preventive actions to be taken before incidents occur [16]. This technology has been shown to improve situational awareness on construction sites, especially on large projects involving many workers and complex equipment [14]. These results support the literature highlighting the role of technology in improving workplace safety [5].

The use of IoT sensors to monitor worker activities also significantly contributes to project safety management [18]. These sensors can detect unsafe movements or high-risk areas, providing immediate notifications to project managers for prompt adjustments [7]. This study found that projects using this technology experienced a 20% reduction in accident rates compared to projects not using real-time monitoring technology [13], indicating significant improvements in workplace safety [19]. Besides improving safety, this study also shows that real-time monitoring technology can support more efficient human resource management [14]. With real-time data on worker attendance and productivity, project managers can more accurately adjust labor allocation, reducing wasted time and increasing overall productivity [5]. This study found that workforce efficiency increased by 12% in projects that implemented real-time monitoring technology, contributing to cost reductions and faster project completion [16].

From an environmental perspective, the use of real-time monitoring technology also positively impacts construction waste management [17]. By directly monitoring material usage and waste production, projects using this technology were able to reduce waste by up to 15%. These findings support the literature emphasizing the importance of technology in helping construction companies meet sustainability targets. This research shows that with real-time performance monitoring, projects can achieve more significant waste reductions compared to projects still using traditional methods [14]. Despite the significant benefits found, this research also identified several limitations of real-time monitoring technology [18]. One is the reliance on robust technological infrastructure, including stable internet networks and reliable hardware [5]. Projects conducted in areas with limited internet access face challenges in maintaining effective real-time monitoring [6], leading to disruptions in data collection and analysis [16]. To address this, the study recommends the development of more resilient monitoring systems that are better able to withstand infrastructure challenges and are more flexible in difficult field situations [14].

Moreover, another challenge is handling the large amounts of data generated by real-time monitoring technology [13]. Managing and analyzing big data requires stronger computing resources and a trained workforce in data analytics [18]. This study found that projects without competent IT teams often struggled to fully utilize the data collected [7], limiting the effectiveness of monitoring technology in improving project performance [6]. Therefore, increased workforce capacity in data analytics, along with investments in technology infrastructure to support big data processing, is needed [5]. Looking ahead, this study proposes further development of more affordable and accessible real-time monitoring technology, particularly for small and medium-sized enterprises [19]. By lowering technology costs and increasing its availability, more construction companies can use this technology to improve the efficiency and sustainability of their projects [14]. Additionally, further integration with other technologies, such as artificial

intelligence (AI) and machine learning, is expected to strengthen the predictive capabilities of real-time monitoring systems, allowing project managers to make more proactive decisions based on more advanced data analysis [13]

IV. CONCLUSION

This study demonstrates that implementing real-time performance monitoring technologies, such as Building Information Modeling (BIM) and the Internet of Things (IoT), significantly enhances the efficiency, sustainability, and management of construction projects. By providing accurate and up-to-date data, these technologies enable project managers to make timely adjustments and optimize resource use, resulting in a 15% reduction in energy consumption, a 10% decrease in material waste, and a 12% improvement in time efficiency. Additionally, the integration of BIM and IoT improves collaboration among stakeholders through enhanced data transparency and coordination, reducing miscommunication risks and increasing accountability.

However, challenges remain, particularly in developing countries and resource-constrained projects, where high implementation costs and a lack of skilled labor hinder adoption. This study contributes to the literature by emphasizing the role of real-time monitoring in improving project efficiency and sustainability. Future research should focus on developing more affordable and user-friendly technologies, as well as improving workforce training to facilitate broader adoption.

Looking ahead, integrating artificial intelligence and machine learning with real-time monitoring could enhance predictive capabilities and data-driven decision-making, further boosting operational efficiency and sustainability. These advancements will support global efforts toward environmental sustainability and more effective project management practices.

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