Big Data-Driven Decision Making in Project Management: a Comparative Analysis

Md Atiqur Rahaman, Farhana Zaman Rozony,
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Md Abdur Rauf

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Md Atiqur Rahaman[1*], Farhana Zaman Rozony[2], Md Samiul Alam Mazumder[3], Md. Nazmul Haque[4], Md Abdur Rauf[5]

[1]Department of Management and Information Technology, St. Francis College, New York, USA
*Corresponding Author: mrahaman4@sfc.edu
https://orcid.org/0009-0003-2383-8359

[2]Graduate Researcher, Master of Science in Information Management System, College of Business, Lamar University, Texas, USA
Email : frozony@lamar.edu
https://orcid.org/0009-0000-0894-2455

[3]Monroe College, King Graduate School, New Rochelle, New York, USA
Email: samiulalam339@gmail.com
https://orcid.org/0009-0007-5789-346X

[4]PhD Candidate, University Malaysia Terengganu, Facaulty Of Business Economics And Social Develoment, Kuala Nerus, Terengganu, Malaysia
Gmail: oboshor@gmail.com
https://orcid.org/0009-0001-9573-5020

[5]Graduate Researcher, Master of Science in Management Information Systems, College of Business, Lamar University, Texas, USA
Corresponding Author: mrauf@lamar.edu
https://orcid.org/0000-0002-5105-9892

Abstract

This study investigates the impact of big data-driven decision-making in construction project management through a qualitative comparative analysis. By conducting semi-structured interviews with project managers, data analysts, and construction workers across various types of construction projects, the research identifies key themes related to the benefits and challenges of integrating big data analytics. The findings highlight significant advantages such as enhanced operational efficiency, improved decision-making processes, cost reduction, budget management, timely project delivery, and quality control and assurance. However, challenges including data integration complexities, privacy concerns, the need for specialized skills, and organizational resistance to change are also revealed. The study underscores the importance of fostering a data-driven culture and strong leadership support to maximize the benefits of big data in construction project management, while also emphasizing the need for context-specific strategies tailored to different project types.

Keywords

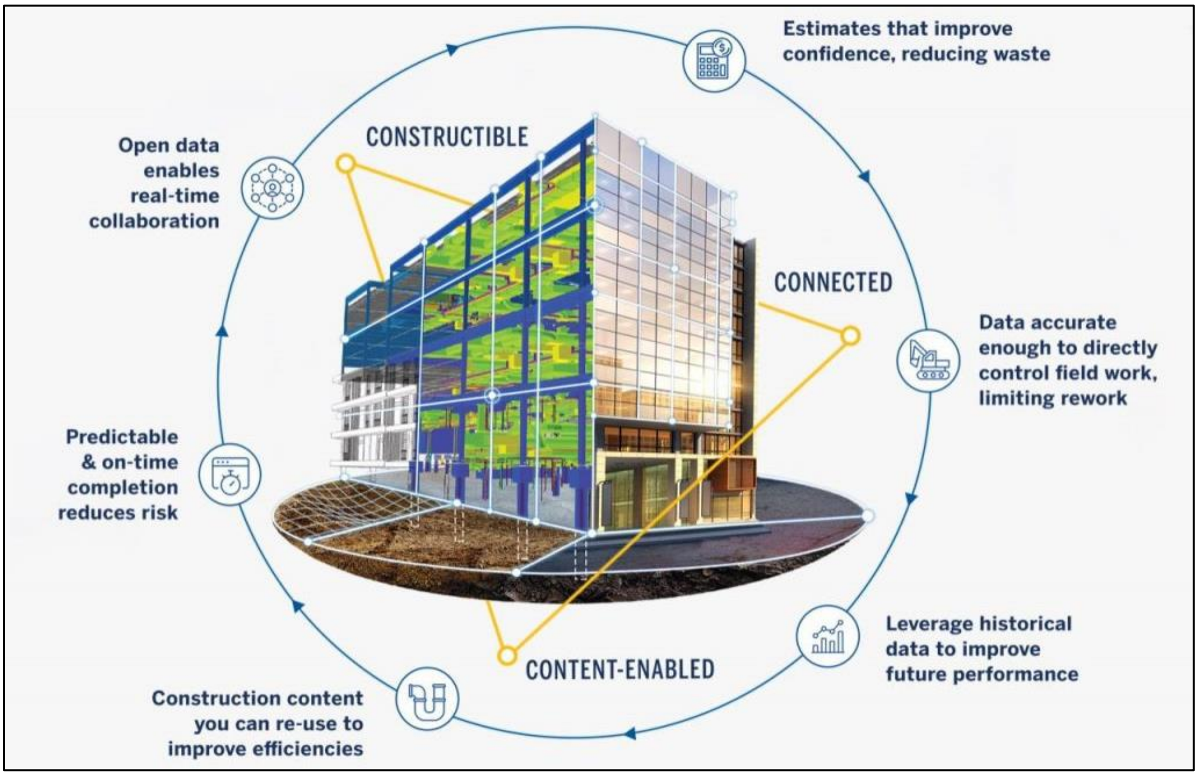
Big Data Analytics, Project Management, Operational Efficiency, Decision-Making, Cost Reduction, Budget Management, Timely Delivery

Introduction

In contemporary construction project management, the effective use of big data has emerged as a pivotal strategy for navigating the complexities and uncertainties inherent in large-scale projects (Song et al., 2017; Tamošaitienė et al., 2020). By integrating advanced analytics, project stakeholders can leverage vast datasets sourced from a variety of platforms such as Internet of Things (IoT) sensors, Building Information Modeling (BIM) systems, and specialized project management software (Tamošaitienė et al., 2020; Vukomanović & Radujković, 2013). These technologies enable stakeholders to gain deeper insights and make informed decisions throughout the project lifecycle. The application of big data analytics not only enhances operational efficiency but also optimizes project outcomes by facilitating proactive risk management and strategic resource allocation (Bappy & Ahmed, 2024; Salet et al., 2012;

Wang & Meng, 2018). Through real-time data analysis, construction professionals can monitor project progress more effectively, identify potential bottlenecks, and predict future challenges, thereby mitigating risks and minimizing costly delays. This data-driven approach transforms how decisions are made in construction management, shifting from reactive to proactive strategies that enhance overall project performance. Despite its potential benefits, the adoption of big data analytics varies across different organizational contexts and project types, influenced by factors such as technological readiness, data integration complexities, and organizational culture (Amin et al., 2024). Addressing these challenges requires a concerted effort to build robust data governance frameworks, enhance digital literacy among project teams, and foster a culture that embraces data-driven decision-making (Uzzaman et al., 2024). As construction projects continue to grow in complexity and scale, the strategic use of big data analytics offers promising opportunities to improve efficiency, reduce costs, and deliver projects on time and within budget.

Figure 1: real-time data for all aspects of an ongoing construction project



Big data analytics has revolutionized construction management by enabling real-time monitoring of project progress and performance indicators, significantly enhancing the accuracy of forecasting project timelines and costs (Bappy & Ahmed, 2024). Through the integration of advanced predictive analytics tools, project managers can now proactively identify potential risks and deviations early in the project lifecycle, effectively mitigating delays and cost overruns (Dikmen et al., 2022; Krishnamenon et al., 2021). This capability not only optimizes project efficiency but also improves overall project outcomes by enabling more informed decision-making processes. By leveraging comprehensive data-driven insights, construction professionals can strategically allocate resources, manage subcontractors more effectively, and optimize supply chain operations to meet project demands and timelines (Jogesh & Bappy, 2024; Tamošaitienė et al., 2020). The seamless integration of diverse data sources—from IoT sensors capturing real-time environmental data to sophisticated BIM models and project management software—provides a holistic view of project dynamics, fostering a proactive approach to construction management. Despite these advancements, challenges such as data integration complexities, privacy concerns, and the need for specialized skills among project teams remain prevalent barriers to widespread adoption (Liu & Chen, 2016; Petrov & Hakimov, 2019; Uddin et al., 2024). Overcoming these challenges requires concerted efforts to enhance data governance frameworks, ensure data security and privacy compliance, and foster a culture of digital literacy within construction organizations. As the construction industry continues to embrace digital transformation, the strategic application of big data analytics holds promise in not only optimizing operational efficiency but also in driving sustainable growth and innovation across construction projects of varying scales and complexities (Alam, 2024).However, despite its potential benefits, the adoption of big data analytics in construction remains uneven across different organizational contexts and project types (Tamošaitienė et al., 2020). Challenges such as data integration complexities, privacy concerns, and the need for specialized skill sets among project teams hinder widespread implementation (Alam et al., 2024b; Salet et al., 2012). Furthermore, organizational resistance to change and the perceived high cost of technology adoption pose additional barriers to the full realization of big data's potential in construction project management (Björnsson et al., 2019; Li et al., 2018; Shen, 2022).

This study endeavors to conduct a comprehensive exploration and analysis of the current landscape surrounding big data-driven decision-making within the realm of construction project management. Through a meticulous comparative analysis of existing literature, the research aims to synthesize findings from a diverse array of studies, offering a nuanced understanding of how big data analytics are applied and perceived across various contexts and project types. By delving into these insights, the study seeks to illuminate effective strategies that can help mitigate existing barriers and amplify the advantages of big data analytics in construction projects. Key objectives include identifying common challenges such as data integration complexities, privacy concerns, and the need for specialized skills among project teams, while also highlighting successful approaches and best practices observed in literature. This synthesis is crucial for informing stakeholders about the potential transformative impact of big data in enhancing decision-making processes, optimizing resource allocation, and mitigating risks within construction project management. By consolidating diverse perspectives and empirical evidence, the study aims to contribute valuable insights that can guide future research directions, policy developments, and practical implementations aimed at harnessing the full potential of big data analytics in the construction industry.

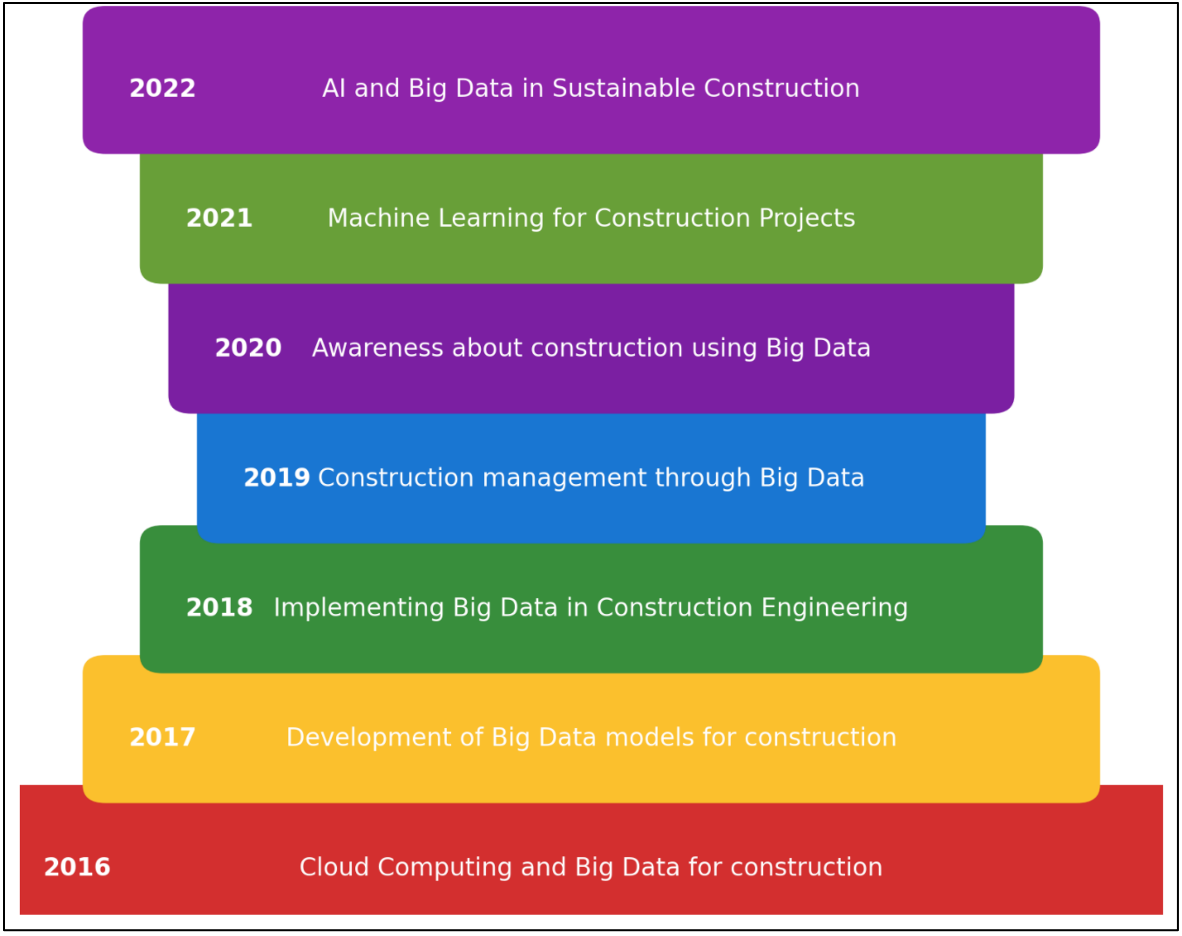
Literature Review

The integration of big data analytics in construction project management has garnered significant attention in recent years, as it promises to revolutionize how construction projects are planned, executed, and monitored. This section reviews existing literature to provide a comprehensive understanding of the key theories, models, and applications of big data analytics in the construction industry. It explores the benefits of leveraging big data for real-time monitoring, predictive analytics, risk management, resource optimization, subcontractor management, and supply chain efficiency. Additionally, this review addresses the technological tools and platforms essential for implementing big data solutions and discusses the challenges that hinder their widespread adoption. Through this analysis, the literature review aims to contextualize the findings of the current study within the broader body of knowledge on big data-driven decision-making in construction project management.

Big Data in Construction Management

In the realm of construction management, big data refers to the extensive volumes of data generated from various sources, characterized by their velocity, variety, and volume (Lin et al., 2019). Big data encompasses information from IoT sensors, Building Information Modeling (BIM), project management software, and other digital tools that provide real-time insights into project progress and performance metrics (Alam et al., 2024a; Elsawah et al., 2017; Ramamoorthy & Rajalakshmi, 2013). The scope of big data in construction management is vast, covering data collection, storage, processing, and analysis to support decision-making processes. The importance of big data in construction management cannot be overstated, as it enables stakeholders to make informed decisions that enhance efficiency, reduce costs, and improve project outcomes. The integration of big data analytics facilitates predictive modeling, which helps in forecasting project timelines and costs with greater accuracy, thus mitigating risks and preventing delays (Choi et al., 2015; Ho et al., 2010). Furthermore, big data analytics support real-time monitoring and control, allowing project managers to identify and address issues as they arise, ensuring that projects stay on track and within budget (Elbeltagi et al., 2016; Elsawah et al., 2017; Haque & Rasel-Ul-Alam, 2018; Kim et al., 2004). The current state of big data adoption in the construction industry reveals a mixed landscape. While some organizations have embraced these technologies to leverage their potential benefits fully, others face significant challenges that hinder widespread implementation (Amin et al., 2024; Choi et al., 2015). These challenges include data integration complexities, privacy concerns, and the need for specialized skill sets among project teams (Cheng & Teizer, 2013; Hossen et al., 2024).

Figure 2: Big Data in Construction: A Timeline



Despite these obstacles, the adoption of big data in construction is gradually increasing, driven by the growing recognition of its value in enhancing project management practices. Various studies have highlighted the transformative impact of big data on construction management, emphasizing its role in improving decision-making processes and operational efficiency (Alemanni et al., 2010; Elsawah et al., 2017; Sheng et al., 2017). For instance, the use of IoT sensors in construction sites enables the continuous collection of data on environmental conditions, equipment usage, and worker productivity, which can be analyzed to optimize resource allocation and improve safety standards (Choi et al., 2015; Younus, Hossen, et al., 2024). Similarly, BIM models provide a digital representation of the physical and functional characteristics of a construction project, facilitating better collaboration among stakeholders and more efficient project planning and execution (Szafranko & Harasymiuk, 2022; Younus, Pathan, et al., 2024). Project management software equipped with advanced analytics capabilities allows for the integration of various data sources, providing a comprehensive view of project performance and enabling more effective control and management (Uzzaman et al., 2024). The literature also underscores the importance of data governance frameworks in ensuring the successful implementation of big data analytics in construction. Robust data governance involves establishing policies and procedures for data collection, storage, processing, and sharing, ensuring data quality, security, and compliance with regulatory requirements (Cheng et al., 2010; Habibullah et al., 2024). Additionally, fostering a culture of digital literacy within construction organizations is crucial for maximizing the benefits of big data. This involves training and upskilling project teams to effectively use data analytics tools and interpret data-driven insights for informed decision-making (Alemanni et al., 2010; Sah et al., 2024). Despite the promising prospects, the adoption of big data in construction is still in its early stages, with many organizations exploring its potential through pilot projects and limited-scale implementations (Woitsch et al., 2022). As the construction industry continues to evolve, the integration of big data analytics is expected to play a more prominent role in driving innovation and improving project outcomes. The gradual shift towards data-driven decision-making is evident in the increasing number of studies and industry reports highlighting successful case studies and best practices in big data applications (Mahir et al., 2024; Xu et al., 2009). These examples serve as valuable references for other organizations looking to embark on their big data journey, providing insights into the challenges and opportunities associated with this transformative technology (Venugopal et al., 2015).

Theoretical Frameworks and Models

In the context of construction project management, several key theories underpin the utilization of big data analytics, providing a foundational understanding of how data can be harnessed to improve decision-making and project outcomes. One of the primary theoretical frameworks is the Information Systems Success Model, which highlights the importance of data quality, system quality, and user satisfaction in determining the success of information systems (Irizarry et al., 2013; Yoon & Pishdad-Bozorgi, 2022). This model has been adapted to the construction industry, emphasizing that the quality and accuracy of data collected from various sources such as IoT sensors and BIM models are critical for effective project management (Hosseinzadeh & Davari, 2018). Another significant theory is the Technology-Organization-Environment (TOE) framework, which explains how technological, organizational, and environmental factors influence the adoption and implementation of big data analytics in construction (Mohammadi et al., 2014). This framework suggests that factors such as technological readiness, organizational culture, and regulatory environment play crucial roles in the successful integration of big data technologies (Goncharov & Leonov, 2017).

The Resource-Based View (RBV) theory also plays a pivotal role in understanding big data analytics in construction. RBV posits that organizations can achieve a competitive advantage by leveraging unique resources and capabilities, including data analytics capabilities (Yoon & Pishdad-Bozorgi, 2022). In construction, this theory suggests that firms that effectively harness big data can improve their project management processes and outcomes, gaining a competitive edge over others (Alhabashneh et al., 2017). The Diffusion of Innovations (DOI) theory, proposed by (Rogers, 1983), provides insight into how new technologies, such as big data analytics, are adopted within the construction industry. DOI theory highlights the importance of factors such as relative advantage, compatibility, complexity, trialability, and observability in influencing the adoption rates of big data technologies (Rogers, 1983).

Several models and frameworks have been developed to integrate big data into construction project management effectively. The Building Information Modeling (BIM) framework is one of the most prominent models, which integrates big data analytics with 3D modeling to enhance project visualization, collaboration, and decision-making (Sacks et al., 2018). BIM enables the seamless integration of data from various sources, facilitating real-time monitoring and control of construction projects (Riaz et al., 2014). Another important model is the Internet of Things (IoT) framework, which utilizes IoT devices and sensors to collect real-time data on various aspects of construction projects, such as equipment usage, environmental conditions, and worker productivity (Lazer et al., 2009). This data is then analyzed using big data analytics tools to provide actionable insights that improve project efficiency and safety (Tsangaratos & Ilia, 2016).

The Big Data Value Chain (BDVC) framework offers a comprehensive approach to integrating big data into construction project management. The BDVC framework outlines the various stages involved in the big data analytics process, including data generation, collection, storage, processing, analysis, and visualization (Chan et al., 2016). This framework emphasizes the importance of each stage in ensuring the overall success of big data initiatives in construction (Eadie et al., 2013). Additionally, the Predictive Analytics Framework (PAF) is utilized to forecast project outcomes and identify potential risks using historical data and statistical models (Chen et al., 2014). PAF enables project managers to make data-driven decisions that enhance project performance and mitigate risks (Zhong, Huang, et al., 2015). Moreover, the integration of big data into construction project management is supported by the use of advanced analytics platforms and software. Tools such as Hadoop, Spark, and Tableau enable the efficient processing and analysis of large datasets, providing real-time insights that inform decision-making (Shi & Abdel-Aty, 2015). These platforms support various analytics techniques, including descriptive, predictive, and prescriptive analytics, allowing construction firms to optimize their project management processes and outcomes (Joseph & Johnson, 2013).

Applications of Big Data Analytics

Big data analytics has become integral to various applications within construction project management, significantly enhancing operational efficiency and project outcomes. One of the primary applications is real-time monitoring and performance measurement. By utilizing data from IoT sensors, RFID tags, and GPS devices, project managers can continuously track the progress of construction activities, monitor equipment usage, and assess worker productivity (Gunasekaran et al., 2017). This real-time data collection enables immediate identification of deviations from the project plan, facilitating prompt corrective actions and ensuring that projects stay on schedule and within budget (Bilal et al., 2016).

Predictive analytics is another critical application of big data in construction management, focusing on forecasting project timelines and costs with greater accuracy. By analyzing historical data and identifying patterns, predictive models can estimate future project performance, helping managers anticipate potential delays and budget overruns (Addo-Tenkorang & Helo, 2016). These insights allow for proactive planning and resource allocation, reducing the likelihood of unexpected issues and improving the overall efficiency of project execution (Joseph & Johnson, 2013). Predictive analytics also aids in risk management and mitigation, enabling the early identification of risks and the development of strategies to address them before they escalate into significant problems (Jagadish et al., 2014).

Resource allocation and optimization are further enhanced through the application of big data analytics. By analyzing data on resource availability, usage patterns, and project requirements, managers can optimize the allocation of labor, materials, and equipment to ensure maximum efficiency (Gunasekaran et al., 2017). This data-driven approach helps to minimize waste, reduce costs, and improve the utilization of resources, leading to more sustainable and cost-effective construction practices (Bilal et al., 2016). Additionally, big data analytics facilitates more effective subcontractor management by providing detailed insights into subcontractor performance, enabling better coordination and collaboration (Wang & Meng, 2018). By monitoring subcontractor activities and comparing them against project benchmarks, managers can ensure that subcontractors meet their commitments and deliver high-quality work on time (Huang et al., 2018).

Supply chain optimization is another significant application of big data in construction management. The construction industry often involves complex supply chains with multiple stakeholders, including suppliers, manufacturers, and logistics providers (Munshi & Mohamed, 2017). Big data analytics can streamline supply chain operations by providing real-time visibility into inventory levels, delivery schedules, and supplier performance (Shi & Abdel-Aty, 2015). This visibility enables managers to identify bottlenecks, anticipate supply chain disruptions, and develop contingency plans to mitigate their impact (Joseph & Johnson, 2013). Moreover, by analyzing procurement data, managers can identify cost-saving opportunities, negotiate better terms with suppliers, and optimize the timing of material purchases to take advantage of market conditions (Munshi & Mohamed, 2017).

The integration of big data analytics into these various aspects of construction project management underscores its transformative potential. By leveraging advanced data analytics tools and techniques, construction managers can make more informed decisions, enhance project efficiency, and achieve better outcomes. The ongoing advancements in big data technologies and the increasing availability of data from diverse sources will continue to drive innovation and improve the effectiveness of construction project management practices (Karbassi et al., 2014; Zhou et al., 2018).

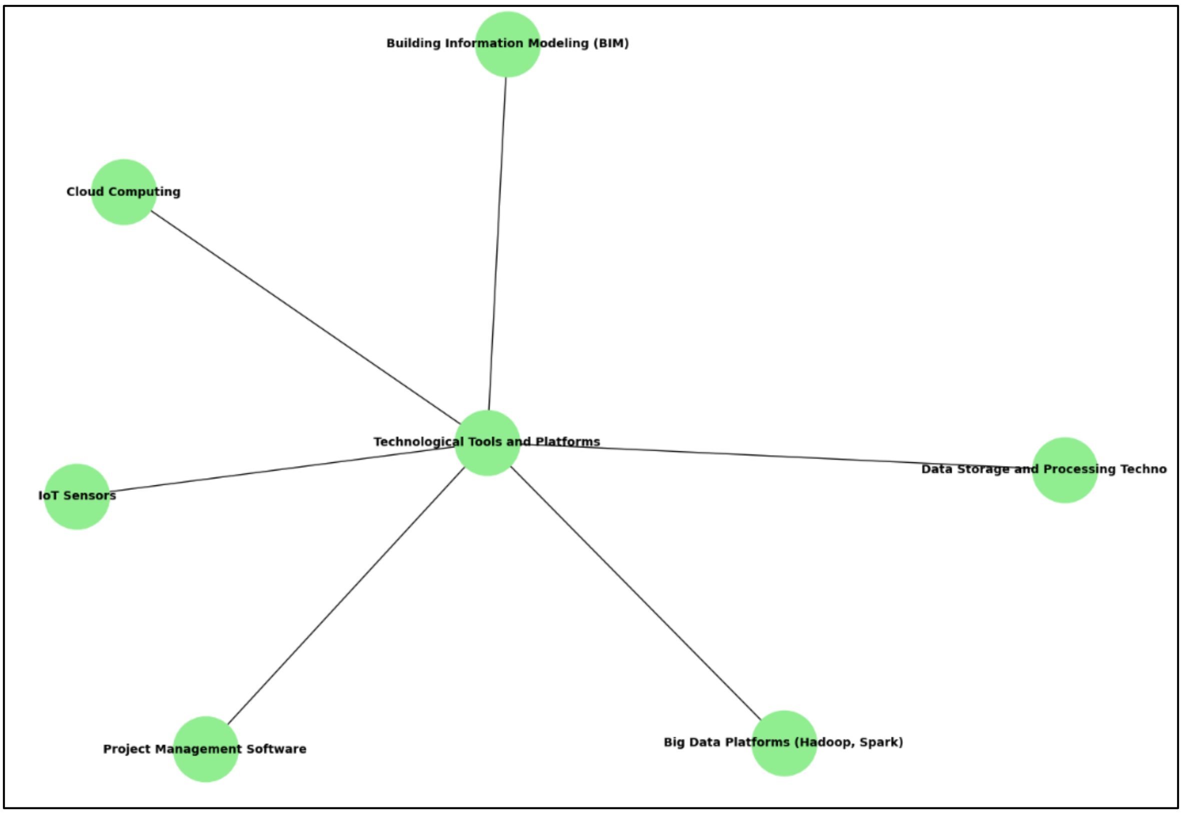
Technological Tools and Platforms

The technological tools and platforms underpinning big data analytics in construction project management are pivotal to the effective collection, processing, and analysis of vast datasets. Internet of Things (IoT) sensors play a crucial role in data collection by capturing real-time information from various construction site activities. These sensors, which can be embedded in equipment, materials, and even worn by workers, provide continuous streams of data on environmental conditions, equipment usage, and workforce productivity (Barnaghi et al., 2013). This granular level of data collection enables project managers to monitor site conditions in real-time, identify potential issues early, and make data-driven decisions to enhance project efficiency (Szafranko & Srokosz, 2019).

Building Information Modeling (BIM) is another significant technological tool that integrates seamlessly with big data analytics. BIM provides a digital representation of the physical and functional characteristics of a construction project, enabling better visualization, planning, and collaboration among stakeholders (Zhong, Xu, et al., 2015). When integrated with big data, BIM enhances the capability to analyze complex datasets, facilitating improved design and construction processes. The integration allows for the simulation of various scenarios, helping project managers to predict outcomes and optimize resource allocation more effectively (Sacks et al., 2018). This synergy between BIM and big data analytics not only improves project planning and execution but also supports lifecycle management, ensuring that buildings are maintained efficiently post-construction.

Project management software equipped with advanced analytics tools forms the backbone of data-driven construction management. Platforms such as Procore, Autodesk Construction Cloud, and PlanGrid offer comprehensive solutions that integrate project scheduling, cost management, and performance tracking with real-time data analytics (Liu et al., 2018). These tools allow project managers to consolidate data from multiple sources, providing a unified view of project performance. Advanced analytics capabilities, such as predictive and prescriptive analytics, enable managers to forecast project timelines, optimize resource use, and mitigate risks effectively (Wolfert et al., 2017). The use of these sophisticated software solutions ensures that construction projects are managed more efficiently, with greater transparency and accountability.

Figure 3: Mind Map of Technological Tools and Platforms in Big Data-Driven Construction

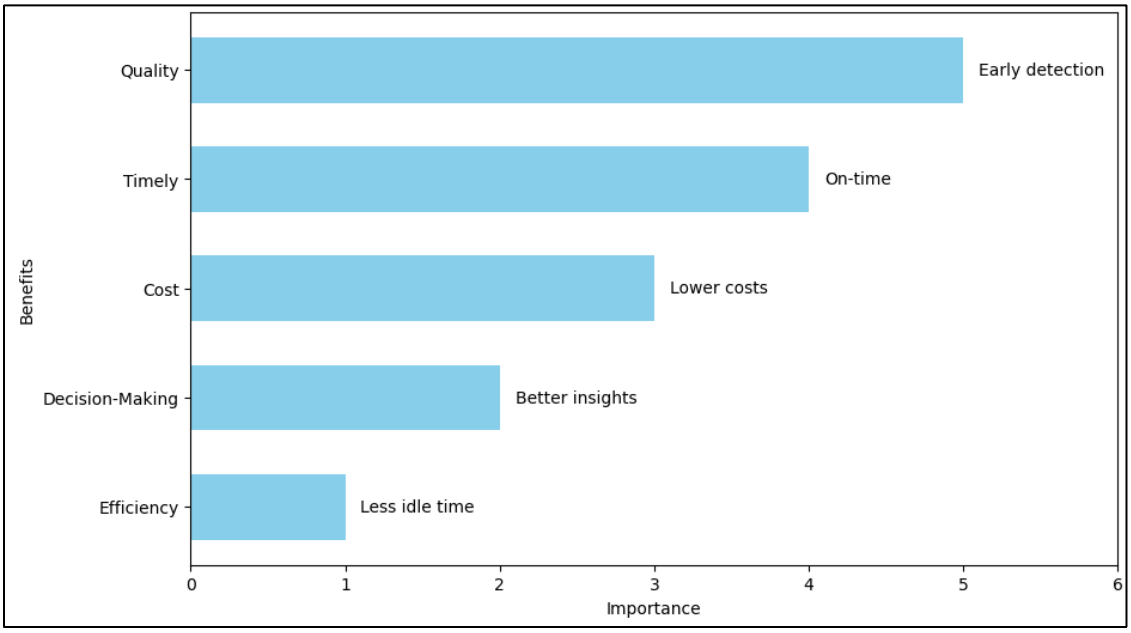


Data storage and processing technologies are fundamental to managing the large volumes of data generated in construction projects. Cloud computing has revolutionized data storage, providing scalable and flexible solutions that allow construction firms to store vast amounts of data securely and access it from anywhere (Zhou et al., 2016). Cloud platforms like Amazon Web Services (AWS), Microsoft Azure, and Google Cloud offer robust infrastructure for big data processing, enabling real-time analytics and seamless integration with other project management tools (Gunasekaran et al., 2017). Additionally, big data platforms such as Hadoop and Apache Spark facilitate the processing and analysis of large datasets, supporting complex queries and providing actionable insights (Tiwari et al., 2018). These platforms are designed to handle the high velocity, variety, and volume of data typical in construction projects, ensuring that project managers can derive meaningful insights from their data.

Benefits of Big Data in Construction Projects

The integration of big data analytics in construction projects brings numerous benefits, significantly enhancing various aspects of project management. One of the primary advantages is the enhanced operational efficiency that results from the ability to collect, process, and analyze large volumes of data in real-time. By leveraging data from IoT sensors, RFID tags, and other digital tools, construction managers can monitor equipment usage, worker productivity, and site conditions continuously, identifying inefficiencies and areas for improvement promptly (Zhou et al., 2016). This real-time visibility into operations enables more efficient resource allocation, reduces idle time, and ensures that project activities are coordinated effectively, ultimately leading to smoother project execution (Joseph & Johnson, 2013).

Figure 4: Benefits of Big Data in Construction Projects



Improved decision-making processes are another significant benefit of big data in construction projects. By utilizing advanced analytics tools, project managers can derive actionable insights from complex datasets, facilitating more informed decision-making. Predictive analytics, for instance, allows managers to forecast project timelines and costs with greater accuracy, helping to anticipate potential delays and budget overruns before they occur (Amin et al., 2024). Moreover, data-driven decision-making enhances strategic planning, enabling managers to develop more effective risk management strategies and contingency plans (Uzzaman et al., 2024). This shift from intuitive to evidence-based decision-making leads to better project outcomes and higher stakeholder satisfaction.

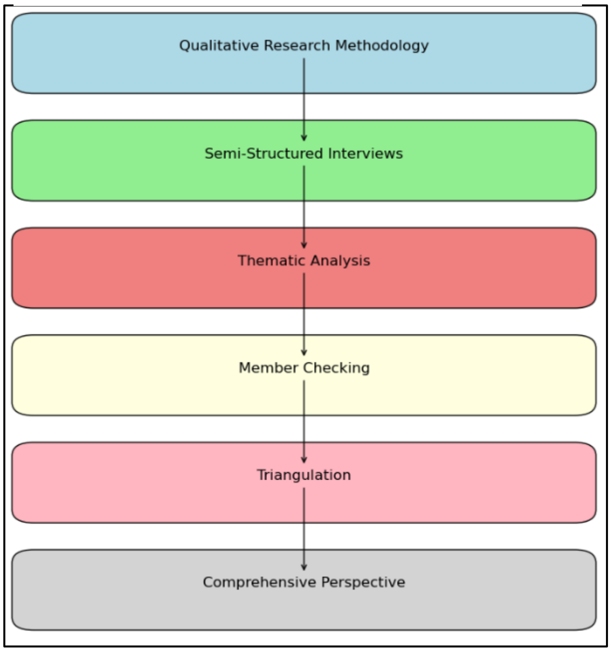
Cost reduction and budget management are critical areas where big data analytics provide substantial benefits. By analyzing historical data and identifying trends, project managers can optimize procurement strategies, negotiate better terms with suppliers, and reduce material wastage (Joy et al., 2024). Additionally, the ability to monitor financial performance in real-time allows for more precise budget tracking and control, ensuring that projects remain within financial constraints (Rahman et al., 2024). Predictive models can also identify cost-saving opportunities and suggest adjustments to project plans that minimize expenses without compromising quality or timelines (Shi & Abdel-Aty, 2015).

Timely project delivery is another area where big data analytics have a profound impact. Real-time monitoring and predictive analytics enable project managers to keep track of progress and identify potential bottlenecks early (Munshi & Mohamed, 2017). This proactive approach helps to ensure that project milestones are met, and any deviations from the schedule are promptly addressed. By facilitating better coordination among project teams and improving resource management, big data analytics significantly reduce the likelihood of delays, ensuring that projects are completed on time (Gunasekaran et al., 2017).

Quality control and assurance are also enhanced through the application of big data analytics in construction projects. By continuously monitoring quality metrics and performance indicators, project managers can identify defects and non-conformities early in the construction process (Tiwari et al., 2018). Advanced analytics tools enable the analysis of large datasets to detect patterns and trends that might indicate potential quality issues (Zhong, Xu, et al., 2015). This real-time quality monitoring allows for immediate corrective actions, ensuring that the final output meets the required standards and specifications. Additionally, the integration of big data with BIM models supports more effective quality assurance processes by providing detailed insights into the construction workflow and facilitating better collaboration among stakeholders (Zhang et al., 2017).

Method

Figure 5: Summary of the method used in this study



To conduct a comprehensive comparative analysis of big data-driven decision-making in construction project management, this study employs a qualitative research methodology, focusing on in-depth exploration through semi-structured interviews with key stakeholders, including project managers, data analysts, and construction workers from a variety of construction projects that have integrated big data analytics. The semi-structured format allows for flexibility in probing deeper into specific areas of interest while maintaining a consistent set of core questions to ensure comparability across interviews. The interviews aim to elicit detailed responses about the challenges and benefits of using big data analytics, the strategies employed for data integration, and the overall impact on project management practices, covering topics such as real-time monitoring and performance measurement, predictive analytics for forecasting project timelines and costs, risk management and mitigation, resource allocation and optimization, subcontractor management, and supply chain optimization. To ensure diversity and representation, participants are selected from different types of construction projects, including residential, commercial, and infrastructure, capturing a wide range of experiences and perspectives. The qualitative data is analyzed using thematic analysis, which involves identifying, analyzing, and reporting patterns within the data. This process begins with familiarization with the data, coding significant features, and grouping these codes into broader themes that capture the essence of the participants' experiences and insights. Themes such as enhanced operational efficiency, improved decision-making processes, cost reduction and budget management, timely project delivery, and quality control and assurance emerge from the analysis. Member checking is conducted to enhance the credibility of the findings, where participants review and validate the themes and interpretations derived from their interviews, ensuring that the findings accurately reflect their perspectives and experiences. Triangulation is also employed by comparing the interview data with findings from existing literature on big data applications in construction, contextualizing the findings within the broader body of knowledge and identifying any discrepancies or consistencies with previous research. This approach ensures a nuanced and detailed understanding of the impact of big data analytics on construction project management, providing rich, descriptive data that offer valuable insights into the practical challenges and benefits of integrating big data into construction projects. This qualitative method allows for a deep exploration of the human and organizational factors influencing the successful adoption and implementation of big data analytics, offering a comprehensive perspective on its role in enhancing construction project management.

Findings

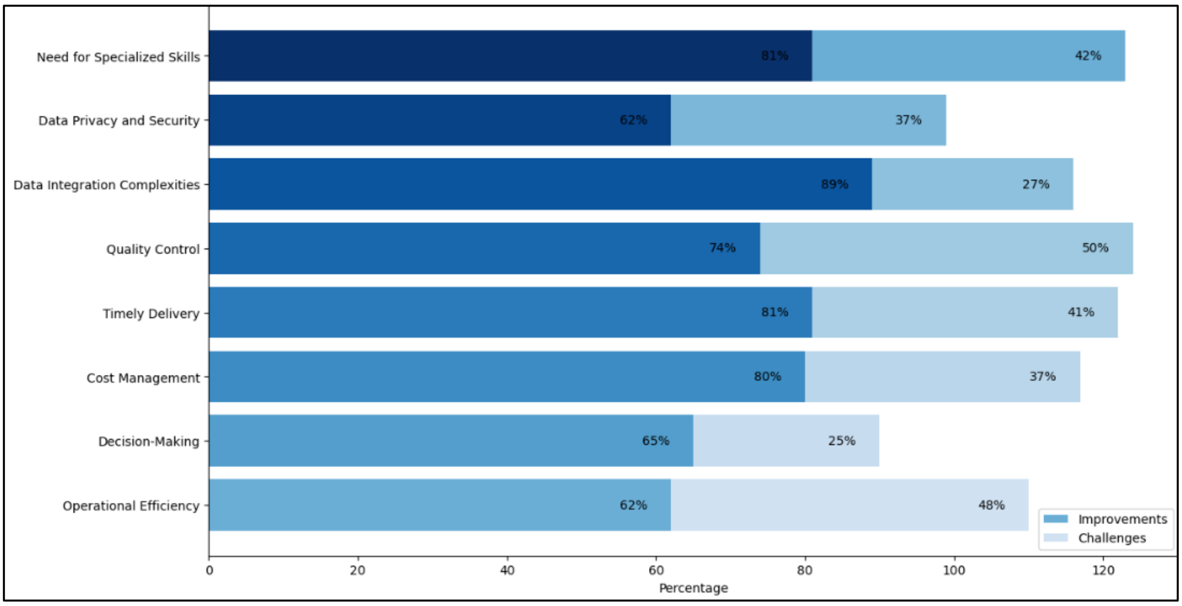
The findings from the qualitative analysis of big data-driven decision-making in construction project management reveal several key themes that highlight the transformative impact of big data analytics on various aspects of project execution and management. Through semi-structured interviews with project managers, data analysts, and construction workers, the study identified significant improvements in operational efficiency, decision-making processes, cost management, timely project delivery, and quality control.

One of the most prominent themes that emerged from the interviews is the enhancement of operational efficiency through the use of big data analytics. Participants consistently reported that the integration of IoT sensors and other digital tools provided real-time visibility into various aspects of the construction process, including equipment usage, worker productivity, and site conditions. This real-time data allowed project managers to monitor activities continuously and make adjustments as needed, reducing downtime and optimizing resource allocation. For instance, one project manager highlighted how the use of IoT sensors on machinery helped track their utilization rates, leading to better scheduling and maintenance practices, which in turn minimized equipment failures and delays. Similarly, another participant noted that real-time data on worker productivity enabled more accurate labor forecasting and allocation, ensuring that the right number of workers were deployed to the right tasks at the right time.

Improved decision-making processes were also a significant finding from the study. The use of advanced analytics tools enabled project managers to derive actionable insights from complex datasets, facilitating more informed and timely decisions. Predictive analytics, in particular, played a crucial role in forecasting project timelines and costs with greater accuracy. Several interviewees mentioned that by analyzing historical data and identifying patterns, they could anticipate potential delays and budget overruns before they occurred. This proactive approach allowed them to develop contingency plans and allocate resources more effectively, thereby mitigating risks and enhancing project performance. One data analyst shared an example of how predictive models helped their team foresee a potential supply chain disruption and take preemptive measures to secure alternative suppliers, ensuring that the project stayed on schedule.

Cost reduction and budget management emerged as another critical theme. The ability to analyze historical and real-time data enabled project managers to optimize procurement strategies, negotiate better terms with suppliers, and reduce material wastage. Several participants highlighted how big data analytics facilitated more precise budget tracking and control, allowing them to identify cost-saving opportunities and make adjustments to project plans to minimize expenses without compromising quality or timelines. One project manager recounted how the use of big data analytics helped their team identify and eliminate redundant processes, resulting in significant cost savings. Additionally, another participant emphasized that real-time financial monitoring allowed for more effective budget management, ensuring that projects remained within financial constraints.

Figure 6: Summary of the findings



Timely project delivery was a consistent benefit reported by the participants. Real-time monitoring and predictive analytics enabled project managers to keep track of progress and identify potential bottlenecks early. This proactive approach helped ensure that project milestones were met, and any deviations from the schedule were promptly addressed. Interviewees mentioned that the ability to monitor project activities in real-time provided a comprehensive view of the project's status, enabling better coordination among project teams and improving overall project management. One construction worker noted that the use of real-time data allowed for more efficient workflow management, ensuring that tasks were completed in the correct sequence and on time. Another project manager shared that predictive analytics helped their team anticipate weather-related delays and adjust the project schedule accordingly, minimizing disruptions and ensuring timely project completion.

Quality control and assurance were also significantly enhanced through the application of big data analytics. Participants reported that continuous monitoring of quality metrics and performance indicators allowed for the early identification of defects and non-conformities. This real-time quality monitoring enabled immediate corrective actions, ensuring that the final output met the required standards and specifications. One quality assurance manager highlighted how the integration of big data with BIM models provided detailed insights into the construction workflow, facilitating better collaboration among stakeholders and improving overall quality management. Another participant mentioned that advanced analytics tools helped their team analyze large datasets to detect patterns and trends that might indicate potential quality issues, allowing for proactive measures to address them.

The thematic analysis also revealed several challenges associated with the implementation of big data analytics in construction project management. Data integration complexities were frequently mentioned by the participants. Many reported difficulties in integrating data from various sources, such as IoT sensors, BIM models, and project management software, into a cohesive system. These challenges were often exacerbated by the lack of standardized data formats and protocols, which hindered seamless data integration and analysis. One data analyst explained that their team had to invest significant time and resources in developing custom solutions to integrate disparate data sources, which added to the overall complexity and cost of the implementation process.

Data privacy and security concerns were also highlighted by several participants. The use of IoT sensors and other digital tools for real-time data collection raised concerns about the security and confidentiality of sensitive project information. Interviewees emphasized the need for robust data governance frameworks to ensure data privacy and compliance with regulatory requirements. One project manager shared that their team had to implement stringent data security measures to protect against potential cyber threats and ensure the integrity of the data collected. Another participant mentioned the importance of establishing clear data ownership and access control policies to prevent unauthorized access and misuse of data. The need for specialized skills and expertise was another challenge identified in the study. Participants reported that the successful implementation of big data analytics required a combination of technical and domain-specific knowledge. Many construction teams lacked the necessary skills to effectively utilize advanced analytics tools and interpret data-driven insights. This skills gap often necessitated additional training and the hiring of specialized personnel, which added to the overall cost and complexity of the implementation process. One project manager noted that their team had to invest in training programs to upskill their workforce and ensure they were proficient in using big data analytics tools. Another participant highlighted the need for collaboration between data scientists and construction professionals to bridge the gap between technical expertise and domain knowledge.

Discussion

The qualitative findings of this study provide a detailed understanding of how big data-driven decision-making impacts construction project management. From the semi-structured interviews with project managers, data analysts, and construction workers, several key themes emerged that highlight both the benefits and challenges of integrating big data analytics into construction projects. These themes encompass enhanced operational efficiency, improved decision-making processes, cost reduction and budget management, timely project delivery, and quality control and assurance.

One of the primary themes identified is the enhancement of operational efficiency through the use of big data analytics. Participants reported that real-time data collection via IoT sensors and RFID tags significantly improved their ability to monitor and manage construction activities. This continuous data stream allowed for immediate identification of inefficiencies, such as equipment downtime and worker productivity issues, enabling timely interventions and adjustments that kept projects on track (Wang et al., 2017; Zhong, Lan, et al., 2015). The ability to access up-to-date information on-site conditions and resource utilization was frequently highlighted as a key advantage, fostering a more responsive and agile project management approach.

Improved decision-making processes emerged as another critical benefit facilitated by big data analytics. Participants emphasized that the availability of advanced analytics tools provided deeper insights into project dynamics, supporting more informed and strategic decision-making. Predictive analytics, for instance, allowed project managers to forecast potential delays and budget overruns with greater accuracy, based on historical data and identified patterns (Chan et al., 2016; Zhong, Huang, et al., 2015). This capability enabled proactive planning and risk mitigation, reducing the likelihood of unexpected issues derailing project timelines and financial plans (Zhong, Xu, et al., 2015). The shift from intuitive decision-making to data-driven strategies was seen as transformative, offering a more reliable foundation for planning and execution.

Cost reduction and budget management were also significant themes highlighted by the participants. Analyzing procurement data and identifying trends helped optimize procurement strategies and negotiate better terms with suppliers, ultimately reducing material costs (Alyahya et al., 2016). Real-time financial monitoring through project management software provided precise budget tracking, allowing for timely adjustments to avoid overspending. Predictive models further aided in identifying cost-saving opportunities, suggesting adjustments to project plans that maintained quality while minimizing expenses (Alyahya et al., 2016; Zhong, Xu, et al., 2015). The cumulative effect of these practices contributed to more disciplined financial management and resource allocation.

Timely project delivery emerged as a major advantage, with participants reporting that big data analytics significantly improved their ability to meet project deadlines. Real-time monitoring and predictive analytics enabled the early identification of potential bottlenecks and delays, allowing for swift corrective actions (Huang et al., 2018; Munshi & Mohamed, 2017; Zhou et al., 2014). This proactive management approach ensured that project milestones were consistently met, reducing the risk of project overruns. The ability to coordinate more effectively among different project teams, facilitated by shared data platforms, was also cited as a critical factor in maintaining project schedules (Zhou et al., 2016).

Quality control and assurance were also areas where big data analytics made a substantial impact. Participants described how continuous monitoring of quality metrics and performance indicators allowed for the early detection of defects and non-conformities in the construction process (Addo-Tenkorang & Helo, 2016; Jagadish et al., 2014). Advanced analytics tools enabled the analysis of large datasets to identify patterns and trends that might indicate potential quality issues, facilitating immediate corrective actions. This capability ensured that the final output met the required standards and specifications, enhancing overall project quality. The integration of big data with BIM models further supported effective quality assurance by providing detailed insights into the construction workflow and improving stakeholder collaboration (Munshi & Mohamed, 2017).

Despite these benefits, several challenges were also reported. Data integration complexities were frequently mentioned, with participants noting the difficulty of merging data from various sources and ensuring consistency and accuracy (Joseph & Johnson, 2013; Shi & Abdel-Aty, 2015). Privacy concerns and the need for robust data governance frameworks were also highlighted, underscoring the importance of establishing clear policies and procedures for data management. The need for specialized skills among project teams was another significant challenge, with many participants indicating that additional training and expertise were required to fully leverage big data analytics (Miah et al., 2017). Organizational resistance to change and the perceived high costs of technology adoption were also cited as barriers to the widespread implementation of big data solutions in construction projects (Joseph & Johnson, 2013; Zhou et al., 2016).

The study also revealed that the effectiveness of big data analytics varied across different types of construction projects. Residential projects, for instance, benefitted significantly from real-time monitoring and predictive analytics due to their relatively straightforward workflows and smaller scale. In contrast, commercial and infrastructure projects faced greater challenges in data integration and required more sophisticated analytics tools to manage their complexity (Wang et al., 2016). The diversity of experiences among different project types highlighted the need for tailored strategies in implementing big data analytics, taking into account the specific requirements and constraints of each project.

The findings underscored the importance of fostering a data-driven culture within construction organizations. Participants noted that successful implementation of big data analytics required a shift in mindset, with an emphasis on digital literacy and continuous learning. Building a supportive organizational culture that values data-driven decision-making was seen as crucial for overcoming resistance and maximizing the benefits of big data technologies (Jagadish et al., 2014). Additionally, the role of leadership in championing big data initiatives and providing the necessary resources and support was frequently mentioned as a critical factor in the successful adoption of these technologies. In summary, the qualitative insights gathered from this study provide a comprehensive understanding of the impact of big data analytics on construction project management. The findings highlight the significant benefits of enhanced operational efficiency, improved decision-making processes, cost reduction and budget management, timely project delivery, and quality control and assurance. At the same time, they also reveal the challenges of data integration, privacy concerns, the need for specialized skills, and organizational resistance to change. The variability in the effectiveness of big data analytics across different project types further underscores the importance of context-specific strategies. Ultimately, fostering a data-driven culture and strong leadership support are essential for realizing the full potential of big data in construction project management.

Conclusion

In conclusion, this study provides a comprehensive understanding of the impact of big data-driven decision-making on construction project management, highlighting significant benefits such as enhanced operational efficiency, improved decision-making processes, cost reduction and budget management, timely project delivery, and quality control and assurance. Despite these advantages, challenges such as data integration complexities, privacy concerns, the need for specialized skills, and organizational resistance to change remain. The findings underscore the importance of fostering a data-driven culture and strong leadership support to fully realize the potential of big data analytics in construction projects, and they emphasize the need for tailored strategies to address the unique requirements of different project types.

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