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Enhancing construction site efficiency through artificial intelligence (AI)

Ruchit Parekh [1,*] and Olivia Mitchell [2]

[1] *Department of Engineering Management, Hofstra University, New York, USA.*
[2] *Department of Civil Engineering, University of California, Berkeley, USA.*

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Abstract

Artificial Intelligence (AI) is profoundly impacting productivity and economic growth across various sectors. In Malaysia, challenges related to AI in construction include limited expertise, privacy concerns, and cultural barriers on construction sites. This research aims to pinpoint key factors that influence AI's effectiveness in enhancing construction site workflows, identify obstacles in improving workflow performance, and assess the relationships between primary factors affecting AI use and the main challenges faced. The study focuses on G7, a contractor company based in Johor Bahru, employing a quantitative method to achieve its goals. The research gathered insights from 226 Grade 7 contractors in Johor Bahru through questionnaires distributed via face-to-face meetings and online forms sent through WhatsApp and email. Out of the respondents, 101 (45%) provided responses. Data was analyzed using SPSS software, incorporating descriptive statistics, frequency counts, and cross-tabulations. The study revealed that the most frequently cited factors and challenges are risk management and limited AI expertise, respectively. The strongest correlation identified was between return on investment and slow electrical supply. These findings offer valuable guidance for contractors to enhance performance, mitigate risks, and boost efficiency. This study paves the way for more targeted interventions and strategic approaches to improve construction site workflows, ultimately benefiting industry stakeholders.

Keywords: Artificial Intelligence (AI); Contractor; Performance; Construction Site; Workflow

1. Introduction

The construction industry is often regarded as one of the most challenging fields due to its complex and unique project characteristics. Each construction project involves various elements, including workers, workspaces, and services, all tailored to meet specific project requirements. The industry is also recognized for its high risk levels due to the intricate nature of construction projects, impacting the activities, processes, environments, and organizations involved (Aripin, Zawawi & Ismail, 2019). This complexity may drive rapid adoption of new technologies globally, as technology increasingly supports daily activities and problem-solving (Matarop, 2023).

1.1. Research Background

The construction sector is crucial for a country's economic stability. According to a report by Utusan Malaysia, the sector showed remarkable performance, with a 15.7 percent increase in construction work value, amounting to RM32 billion in the fourth quarter of 2022, as confirmed by the Department of Statistics (Nadzari, 2023). Artificial Intelligence (AI) involves replicating human intelligence in computers through sophisticated programming to simulate human thought and action (Frankfield, 2023). AI significantly impacts daily life and business efficiency, with a recent focus on operations, service processes, and industrial productivity (Abioye et al., 2021). The construction sector is undergoing a major transformation due to the widespread adoption of AI, which is enhancing project delivery quality in Malaysia

* Corresponding author: Ruchit Parekh

(Mohamed, Ahmad & Mohamad, 2021). Effective construction workflows ensure smooth task progression and successful project completion, while poorly designed operations can lead to team discord, disorder, delays, and contract cancellations (Kukhnavets, 2023). Ensuring optimal workflow performance is essential for timely project completion within budget while maintaining high-quality standards (Weller, 2021).

1.2. Problem Statements

Despite technological and project management advancements, the construction industry still struggles with optimizing workflow performance at construction sites. Issues such as inadequate resource allocation, material delays, poor scheduling, and lack of real-time communication among site personnel contribute to delays, increased costs, and reduced quality (Akintoye et al., 2017). The absence of AI technologies exacerbates inefficiencies, leading to ineffective plans and decreased competitiveness. Challenges in measuring AI benefits include uncertainty about potential returns on investment, with large construction firms sticking to traditional methods and small subcontractors adopting similar models (Regona et al., 2022). Additionally, the scarcity of skilled AI professionals impacts the industry's productivity and effectiveness (Abioye et al., 2021). While the Industrial Revolution 4.0 has advanced AI use in construction, the industry has yet to fully leverage its benefits (Abioye et al., 2021). Duggal (2023) highlights that some relationship aspects are still unclear. This research aims to explore the challenges and potential solutions associated with the lack of AI implementation in improving workflow performance at construction sites. Current research lacks comprehensive measurement of the connection between AI's primary drivers and workflow performance challenges.

1.3. Research Questions

- What are the key factors influencing AI's role in enhancing construction site workflow performance?
- What challenges does AI face in improving construction site workflow performance?
- How strong is the relationship between major AI influencing factors and the main challenges in improving construction site workflow performance?

1.4. Research Objectives

- To identify the key factors influencing AI's effectiveness in improving construction site workflow performance.
- To identify the challenges associated with using AI to improve construction site workflow performance.
- To analyze the relationships between key AI influencing factors and the main challenges in enhancing construction site workflow performance.

1.5. Research Hypothesis

- H0: There is no significant relationship between key AI influencing factors and the main challenges in improving construction site workflow performance.
- H1: There is a significant relationship between key AI influencing factors and the main challenges in improving construction site workflow performance.

1.6. Research Scope

This research examines the latest technological advancement, AI, and its application in the construction sector. AI has the potential to significantly increase productivity within the construction industry (Akinosho et al., 2020). The study focuses on Johor Bahru, given that Johor is the second highest in private sector projects and the third highest in government sector projects, according to the Ministry of Public Works (KKR) (2018) (Latiffi, 2021). Johor Bahru has the highest number of Grade 7 (G7) contractors in the state (CIDB, 2023). There are 527 Grade 7 (G7) construction companies registered in Johor Bahru (CIDB, 2023). All Grade 7 contractors must now have ISO 9000 Quality Management System certification, as mandated by the Construction Industry Development Board (CIDB). Failure to meet this requirement can impact their business operations (Marhani et al., 2012). Increasing numbers of construction firms are seeking ISO certification to address issues such as subpar materials and craftsmanship, delays, accidents, and environmental concerns (Khan, Liew & Razali, 2014).

1.7. Significance of Study

This study is crucial for identifying effective AI approaches to enhance workflow performance at construction sites. The findings will benefit contractors by providing insights into key considerations for implementing AI in the construction sector. Contractors can also explore the challenges of using AI to improve site workflow performance. Additionally, the research will offer valuable information to organizations on the importance of AI in construction projects and the challenges faced. This may encourage more proactive AI adoption within the industry, leading to improved future

prospects for organizations. The study's results could also serve as a reference for students, researchers, and educators interested in AI's role in enhancing construction site workflow performance.

2. Literature Review

2.1. Factors Influencing the Use of AI in Enhancing Construction Site Workflow Performance

The integration of Artificial Intelligence (AI) into the construction industry is increasingly prevalent, marking a significant shift across various sectors and driving technological advancements. AI has garnered attention as a novel strategic tool within construction (Tjebane, Musonda & Okoro, 2022). Here are nine key factors influencing AI's role in improving construction site workflow performance:

2.1.1. Information Processing Capabilities

AI significantly enhances information processing capabilities, handling vast amounts of data efficiently. Businesses with high data processing needs are expected to be more receptive to adopting AI (Ghobakhloo & Ching, 2019).

2.1.2. Return on Investment (ROI)

AI enables customization of components to meet specific needs, promoting more efficient construction practices. It reduces worker risks on construction sites, thereby lowering overall construction costs (Turner et al., 2020).

2.1.3. Risk Management

Incorporating AI into risk management can greatly improve workflow performance on construction sites by enhancing risk analysis and decision-making processes. AI's predictive and real-time capabilities help project managers quickly address new challenges, such as workforce shortages due to pandemics (Malsam, 2022; Skinner, 2023).

2.1.4. Organizational Culture and Change Management

The successful adoption of AI in construction is influenced by organizational culture and the ability to manage change. Factors such as leadership support, staff training, and change management strategies significantly impact AI integration (Bley et al., 2022).

2.1.5. Data Availability and Quality

AI facilitates real-time data analysis, enabling the early detection of potential issues and defects. Managing the large volume of data through advanced analytics transforms it into actionable insights, improving waste management and overall workflow quality (Marketing Indovance, 2023; Abioye et al., 2021).

2.1.6. Industry Standards and Best Practices

Standards and benchmarks ensure the quality and interoperability of AI systems. Research has demonstrated that establishing AI capabilities through unique resources can leverage investments, generate commercial value, and provide a competitive advantage (Mikalef & Gupta, 2021; Abioye et al., 2021).

2.1.7. Operational Efficiency and Optimized Outcomes

Despite concerns about reliability and privacy, the development of AI technology is embraced by managers aiming to enhance their effectiveness. AI facilitates operational efficiency, team development, and proficiency in project management (Holzmann & Lechiara, 2022; Kaplan & Haenlein, 2019).

2.1.8. Human Intervention

AI significantly aids in building plan development by utilizing autonomous technology. AI's ability to navigate and gather data for creating 3D maps, drawings, and construction plans transforms what was once a labor-intensive process into a quicker, cost-effective task (Parveen, 2018).

2.1.9. Excessive Spending

Although the construction industry has been slow to adopt AI compared to other sectors, AI can address cost overruns by reducing overhead expenses. Automated systems for routine tasks can lead to significant cost savings and potentially

increase revenue and profit margins throughout the construction project lifecycle (Blanco et al., 2018; Alice Technologies, 2022).

2.2. Challenges of AI in Enhancing Construction Site Workflow Performance

The construction industry faces several challenges that have impeded its growth and resulted in notably lower productivity compared to sectors like manufacturing (Abioye et al., 2021). These challenges complicate the implementation of AI for improving construction site workflow performance.

2.2.1. Validation and Acceptance of AI

The adoption of AI in construction is often delayed due to a lack of understanding of its benefits, fears of obsolescence, and difficulty accessing relevant technology (Editorial Team, 2022). The industry tends to favor traditional methods over newer, unproven technologies despite their potential for significant gains (Babic & Rebolj, 2016; Abioye et al., 2021).

2.2.2. Limited AI Expertise in Construction

The shortage of AI professionals is partly due to inadequate educational and training programs that do not keep up with rapid advancements in AI technology. There is a gap in experienced AI practitioners needed to lead the integration of AI into construction practices (Marr, 2018).

2.2.3. High Initial Investment for AI

Implementing AI often requires substantial investment in hardware, software, and skilled personnel. Given the budget constraints typical in construction projects, allocating resources for AI adoption and maintenance can be challenging. Organizations must conduct thorough cost-benefit analyses to identify potential savings and assess the return on investment (Reilly, 2023; Urie, 2023).

2.2.4. Complex and Dynamic Environments

AI implementation is complicated by unpredictable environmental conditions and non-standardized building designs. The sector is gradually adopting AI to transition from traditional methods to more digital and autonomous processes (Regona et al., 2022).

2.2.5. Challenges with Explainability and Trust

In safety-critical sectors like construction, ensuring that AI outputs are explainable and trustworthy is crucial. A lack of transparency in AI systems can lead to skepticism and slow adoption rates. Achieving transparency and interpretability in AI systems is essential for gaining widespread acceptance (Philip, 2019; Mahmood, 2023).

2.2.6. Data Privacy and Cybersecurity

AI systems in construction often handle sensitive data, such as personal information and project specifications. Protecting data privacy and ensuring robust cybersecurity can be difficult due to evolving cyber threats and the need for stringent security measures (Kuzlu, Fair & Guler, 2021).

2.2.7. Dependence on Reliable Electrical and Internet Services

AI technologies on construction sites require stable electricity and internet connections to function effectively. Disruptions in these services can present significant challenges for AI applications such as robotics and site monitoring systems (Abioye et al., 2021; Urie, 2023).

2.2.8. Impact on Employment and Job Creation

AI is transforming the labor market, with projections suggesting the displacement of 85 million jobs globally by 2025, according to the World Economic Forum's "The Future of Jobs Report" (2020). Many of these jobs may be lost as robots and automation take over routine tasks (PBCToday, 2018).

2.2.9. Cultural Barriers on Construction Sites

The construction industry's preference for traditional techniques over innovative technology is driven by the high stakes involved in construction projects. The fragmented nature of the industry makes it challenging to implement

change. Successful adaptation requires consistency in site operations, design, management, and employment practices (Regona et al., 2022).

2.2.10. Legal and Regulatory Challenges

The adoption of AI in construction is subject to various regulations and legal considerations. Compliance with data protection laws, intellectual property rights, and ethical standards can be challenging when developing and deploying AI solutions (Parveen, 2018).

2.3. Relationship Between AI Influencing Factors and Challenges in Enhancing Construction Site Workflow Performance

The construction industry is progressively integrating digital technologies such as real-time data capture, site monitoring, and data analysis. AI, a notable technological advancement, is gaining significant attention for its potential to revolutionize the sector, similar to its impact on other industries (Golstein & Branthonne, 2020). AI is poised to influence construction processes due to its capacity for future development. Despite its potential, there are often valuable insights from computing and data analysis in construction that remain underutilized (Kumar, 2022).

Existing research highlights a considerable knowledge gap regarding the relationship between AI influencing factors and the challenges associated with improving construction site workflow performance. No previous studies have thoroughly explored the connections between these factors and their effects on construction workflow efficiency. This gap signifies the need for further investigation and analysis to understand and address these dynamics effectively.

3. Research Methodology

3.1. Research Design

3.1.1. Research Procedure

The research methodology for this study is outlined in Appendix A. The study is divided into five phases, each representing a distinct part of the research process.

3.1.2. Research Method

This study utilizes a quantitative research approach to meet its objectives. Quantitative research presents findings numerically and involves creating specific questions and surveys that align with the study's goals. These questions are structured in an organized manner.

3.1.3. Respondents

The sample size for this study was determined using the Krejcie & Morgan (1970) Table. The study targets Grade 7 contractors in Johor Bahru, with an estimated population of approximately 527 respondents according to CIDB (2023). Consequently, the sample size is around 226 (see Appendix B).

3.1.4. Research Instrument

A questionnaire was employed to evaluate contractors' views on the factors influencing AI use in enhancing construction site workflow performance, the challenges associated with AI, and the relationships between these influencing factors and AI challenges. The questionnaire used a five-point Likert scale, ranging from strongly agree to strongly disagree. It consists of Sections A, B, C, and D, covering respondent background, AI influencing factors, AI challenges, and the relationship between these elements, respectively. The full questionnaire can be found in Appendix C.

3.2. Pilot Study

A pilot study was conducted where a set of questions was answered by 7 participants in Johor Bahru via an online questionnaire. According to Bullen (2021), an optimal pilot study typically involves 10 respondents, a number chosen for its flexibility and effectiveness in gathering preliminary feedback. The pilot study is a crucial phase of the research, aimed at identifying potential issues and weaknesses in the research tools and procedures before the full study (Hassan et al., 2006).

3.2.1. Reliability Analysis

Cronbach's alpha was used to assess the reliability of the Likert scale surveys containing multiple questions. This measure evaluates latent variables, such as an individual's precision or openness (Glen, 2021). The reliability guideline is as follows: $\alpha > 0.9$ is Excellent; $\alpha > 0.8$ is Good; $\alpha > 0.7$ is Acceptable; $\alpha > 0.6$ is Questionable; $\alpha > 0.5$ is Poor; and $\alpha < 0.5$ is Unacceptable. The reliability analysis of the data showed a Cronbach's Alpha value of 0.939, indicating that the questionnaire is reliable and demonstrates a high level of internal consistency.

3.3. Data Collection

A total of 101 Grade 7 contractors in Johor Bahru were surveyed using an online questionnaire to collect data. The questionnaire was distributed both manually (in person) and online using a Google Forms template. The Google Form link was shared through various platforms, including WhatsApp and email, to maximize reach and participation.

3.4. Data Analysis

To ensure accurate results, data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) software. The Likert Scale Questionnaire was the primary tool for data collection. The collected data was analyzed and presented through various formats, including tables, graphs, and pie charts, to facilitate comprehensive understanding and interpretation.

4. Results and Discussions

4.1. Response Rate and Validity

Out of a total of 226 distributed questionnaires, 101 were completed and returned, representing a 45% response rate. According to Keeter et al. (2006), surveys with lower response rates (around 20%) can yield more reliable results than those with higher response rates (60% to 70%), indicating that the study's response rate is acceptable and the analysis is valid.

4.1.1. Section A: Respondent's Background

- **Gender Distribution**: Of the 54 respondents, 54% were male.
- **Age**: The majority (74%) were between 30 and 49 years old.
- **Ethnicity**: Malay respondents made up 63% of the 63 responses.
- **Education**: 77% of the 78 respondents had a degree.
- **Experience**: 74% had 11 to 20 years of experience in the construction industry.
- **Job Titles**: Engineers were the most common job title, making up 26% of the responses.

Table 1 Background #1

Respondents Background	Frequency	Percentage (%)
Gender		
Male	54	54%
Female	46	46%
Age		
Between 18 to 29 years old	25	25%
Between 30 to 49 years old	75	74%
Between 50 to 59 years old	1	1%
60 years old and above	0	-
Race Malay		
Indian Chinese Other	63 11 26	63% 11% 26%

	1	1.0%
Highest Qualifications		
Primary/Secondary Diploma Degree Master/Ph.D.	0 15 78 8	- 15% 77% 8%
Years of Service in Construction Industry		
Between 1 to 5 years	7	7%
Between 6 to 10 years	18	18%
Between 11 to 20 years	75	74%
21 years and above	1	1%
Job Title		
Architect	24	24%
Engineer	27	26%
Project Manager	16	16%
Quantity Surveyor	16	15%
Site Supervisor	14	15%
Other	4	4%

4.1.2. Section B: Influencing Factors in the Use of AI in Improving Construction Site Workflow Performance (Objective 1)

The mean scores for influencing factors were categorized into low, moderate, and high levels based on the data presented in Table 3.

Table 2 Background #2

Mean Score Range	Level	Mean Score
1.00-2.33	Low	(Not Agree/ Not Helpful/ Unsatisfied/ None/ Sometimes/Not Sure)
2.34-3.66	Moderate	(Agree/ Helpful/ Satisfied)
3.67-5.00	High	(Strongly Agree/ Fully Satisfied/ Really Helpful)

Table 3 Background #3

Influencing Factors in the Use of AI in Improving Construction Site Workflow Performance.	Mean	Agreement Level	Ranking
Technologically	**4.4332**	**High**	**2**
Significant facilitator	4.3365	High	3
Real with virtual worlds	4.3267	High	4
Automate processes	4.5149	High	2
Speed up processes	4.5545	High	1
Return on Investment	**4.1881**	**High**	**8**
Efficient practices	4.1188	High	3

Satisfactory on income	4.1386	High	2
Reduction in expenses	4.3069	High	1
Management of Risks	**4.4530**	**High**	**1**
Risk analysis	4.3465	High	4
Decision-making processes	4.4554	High	3
React quickly to new problems	4.5446	High	1
Monitor the progression	4.4653	High	2
Organization Culture	**4.2277**	**High**	**7**
Encourages a collective goal	4.2178	High	2
Overcome anticipated team anxiety	4.0792	High	3
Connection with technologies	4.3861	High	1
Data Availability	**4.3465**	**High**	**3**
Make accurate forecasts	4.2376	High	3
Use data responsibly-2	4.2970	High	2
High performance quality	4.5050	High	1
Industry Standard Practices	**4.3333**	**High**	**4**
Unbiased system	4.1386	High	3
Have a positive purpose	4.3861	High	2
Optimize project's capability	4.4752	High	1
Human Intervention	**4.3069**	**High**	**5**
Acquire sufficient information	4.2574	High	2
Save costs	4.1683	High	3
Time consuming procedure short	4.4950	High	1
Excessive Spending	**4.2673**	**High**	**6**
Reduced expenditures	4.2178	High	3
Cost savings	4.2079	High	4
Increasing revenue	4.2970	High	2
Increasing profit margins	4.3465	High	1

4.1.3. Section C: AI Challenges in Improving Construction Site Workflow Performance (Objective 2)

Top Challenges:

- **Limited AI Expertise**: Highest mean score of 4.5016, indicating strong agreement.
- **Privacy Risks**: Mean score of 4.4356.
- **Sluggish Electrical Service**: Mean score of 4.4290.
- **Validation and Acceptance**: Mean score of 4.3564.
- **Starting Investment**: Mean score of 4.3003.

Respondents showed high agreement with all listed challenges in improving construction site workflow performance.

Table 4 Background #4

AI Challenges in Improving Construction Site Workflow Performance.	Mean	Agreement Level	Ranking
Validation and acceptance of AI	**4.3564**	**High**	**4**
Judgement on AI	4.3663	High	2
Lack of knowledges on AI	4.3762	High	1
Hard to win stakeholders' confidence	4.3267	High	3
Limited AI expertise in the construction industry	**4.5016**	**High**	**1**
AI skills shortage	4.4653	High	3
Hard to find construction AI experts	4.4851	High	2
Invest more money for training	4.5545	High	1
Greater starting investment required for AI	**4.3003**	**High**	**5**
Hard to allocate resources	4.1386	High	3
Invest more maintenance	4.3861	High	1
More work for the investor	4.3762	High	2
Occurs in a complex and dynamic environment	**4.1947**	**High**	**9**
Unpredictability building sites activities	4.1980	High	2
Non-standardized building designs	4.1386	High	3
Navigating the complexities	4.2475	High	1
Empowerment	**4.2541**	**High**	**6**
Slow down the rate	4.0495	High	3
Lack of confidence	4.3366	High	2
Lack of training data	4.3762	High	1
Risks of privacy violation	**4.4356**	**High**	**2**
Cyber security	4.4455	High	2
Unauthorized access to personal information	4.4554	High	1
Exploit vulnerabilities in systems	4.4059	High	3
Sluggish electrical service	**4.4290**	**High**	**3**
Disruptions to the supply of electricity	4.3960	High	2
Disruptions of internet connection	4.3960	High	2
Too reliable supply	4.4950	High	1
Increasing deployment	**4.1551**	**High**	**10**
Robots take over routine work	4.1683	High	2
Increased demand for workers	3.9505	High	3
Increased unemployment	4.3465	High	1
Confronting cultural	**4.2541**	**High**	**6**
Work procedure is complicated	4.2574	High	2
Inherently hazardous	4.1188	High	3

Still use traditional techniques	4.3861	High	1

4.1.4. Section D: Strength of Relationship Between Main Influencing Factors and AI Challenges (Objective 3)

Significance: The analysis, as shown in Table 6, used an approximate significance value of < 0.05 and correlation values < 0.5 to determine relationships between variables.

Hypotheses:

- **H0**: No significant relationship exists.
- **H1**: A significant relationship exists.

The study employed the "one in five rules" for prediction modeling, which limits the number of variables based on data size (Chowdhury et al., 2020). The analysis focused on three main ranking variables for each influencing factor, selected based on high respondent agreement and relevance to the study objectives (McCombes et al., 2022). The same approach was applied to AI challenges, measuring variables based on their strength of association with the identified issues.

5. Results and Discussion

The study aimed to address three primary objectives, which guided the research process and ensured comprehensive results. The key findings and recommendations derived from the research are summarized as follows:

6. Conclusion

In conclusion, the effective application of AI in construction holds significant promise for improving site workflow performance.

Recommendations

Addressing the identified challenges and following the recommended strategies will be crucial for leveraging AI's full potential in the construction industry.

6.1.1. Recommendations for AI Integration:

Develop Comprehensive Guidelines:

Authorities such as the CIDB (Construction Industry Development Board) in Malaysia should create detailed guidelines outlining the requirements for contractors to effectively engage in AI practices.

Ensure Compliance:

It is crucial for regulatory bodies to enforce adherence to standards and legislation related to AI in construction. This will help maintain high standards and ensure proper implementation of AI technologies.

Acquire Advanced Technology:

To successfully implement AI on construction sites, authorities should invest in and acquire state-of-the-art technology from advanced nations. This will support the effective integration and utilization of AI tools.

6.1.2. Achievement of Research Objectives:

The study successfully met its objectives by analyzing the data collected from fully completed questionnaires. This analysis provided valuable insights into the influencing factors and challenges associated with improving construction site workflow performance.

6.1.3. Identified Influencing Factors and Challenges:

The research highlighted several key factors influencing AI's role in construction, including the need for better data management, risk management, and organizational support. It also identified significant challenges, such as limited AI expertise, privacy concerns, and investment costs.

6.1.4. Significance of AI Implementation:

The findings emphasize the importance of incorporating AI in construction to enhance workflow performance. Given AI's relatively recent introduction to the industry, there is a clear need for guidance, incentives, and methodologies to effectively manage and deploy AI solutions.

6.1.5. Optimistic Outlook:

The study suggests a positive outlook for the construction industry if the identified issues are addressed through the recommended strategies. By adopting these measures, the industry can achieve higher standards of efficiency and success.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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