# TECHNOLOGICAL SOLUTIONS TO LABOR SHORTAGES IN CONSTRUCTION: ASSESSING PRODUCTIVITY AND INNOVATION ADOPTION

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## Abstract

This study assesses the integration of technology in the construction sector to address labor shortages. Traditional methods show deficiencies in coping with workforce deficits. A survey design was employed, utilizing exploratory and inferential statistical techniques, including a two-step cluster analysis, Spearman's rho, and Mann-Whitney U tests, to examine the relationship between firm size, technological implementation, and productivity in the construction industry. Results indicate that larger firms leveraging technology report higher productivity. This study's contribution lies in highlighting technology's role in mitigating labor shortages and enhancing productivity, with implications for strategic industry decision-making and policy development.

## Introduction

The construction industry is currently experiencing a severe global labor shortage (AGC, 2022), resulting in increased costs and delays in projects. This scarcity of skilled workers poses widespread challenges, escalating expenses, and prolonging timelines for construction projects globally. Addressing this issue is pivotal for mitigating its impact on finances and project completion timelines (ABC 2023).

Since the 1980s, the North American construction industry has consistently faced a shortage of skilled labor, exhibiting cyclical patterns over the past three decades (Karimi et al., 2018). This shortage, influencing the national economy and citizens' well-being, is tied to the overall performance of the U.S. economy, with construction demand fluctuating accordingly (Al-Bayati et al., 2020). The increased demand for construction services has led to a critical labor issue, affecting both skilled and unskilled workers, resulting in project delays, cost escalations, and compromised project quality. In this context, the research conducted by Sadeh et al. (2021) becomes particularly relevant. It highlights the industry's division into conventional and avant-garde firms in response to technological and market changes. Sadeh (2023) further underscores the industry's productivity lag due to insufficient digitalization, a challenge particularly acute for small and medium-sized firms. Additionally, Sadeh et al. (2022) reveal the underutilization of Building Information Modeling (BIM) in large U.S. construction firms, indicating a gap in digital proficiency. These studies collectively underscore the need for increased technology integration and digital proficiency in the construction industry. At the same time, the construction labor market's complexity requires a comprehensive approach to understand and address these challenges (Cheung et al., 2011). Additionally, the Department of Labor's concern over the aging workforce and the need for approximately 240,000 new workers underscores the importance of attracting and training a new generation to sustain industry growth and adapt to evolving demands (Kim et al., 2020). Despite its substantial contribution to global economic development—accounting for 9% of GDP and employing 7% to 8.5% of the workforce worldwide—the construction industry struggles with low productivity and minimal technological advancements (Hossain et al., 2020). Global construction spending, which reached USD 11.4 trillion in 2018 and is expected to rise to USD 14 trillion by 2025, contrasts starkly with the industry's mere 1.5% investment in technology in the U.S., significantly lower than that of manufacturing (3.3%) and the overall economy (3.6%) (Changali et al., 2015). This discrepancy is particularly notable given that productivity in construction has largely stagnated, in contrast to the manufacturing sector, which has nearly doubled its productivity. Contributing to these performance challenges, as identified by Gupta (2019), are factors such as regular payment delays, advancements in technology, labor efficiency, and the availability of skilled professionals, all of which are pivotal in shaping the outcomes of construction projects.

In response to the prolonged labor shortage and improving production quality, the construction industry is increasingly embracing technology. Major firms are not only establishing innovation departments and investing in new technologies but also conducting on-site product testing (Jackson, N.D., 2020). There is a growing interest and application in various forms of automation such as virtual reality, augmented reality, drones, robotic arms, reduced scanning/photogrammetry, and 3D printing, all actively researched and utilized, albeit often confined to specific projects (Hossain et al., 2020). In addition to these technologies, the Internet of Things (IoT), drones, and prefabrication are emerging as game-changers due to their cost-effectiveness and minimal disruption to traditional construction practices, thereby shaping the future of construction job sites (Jackson, N.D., 2020). Complementing these technological advancements Cai et al.'s research (Cai et al., 2018; Cai et al., 2019) delves into the application of automation and robotics in high-rise construction, addressing labor shortages and safety risks. Moreover, Halder et al. explored the integration of inspector assistant quadruped robots (Halder et al., 2023) and developed a computational framework for remote navigation of these robots, integrating live-streaming and AR with BIM models (Halder et al., 2022). Goh et al. (2019) conducted a detailed simulation study of modular construction operations, known as Prefabricated Prefinished Volumetric Construction (PPVC), in Singapore. Their work provides valuable insights for future applications in offsite construction research. These advancements highlight the industry's increasing reliance on technology to tackle labor shortages and improve productivity. However, the path to technological integration is not without its challenges. These include the critical task of evaluating the investment value of new technologies and overcoming resistance from tradesmen who might view certain technologies as inefficient or unnecessary (Jackson, N.D., 2020). In addition to these practical challenges, the industry faces broader issues such as low productivity and limited technological progress, especially evident in Digital Twin (DT) applications, as highlighted by Opoku et al. (2021). Naderi & Shojaei (2022) further underscore the complexities of infrastructural projects and the nascent nature of digital twins, pinpointing the lack of consensus among stakeholders as a major barrier to the adoption of infrastructure digital twins (IDTs). To address production issues in construction, Antunes et al. (2018) proposed a framework integrating automatic supervisory control and data acquisition, while also noting the often-isolated implementation of information technology and automation within the industry. Melenbrink et al. (2020) explored the challenges in achieving fully autonomous construction in unstructured environments, stressing the need for development across all construction task groups and coordination between task-specific robots. On the sustainability front, Adaloudis et al. (2021) utilized grounded theory methods to assess the benefits of 3D concrete printing (3DCP), with a focus on balancing environmental, economic, and social sustainability aspects. Their research indicates that firms are increasingly motivated to invest in technologies like 3DCP to enhance automation and address skilled labor shortages. Furthermore, Liu-Lastres et al. (2022) analyzed the causes and effects of the Great Resignation, concentrating specifically on labor shortages in the construction industry and proposing various strategies to manage these challenges effectively.

The primary aim of this study is to investigate how construction firms are utilizing technology to navigate the challenges of labor shortages and how this strategy influences their operational dynamics. It is driven by two core research questions: First, it seeks to understand the ways in which technology is leveraged to address labor shortages within the construction industry and how this approach interacts with variables such as firm size, project type, and productivity to shape the firms' operational profiles. Second, it examines the impact of technology usage on the productivity of construction firms, exploring the potential for a notable relationship between the size of these firms and their levels of productivity. These research questions will provide insights into strategic decision-making and policy development in the face of labor shortages.

## Research Questions

**RQ1:** How are construction firms leveraging technology to address labor shortages, and how does this strategy interact with firm size, project type, and productivity to define their operational profiles?

**RQ2:** How does the use of technology to mitigate labor shortages affect the productivity of construction firms, and is there a relationship between the size of these firms and their productivity levels?

**Hypothesis 2A (Firm Size and Productivity)**

- **$H_1$:** There is a monotonic relationship between firm size and productivity in construction firms.

**Hypothesis 2B (Technology Usage and Productivity)**

- **$H_1$:** There is a statistically significant difference in the median productivity scores between construction firms that use technology to mitigate labor shortages and those that do not.

## Methods and Materials

The methodology is comprised of the design and implementation of a survey instrument as a component of a comprehensive electronic questionnaire. The questionnaire was developed based on an extensive literature review to assess workforce development within the construction sector and was formed as part of a broader research initiative. In the comprehensive survey conducted, a total of thirty-seven questions were presented to participants, encompassing demographic information, organizational insights, and practices, as well as technology adoption strategies. However, for the scope of this article, focused analysis was conducted on a subset of these questions that directly contribute to our examination of workforce development challenges and the role of technology in mitigating labor shortages within the construction sector. These questions were selected based on their direct relevance to our research objectives, which underscored their importance in addressing the core themes of our investigation. The rationale for focusing on these questions is further supported by their potential to illuminate the key dynamics of workforce development and technology integration in the construction industry. The first section contained multiple-choice questions related to the demographics of respondents and company profiles. The second section comprised closed-ended yes/no questions and Likert scale items ranging from 1 to 5. The respondents were asked to rate the productivity of both their craftsmen and office personnel. Additionally, they were also questioned about their adoption of technology as a strategy to counter labor shortages. For those affirming the use of technological solutions, the survey further delved into identifying the specific types of technologies being employed. Prior to its distribution, a pilot study was conducted to evaluate the validity and reliability of the survey questions, ensuring the instrument's effectiveness in accurately capturing the relevant data. Based on the findings, certain questions were revised or removed. Data collection occurred over a three-week period at CM Expos and job fairs organized for construction management students on three university campuses across the United States, located in Virginia, New York, and California. These events attracted 270 companies, including both national and regional contractors, and provided a valuable opportunity for data gathering. The process was designed to secure a representative sample of the industry. The questionnaire, however, was only distributed to around 125 construction firms, of which 92 responses were received, and 86 were complete and deemed suitable for analysis, resulting in a response rate of 73.6%. Based on the research goals and questions, appropriate exploratory and inferential statistical techniques were employed and analyzed using SPSS 29. A two-step cluster analysis was conducted for Research Question 1, while Spearman's rho and Mann-Whitney U were used for Research Question 2. The demographics of the respondents and the companies' profiles are shown in Tables 1, 2, 3, 4, and Figure 1 below. Most of the firms were commercial contractors with revenues encompassing $500 million per year.

*Table 1:Roles of Respondents*

| Role | Frequency | Percent |
|---|---|---|
| Project Manager | 20 | 23.3 |
| Field Engineer | 6 | 7.0 |
| Project Engineer | 17 | 19.8 |
| HR | 10 | 11.6 |
| Superintendent | 6 | 7.0 |
| Executive Leader | 25 | 29.1 |
| BIM Specialist | 2 | 2.3 |
| Total | 86 | 100.0 |

*Table 2: Experience of Respondents*

| Duration | Frequency | Percent |
|---|---|---|
| Under 5 | 36 | 41.9 |
| 6 - 10 | 14 | 16.3 |
| 11 - 15 | 10 | 11.6 |
| 16 - 20 | 6 | 7.0 |
| 21 + | 20 | 23.3 |
| Total | 86 | 100.0 |

*Table 3: Firm Size*

| Employees | Frequency | Percent |
|---|---|---|
| 1 - 49 | 7 | 8.1 |
| 50 - 249 | 26 | 30.2 |
| 250 - 499 | 20 | 23.3 |
| 500 - 999 | 15 | 17.4 |
| 1000+ | 18 | 20.9 |
| Total | 86 | 100.0 |

*Table 4: Project Type*

| Type | Frequency | Percent |
|---|---|---|
| Commercial | 50 | 58.1 |
| Residential | 8 | 9.3 |
| Heavy Civil | 15 | 17.4 |
| Mix-Use | 8 | 9.3 |
| Institutional | 5 | 5.8 |
| Total | 86 | 100.0 |

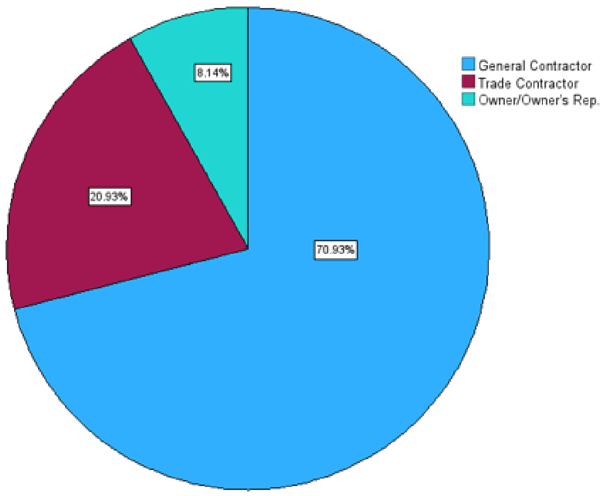


*Figure 1:Firm Type*

## Results and Discussion

### Usage of Technologies in the Industry (RQ1)

Figure 2 below shows the types of technologies that construction contractors are utilizing to mitigate the impact of workforce labor shortages.

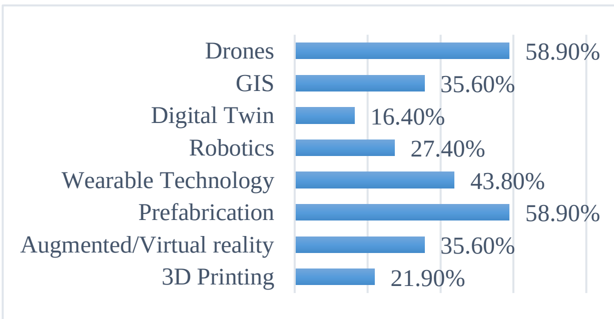


*Figure 2:Technology Type*

Drones and Prefabrication are the most widely adopted technologies, both at 58.9%. This suggests a significant trend in the construction industry towards automating and streamlining processes. Drones can be used for surveying, monitoring job sites, and ensuring that projects are progressing as planned while offsetting tasks usually performed with manual labor. Prefabrication indicates a shift towards constructing parts of buildings in a controlled environment before being transported to the site, improving efficiency, and requiring less on-site labor. Wearable technology emerges as another significant contributor, with 43.8% of industry professionals integrating it into their operations. This category includes advanced gear such as exoskeletons, which alleviate physical strain on workers, and smart helmets that enhance operational efficiency through real-time data delivery. The integration of such technology not only compensates for labor deficits but also promotes worker safety and productivity. Both Geographic Information Systems (GIS) and Augmented/Virtual Reality (AR/VR) are being utilized by 35.6% of respondents. GIS is used for planning and managing construction projects, while AR/VR can be used for training purposes and to visualize projects before they are built, which can reduce the need for rework and thus the demand for additional labor. Further, Robotics are being used by 27.4% of the respondents. Robots can perform tasks such as bricklaying, welding, and even more complex construction activities, which helps to alleviate the need for skilled labor. At 21.9%, 3D printing technology is adopted by a fifth of the respondents. This technology can be used to create building components or even entire structures with less manual labor required. Lastly, Digital Twin technology, while currently the least adopted at 16.4%, holds a significant promise for the future of construction and represents a significant undeveloped potential. This technology creates a virtual replica of physical construction sites, allowing for meticulous planning, real-time monitoring, and maintenance which, in turn, can lead to a more efficient allocation and utilization of labor.

### Firms' Segmentation and Operational Profile (RQ1)

The two-step cluster analysis was utilized to categorize firms into five distinct groups, leveraging the inherent groupings that arise from variations in key variables within the dataset. This analysis considered four variables: Firm Size; Technology Usage, which indicates whether firms employed technology to mitigate labor shortages; Project Type; and Productivity, a continuous variable that measures the output of craftsmen and office personnel, including project managers, estimators, schedulers, and project engineers. The analysis resulted in five unique clusters as shown in Figure 3, with Figure 4 providing a graphical representation of the relative distribution of these clusters based on the four variables. Cluster 1, accounting for 17.4% of the sample, included medium-sized firms with 250-499 employees. These firms uniformly utilized technology and primarily engaged in heavy civil projects, recording a productivity total of 6.93. Cluster 2, which accounted for 15.1% of the firms, consisted mainly of small firms with 1-49 employees. Most of these firms did not use technology and focused on commercial projects, achieving a productivity total of 6.00. Cluster 3, representing 24.4% of the sample, included medium-scale commercial technological firms with 500-999 employees. These firms had a complete adoption of technology and closely matched Cluster 1 in productivity total with 6.95. Cluster 4 comprised 25.6% of the firms, including small-to-medium-sized firms (50-249 employees) that fully adopted technology and specialized in commercial projects, with a productivity total like Cluster 3 of 6.95. Finally, Cluster 5, which included very large firms with over 1000 employees, formed 17.4% of the sample. Most of these firms were technology users focusing primarily on commercial projects and showed the highest productivity total of 7.47. The segmentation indicated by the results is marked, with firm size, technology adoption,

| Cluster | 4 | 3 | 1 | 5 | 2 |
|---|---|---|---|---|---|
| Size | 25.6% (22) | 24.4% (21) | 17.4% (15) | 17.4% (15) | 15.1% (13) |
| Inputs | Firm Size 50 - 249 (100.0%) | Firm Size 500 - 999 (57.1%) | Firm Size 250 - 499 (46.7%) | Firm Size 1000+ (93.3%) | Firm Size 1 - 49 (46.2%) |
| | Technology Usage Yes (100.0%) | Technology Usage Yes (100.0%) | Technology Usage Yes (100.0%) | Technology Usage Yes (86.7%) | Technology Usage No (92.3%) |
| | Project Type Commercial (68.2%) | Project Type Commercial (81.0%) | Project Type Heavy Civil (60.0%) | Project Type Commercial (73.3%) | Project Type Commercial (53.8%) |
| | Productivity 6.95 | Productivity 6.95 | Productivity 6.93 | Productivity 7.47 | Productivity 6.00 |

*Figure 3: Grouping of Clusters*

project type, and productivity levels acting as distinguishing characteristics. Clusters 3, 4, and 5 demonstrated a strong technological integration, suggesting a trend towards digital transformation, especially among medium to very large firms. Clusters 1 and 5, which include the larger firms, reported higher productivity totals, implying a possible link between firm size and productivity, potentially attributable to economies of scale or greater resource investment in adaptation and process optimization. Notably, Cluster 2 stands out as the sole group where most firms did not embrace technology, coinciding with the smallest firm size and the lowest productivity, highlighting the critical influence of technology adoption on productivity.

The analysis of predictor importance, presented in Figure 5, provides valuable insights into the relative impact of each variable on the cluster assignments. Firm Size emerged as the most significant predictor, suggesting that the number of employees is a fundamental factor in differentiating the clusters. This emphasizes the role of firm size in operational practices, as well as its potential influence on the adoption of technology and the types of projects undertaken. Following in significance was Technology Usage, which stands as the second most critical predictor. This underscores the influence of digital adoption on how firms are classified, reflecting the centrality of technology in shaping business operations and productivity within the industry. Project Type also played a moderate role in the clustering, indicating that the nature of projects—whether commercial or heavy civil—has a discernible, though lesser, effect on the grouping of firms compared to size and technology usage. Productivity, while relevant, was the least influential predictor in the clustering process. This suggests that productivity, as a performance metric, does not contribute to cluster differentiation as strongly as the other variables, potentially because it is impacted by firm size and technology usage to an extent that limits its independent variation across clusters.

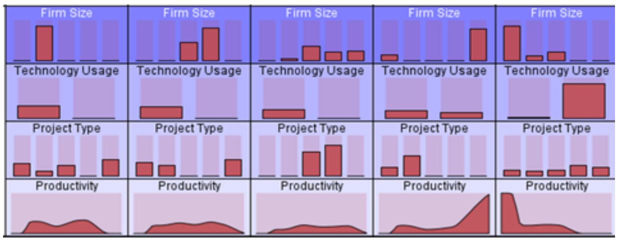

*Figure 4:Relative Distribution of Clusters*

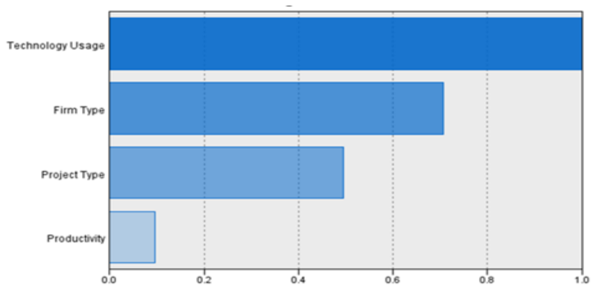

*Figure 5: Predictor Importance*

**Impact of Technology on Productivity (RQ2)**

In the context of examining the impact of technology usage on the productivity, the construction firms, particularly as a strategy to combat labor shortages, the Mann-Whitney U test provides a non-parametric means for assessing whether the median productivity scores differ between technology-using firms and non-technology-using firms. This test is particularly apt for situations where the data does not satisfy the assumptions necessary for a traditional t-test, such as non-normal distribution or ordinal measurements, as is the case with the sample for this study. The analysis incorporated 72 firms, shown in Table 5, that reported using technology to mitigate labor shortages, compared to 14 firms that did not employ technology for this purpose. The Mann-Whitney U test results revealed a mean rank of productivity of 46.19 for the technology-using firms, with their cumulative ranks summing up to 3326.00. Conversely, the non-technology-using firms exhibited a lower mean rank of 29.64, with a summed rank of 415.00. The marked disparity in the mean ranks suggests that firms engaging in technology tend to report higher productivity. The Z-score associated with the test statistic was -2.341, which indicates that the observed ranks are 2.341 standard deviations below the mean rank sum that would be expected under the null hypothesis of no difference between the groups. Crucially, the asymptotic significance (two-tailed) value was 0.019. This p-value is indicative of the probability of obtaining the observed results, or more extreme, under the null hypothesis that there is no difference between the two groups' median productivity. Since the p-value is less than the conventional alpha level of 0.05, the null hypothesis can be rejected at the reference confidence level. This implies that the difference in productivity ranks between firms using technology and those that do not is statistically significant. Therefore, the statistical analysis suggests a clear association between the implementation of technology and increased productivity among construction firms. The implication of this finding is that technology usage appears to be an effective measure in addressing labor shortages within the industry, as evidenced by the higher productivity rankings among firms that adopt technological solutions. This conclusion aligns with the ongoing narrative within the sector that technology not only serves as a stopgap for labor deficit but also enhances operational efficiencies and outputs. These results can guide industry stakeholders in decision-making processes regarding investments in technology to combat the pervasive challenge of labor shortages.

**Impact of Firm Size on Productivity (RQ2)**

This analysis sought to determine the relationship between firm size and productivity within the construction industry. Utilizing Spearman's rho, shown in Table 6, to measure the strength and direction of association between these two ordinal variables, we observed a correlation coefficient (rho) of 0.215.

*Table 5:Mann Whitney Test*

| Technology Usage | | N | Mean Rank | Sum of Ranks | Mann-Whitney U | Wilcoxon W | Z | Asymp. Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| Productivity | Yes | 72 | 46.19 | 3326.00 | 310.000 | 415.000 | -2.341 | 0.019 |
| | No | 14 | 29.64 | 415.00 | | | | |
| | Total | 86 | | | | | | |

a. Grouping Variable: Technology Usage

This positive correlation, while weak, indicates that larger firms tend to have slightly higher productivity levels. Notably, this association was statistically significant (p = 0.047), suggesting that the observed relationship is unlikely to have occurred by chance. Therefore, we reject the null hypothesis in favor of the alternative hypothesis, concluding that there is evidence of a monotonic relationship between firm size and productivity in the population from which the sample of construction firms was drawn. Given the sample size of 86 firms, these findings provide some evidence that firm size may be a factor in productivity outcomes in the construction sector. However, given the modest strength of the correlation, further research should explore additional variables that might influence productivity more strongly.

*Table 6:Spearman's rho Test*

| | | | Firm Size | Productivity |
|---|---|---|---|---|
| Spearman's rho | Firm Size | Correlation Coefficient | 1.000 | .215* |
| | | Sig. (2-tailed) | . | .047 |
| | | N | 86 | 86 |
| | Productivity | Correlation Coefficient | .215* | 1.000 |
| | | Sig. (2-tailed) | .047 | . |
| | | N | 86 | 86 |

*. Correlation is significant at the 0.05 level (2-tailed).

## Conclusion

The comprehensive analysis presented in this study offers important insights into how construction firms are leveraging technology to mitigate labor shortages and the subsequent impact on productivity. Particularly, the study's findings underscore the prevalence of technological adoption across the construction sector, with a particular emphasis on drones and prefabrication as leading strategies. The data suggests a strong relationship between firm size, technology usage, project type, and productivity, with larger firms demonstrating an inclination towards higher productivity levels, potentially reflecting the benefits of economies of scale and enhanced resource allocation.

The segmentation of firms into five distinct clusters highlights the nuanced ways in which these variables interplay to shape operational profiles within the industry. Firms that embrace technology, particularly those of medium to large scale, show a clear trend towards higher productivity totals, reinforcing the narrative that digital transformation is a key driver of efficiency and output in the face of labor challenges. In contrast, the standout characteristic of the smallest firms—many of which have not adopted technology—correlates with the lowest productivity scores, emphasizing the pivotal role of technology in enhancing productivity. Empirical findings from the Mann-Whitney U test and Spearman's rho analysis further validate the hypotheses set forth at the outset of the study, i.e., confirming a statistically significant difference in productivity between firms that utilize technology and those that do not, as well as a positive correlation between firm size and productivity. However, the study's conclusions are offered with the acknowledgement of several limitations. The method of data collection, primarily through university job fairs, could potentially introduce a selection bias. This is because firms participating in these fairs might be inherently more inclined towards innovation and technological advancements, while leveraging employment shortages, possibly skewing the sample towards more technologically progressive companies. Another key limitation lies in the reliance on self-reported data, which carries an inherent risk of reporting biases, as firms might tend to overestimate their productivity or the impact of their technological implementations. Lastly, the cross-sectional design provides a snapshot that cannot capture the dynamic nature of technology adoption over time. Despite these limitations, the findings suggest that the construction industry is actively adapting to labor challenges through technology, and the high response rate reinforces the reliability of this conclusion. This research has significant implications for industry stakeholders, suggesting that investments in technology are not only a viable response to labor shortages but also a critical component of enhancing overall firm productivity. The study’s insights are valuable for informed strategic decision-making and policy formulation aimed at improving growth and sustainability within the construction sector. Future research should aim to build upon these findings, exploring the broader implications of technology adoption and firm size on productivity, with an eye towards identifying other contributory factors that could further refine our understanding of these complex dynamics.

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