Grenze International Journal of Engineering and Technology, June Issue

A Descriptive Study of Errors and Omissions in MEP Rough-in for Concrete Construction

Amani Qasrawi[1] and Tulio Sulbaran[2]
[1-2]The University of Texas at San Antonio, Texas, USA
Email: amani.qasrawi@my.utsa.edu, Tulio.sulbaran@utsa.edu

***Abstract*— Correctly placing Mechanical, Electrical, and Plumbing (MEP) systems in concrete slab rough-ins is important for ensuring efficient workflow in construction sites. The three main components used during the rough-in phase are: a) Embedded items (anchors or inserts), b) Slab spaces created with forms (block-outs or bulkheads), and c) Trade place tubes (sleeves). However, these components are susceptible to four common types of errors and omissions (E&O): i) Dimension errors, ii) Positioning errors, iii) Securing problems, and iv) Complete omissions. These E&O can cause delays and require rework. Unfortunately, there is limited research addressing these E&O. This study aims to fill the gap in published research on E&O in MEP rough-ins and develop a structural component-issue classification framework. Therefore, the objective of this paper is to identify and uncover patterns and correlations among different types of E&O, providing insights to improve construction accuracy and efficiency. The methodology employed in this paper was quantitative, utilizing three descriptive analysis methods: 1- Box and Whisker Plot, 2- Correlation Matrix Heatmap, and 3- Bar Chart. The results indicate that dimension and positioning errors, particularly for components such as, Embedded items (anchors or inserts), and trade placed tube (Sleeves), are consistently problematic. These findings provide baseline insights that may inform quality control prioritization and construction management education, while establishing an analytical foundation for future field-validated research.**

***Index Terms*— Errors and Omissions, Concrete slabs, Slab penetrations.**

I. INTRODUCTION

The construction industry is continually on the lookout for innovative strategies to enhance both the efficiency and quality of its projects. However, challenges such as errors and omissions (E&O) frequently arise, which can have a significant Impact. These E&O can result in negative consequences, such as safety hazards and disputes between contracting parties [1]. In particular, E&O in the concrete slab rough-in for mechanical, electrical, and plumbing (MEP) systems can significantly impact both cost and timeline, especially due to the rework required and the common use of concrete slabs across various project types [2]. Specifically, documentation errors related to mechanical, electrical, and plumbing systems are a pervasive problem, contributing to significant cost overruns, reduced productivity, and contractual disputes in the construction and engineering industry [3]
Concrete slabs are essential components of construction, providing stable foundations for various structures [4]. During slab construction, it is important to accurately position, dimension, and secure MEP components before placing the concrete.

Grenze ID: 01.GIJET.12.2.174_24

Industry standards emphasize the importance of tolerances, anchorage, and pre-pour verification procedures to minimize rework and misalignment [5], [6]. Despite these guidelines, field-based E&O during MEP rough-ins remains common. Despite these guidelines, field-based E&O during MEP rough-ins remains common. These errors often lead to extensive reworks, impacting project schedules and budgets significantly, particularly when undetected until later construction phases [7]. Such deficiencies in design documentation, particularly concerning the exact placement of penetrations and the spatial coordination of crowded rebar connections, frequently manifest as costly issues during the construction phase [8].

Existing research has examined construction rework, coordination failures, and inspection practices broadly. Studies have explored QA/QC implementation, digital inspection tools, and technology-enhanced monitoring approaches [9], [10]. However, there is limited research that systematically categorizes slab-based MEP rough-in errors at the component level or examines how different types of errors relate to each other. Specifically, there is a lack of structured empirical analysis that connects predefined MEP component categories with common problems that occur during slab installation.

To address this gap, this study adopts definitions from the American Concrete Institute (ACI 347), to systematically categorize slab-based MEP rough-in components and their associated error types. According to ACI-347, the three most common MEP rough-in components are: Embedded items (anchors or inserts), Slab spaces created with forms (block-outs or bulkheads), and Trade place tubes (sleeves). Additionally, the four most common issues associated with these components align with construction challenges highlighted in ACI standards. These standards stress the importance of proper placement, tolerances, anchorage, and pre-pour verification of embedded items and sleeves [6] [4]: Dimension errors, Position errors, Securing errors, and Complete omissions. These E&O can lead to various problems, including delays and rework.

A. MEP Rough-in Components

This section offers detailed definitions for each component related to MEP rough-in, explaining their functions and importance within the overall system.

- Embedded items include anchors or inserts: "Anchor: in slabs-on-grade or walls, to fasten to rock or adjacent structures to prevent movement of the slab or wall with respect to the foundation, adjacent structure, or rock "[12]. "Insert: anything other than reinforcing steel that is rigidly positioned within a concrete form for permanent embedment in the hardened concrete "[12].
- Slab spaces created with forms including block-outs or bulkheads: "Bulkhead: a partition in formwork blocking fresh concrete from a section of the form, or a partition closing a section of the form, such as at a construction joint "[12]. Blockout: a space within a concrete structure under construction in which fresh concrete is not to be placed, called core in the United Kingdom [12].
- Trade place tubes, also known as sleeves: "Sleeve: (1) a pipe or tube passing through formwork for a wall or slab through which pipe, wires, or conduit can be passed after the forms have been stripped; (2) a device used around an anchor to accommodate adjustment and preloading of the anchor after the concrete has hardened "[12].

B. MEP Rough-in Common Issues

The following definitions outline the four most common issues related to the three components mentioned above: (1) Dimensional errors: these occur when the dimensions of the Mechanical, Electrical, and Plumbing (MEP) rough-ins at the job site do not correspond with the sizes indicated in the construction drawings. Such discrepancies can lead to significant complications during installation and affect the overall project timeline. (2) Positional errors: arise when MEP rough-ins are either misaligned or incorrectly oriented at the job site. This misalignment contrasts with the specified coordinates detailed in the construction drawings, often resulting in additional work and modifications to achieve proper placement. (3) Securing errors: refer to situations where the MEP rough-ins lack adequate anchorage or stability at the job site. Without proper securing, the rough-ins can shift or become dislodged, compromising both safety and functionality. (4) Complete omissions: occur when MEP rough-ins are entirely absent from the job site, resulting in critical gaps in the systems intended to be installed. Such omissions can severely delay project progress and lead to costly rework.

These common issues often lead to significant discrepancies in the spatial coordination of mechanical, electrical, and plumbing elements, particularly concerning conduit placement within reinforced concrete diaphragms [13]. Such discrepancies can significantly hinder the integration of building information modeling with real-world construction, leading to diminished precision in project execution and increased potential for costly revisions [14], [15].Furthermore, these types of discrepancies can contribute to hard and soft clashes, necessitating extensive rework and potentially impacting project timelines and budgets [16].Therefore, the objective of this paper is to identify and uncover patterns and correlations among different types of E&O. To accomplish this, the research introduces and develops a systematic classification framework linking ACI-defined MEP components with common error categories, enabling structured analysis at the component–issue level. Using a descriptive approach, the study provides a baseline dataset that highlights variability and co-occurrence trends among E&O categories. By focusing specifically on slab-based MEP rough-ins, this work establishes an analytical framework intended to support future field-validated investigations and technology-assisted inspection research.

II. Methodology

In this study, a quantitative descriptive research approach was employed to systematically investigate and analyze E&O during MEP rough-in installation in concrete slabs. Quantitative methodology was chosen because it facilitated systematic investigation through the collection and analysis of numerical data [17]. Descriptive research was used as it allows for the characterization of variables without manipulating them [18].

A. Survey Design and Participants

Data were collected using an online survey developed in Qualtrics. The survey consisted of 21 questions, including 16 closed-ended questions for quantitative analysis and 5 open-ended questions for additional insights. The target population included construction professionals involved in the installation of MEP systems on concrete projects. Participants were selected using a purposive, non-random sampling method to align with the study's objectives [19]. The survey was presented at two Construction Career Fairs and one meeting of the National Association of Women in Construction. Industry professionals were approached, resulting in 50 individuals expressing interest in participating. The survey was then emailed to these 50 professionals, though not all completed it.

B. Data Handling and Quantification

To facilitate numerical analysis, qualitative data collected from responses (e.g., "1% to 5% of the projects") were converted into quantitative values (e.g., a numeric value of 3). Normalization techniques were applied to standardize the data, ensuring comparability across responses and E&O types. No inferential statistics, predictive modeling, or hypothesis testing were conducted.

C. Analytical Approach

The three commonly used analytical methods were employed to visualize and prioritize E&O types based on their occurrence: 1- Box and Whisker Plot, 2-Correlation Matrix Heatmap, and 3- Bar Chart to prioritize E&O types by severity and occurrence for resource allocation. These methods were used to address the following research questions:
Q1 - How do variations in average values, variability, and unusual data points across the three components and four common issues affect our understanding of the dataset?
Q2 - What is the correlation between different common errors and omissions (E&O)?
Q3 - How frequently do different types of E&O occur in relation to MEP rough-in components?

III. Results and Analysis

The survey data was analysed using the three methods described above with the help of Excel to provide insights into the prevalence of E&O in concrete slab rough-ins for MEP systems. The analyses helped identify the primary factors contributing to these E&O, enabling targeted interventions to improve accuracy and reduce future occurrences.

A. Demographics of Survey Participants

While not all professionals answered every question, there were 23 responses to the "Company Type" question, ensuring a comprehensive overview (see Figure 1). According to the responses, 47.8% of participants identified as general contractors, 21.7% as sub-contractors or specialty contractors, 13.0% as engineering firms, 13.0% as design firms, and 4.3% as owners or owner representatives. These results indicate a diverse mix of participants from various sectors of the construction industry.
This distribution illustrates the involvement of various stakeholder groups in slab-based MEP coordination. However, the sample size is limited, and the representation of specific trades, especially among mechanical, electrical, and plumbing subcontractors, is insufficient for subgroup statistical comparisons. Consequently, the

findings should be viewed as exploratory and perception-based rather than fully representative of the wider construction industry.

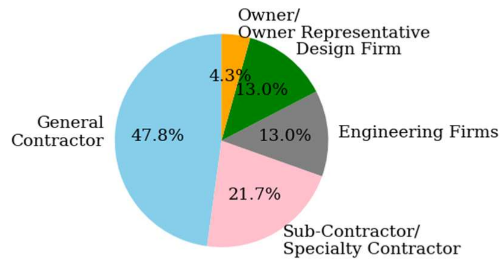

Figure 1: Distribution of Participants' Organization Types

B. Descriptive Approaches for Analyzing the Data

This study analyses three key MEP rough-in components: a) embedded items (anchors or inserts), b) slab space created with formwork (block-outs or bulkheads), and c) trade-placed tubes (sleeves). It also examines four common issues: i) dimensions, ii) position, iii) securing errors, and iv) complete omissions. The participants were asked the question: "During the formwork construction for concrete slabs, how often does each of the E&O listed impact your projects (Approximately)?". There were 17 responses to this question.

Q1: The variations in central tendency, spread, and outliers across the three components and four common issues shape the interpretation of the dataset (Analysis of Variability and Outliers in MEP Rough-In Data).

The Box and Whisker Plot visualization illustrates the distribution values for the three components and the four common issues. It helps in understanding the variability, central tendency, and presence of outliers within the dataset. The box delineates the range between the 25th percentile and the 75th percentile, while the horizontal line inside each box indicates the median value. The "value" as a term means the number from the survey summary (like the minimum, maximum, or average number for each component). The larger the box is, the wider the spread of values, suggesting greater variability in that category. A larger box signifies a wider spread of values, suggesting greater variability within that category. The whiskers extend from the minimum and maximum values, excluding outliers. Longer whiskers indicate a greater spread of values beyond the interquartile range.

Variability Across MEP Rough-In Components

The Box and Whisker Plot for MEP rough-in Components (Figure 2) displays the distribution of responses for Embedded Items, Block-outs and Bulkheads, and Sleeves, highlighting variations and potential outliers. Embedded Items have a median value of 7.75, with a moderate interquartile range (IQR) between 3.00 and 21, but a significant outlier at 79.5, indicating extreme variations potentially due to specific project requirements or inconsistencies. Block-outs and Bulkheads have a median of 5.38 and a similar IQR, but an outlier at 49.5, suggesting an unusual deviation, with shorter whiskers indicating a more compact data distribution. Sleeves, with a median of 7.75 and an IQR of 3.00 to 26, show the widest whisker extension, indicating higher variability. Unlike Embedded Items, Sleeves show a more evenly distributed spread, with a maximum value of 50.25. This analysis provides insights into data dispersion and irregularities within these MEP rough-in components, highlighting areas that may require further quality control. The distribution is also skewed to the right, meaning that while most responses are concentrated at lower E&O frequencies, a few extreme values pull the distribution's tail toward the higher end. This right skew highlights the potential for occasional but impactful deviations from the norm that may warrant closer quality control or process improvements.

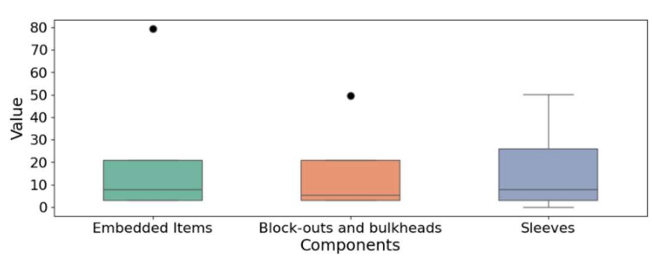

Figure 2: Box and Whisker Plot for MEP rough-in Components

Variability Across Common Issues

The Box and Whisker Plot for Error Types in Construction (Figure 3) illustrates the distribution of E&O across the four common issues: Completely Omitted, Dimension Errors, Position Errors, and Securing Errors, highlighting variability and outliers. Completely Omitted Errors have a median of 9.33 with IQR from 3 to 18.17, but an outlier at 49.5 suggests instances where items were omitted at an unusually high rate. Dimension Errors show a higher median of 12.5 and a wider IQR, indicating greater variability, with an outlier at 56.17, reflecting significantly large deviations in some cases. Position Errors exhibit the largest spread, with a median of 12.5 and a maximum value of 56.17, indicating inconsistent positioning accuracy, though no extreme outliers were detected. Securing Errors have the smallest IQR and lowest median (6.17), suggesting minimal variation, yet an outlier at 56.17 indicates occasional extreme cases that may require further investigation. This analysis looks at E&O patterns in MEP rough-in components and underscores the necessity for targeted quality control measures.

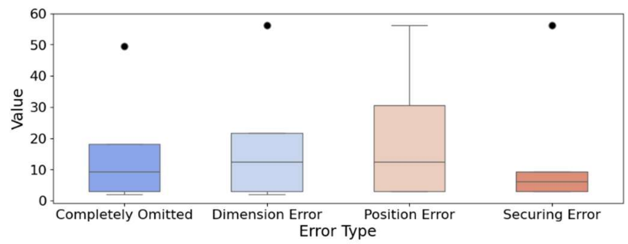

Figure 3: Box and Whisker Plot for Error Types in Construction

Components and Common Issues of MEP Rough-in E&O in the Project

The Box and Whisker Plot illustrating the components and common issues of MEP rough-in E&O (Figure 4) reveals significant variations in E&O occurrences across different categories. Errors associated with Embedded items (anchors or inserts)-Securing, slab space created with form (block-outs or bulkheads)-Completely Omitted, and C-Securing have low median values, indicating that errors in these categories are relatively minor and more consistent. However, Trade place-tube (Sleeves)-Position Error has the highest median, reflecting frequent large errors in positioning, and its widest IQR suggests high variation in these errors. Additionally, slab space created with form (block-outs or bulkheads)-Position Error and Trade place-tube (Sleeves)-Dimension Error have large IQRs, further emphasizing the inconsistency of these errors across different projects. These variations suggest that positioning and dimension errors require more precise control and monitoring to mitigate inconsistencies in construction processes.

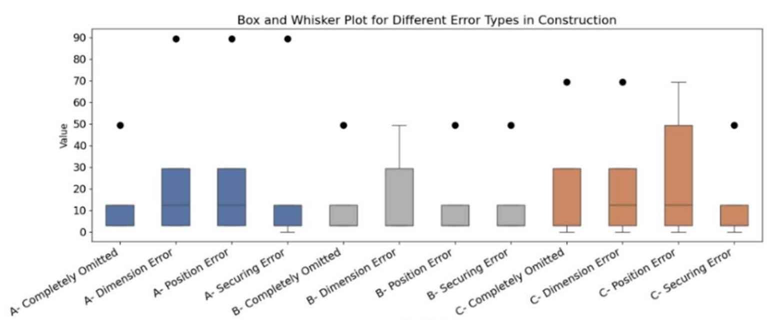

Figure 4: Box and Whisker Plot for Different Error Types in Construction

Legend: A- Embedded items (anchors or inserts), B- Slab space created with form (block-outs or bulkheads), and C- Trade place-tube (Sleeves)

Q2: The correlation coefficients between different common E&O illustrate the strength and type of their relationships.

The correlation matrix heatmap for the E&O as shown in (Figure 5), represent the correlation coefficients between different common E&O. The colour indicates the strength of these correlations, where red represents a strong positive correlation, blue represents a weak or negative correlation, and lighter shades indicate moderate correlations.

The analysis reveals strong correlations between Embedded Items-Dimension Error and Embedded items (anchors or inserts)-Position Error (0.96), as well as between Embedded items (anchors or inserts)-Dimension Error and Embedded items (anchors or inserts)-Completely Omitted (0.95). These findings suggest that dimension-related errors are frequently associated with both position and omission errors. Similarly, the correlation between Slab space created with form (block-outs or bulkheads)-Dimension Error and Slab space created with form (block-outs or bulkheads)-Position Error (0.94) indicates that errors related to dimensions and positioning often co-occur in Slab space created with form (block-outs or bulkheads). Conversely, Slab space created with form (block-outs or bulkheads)-Securing Error shows weak correlations with most other errors, suggesting that securing errors are relatively independent when compared to dimension and position errors.
Moderate correlations are observed between Errors in Trade place-tube (Sleeves) (Completely Omitted, Dimension Error, and Position Error) and both Embedded items (anchors or inserts) and, Slab space created with form (block-outs or bulkheads. This indicates that while errors across different sections may be interconnected, they are not as strongly correlated as those within the same category. The heatmap underscores the importance of enhancing dimensional accuracy to potentially mitigate both omission and positioning errors, highlighting a critical focus area for quality control in construction projects. This suggests that improving dimensional accuracy may help reduce the likelihood of components being placed incorrectly or completely omitted.

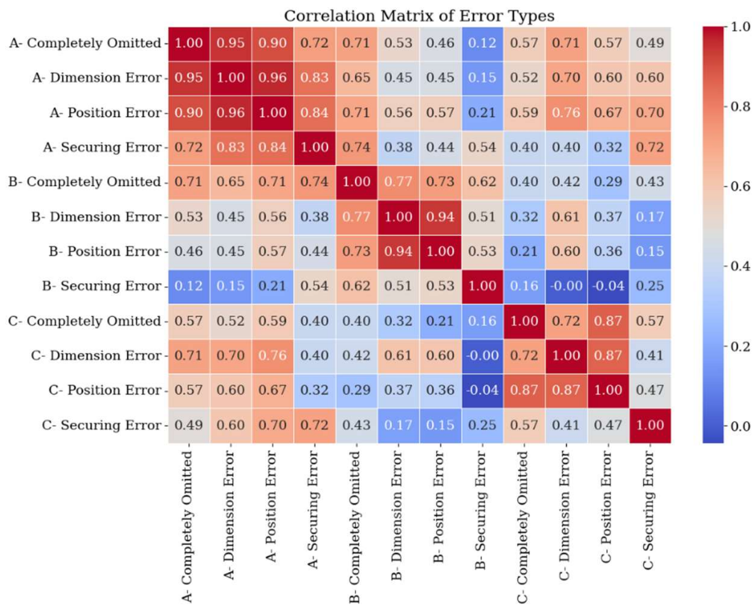

Figure 5: Heatmap of Errors and Omissions in MEP Rough-In for Concrete Slabs

Legend: A- Embedded items (anchors or inserts), B- Slab space created with form (block-outs or bulkheads), and C- Trade place-tube (Sleeves)

Q3: The occurrences of E&O with MEP rough-in components,
The bar chart in (Figure 6) compares various E&O with MEP rough-in components: a) embedded items (anchors or inserts), b) slab space created with formwork (block-outs or bulkheads), and c) trade-placed tubes (sleeves). It also examines four common issues: i) dimensions, ii) position, iii) securing errors, and iv) complete omissions. It summarizes the average values for each E&O type, helping to identify the most and least occurrences of E&O.
The chart highlights the high occurrences, suggesting these are critical areas requiring attention. This visualization emphasizes the need for targeted quality control measures to minimize errors and omissions that significantly impact construction accuracy and efficiency.
The Comparison of Errors and Omissions Between Components (Figure 6) highlights critical areas that require quality control improvements to enhance construction accuracy and efficiency. High-occurrence errors are observed in Embedded Items (Anchors or Inserts), particularly in Dimension and Position Errors, emphasizing the need for better precision in placement and measurement. Similarly, Trade-Placed Tubes (Sleeves) show frequent Position Errors, indicating recurring challenges in alignment during installation. Moderate-occurrence errors are found in Slab Space Created with Form (Block-outs or Bulkheads), where Dimension and Position

Errors occur at a notable rate, though with less urgency than Embedded Items. Additionally, Complete Omissions for both Embedded Items and Trade-Placed Tubes fall within a moderate range, indicating the need for oversight to minimize these E&O. Low-occurrence errors include Securing Errors across components (Sleeves, Block-outs, and Embedded Items), therefore, it is important to enhance quality management to ensure the proper placing of these components. This visualization underscores the importance of targeted quality control measures to reduce E&O and improve overall construction efficiency.

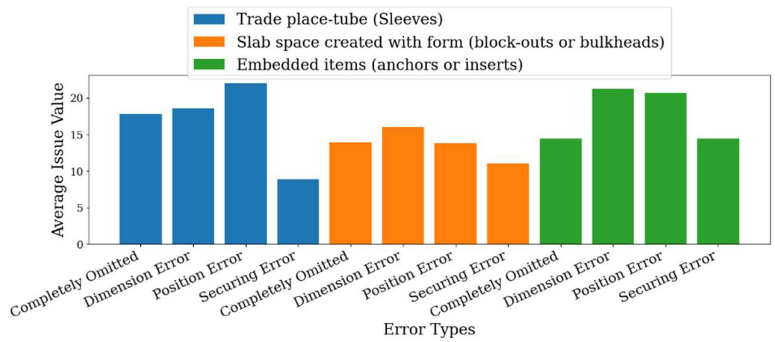

Figure 6. Comparison of Errors and Omissions Between Components

IV. Conclusions and Practical Implications

This study provided quantitative insights and patterns of E&O in the MEP rough-in phase of construction projects. Using descriptive analytical methods, including box and whisker plots, correlation matrix, and bar charts, the research identified variation, recurring error patterns, and component-specific that impact construction accuracy, cost, and scheduling.

Q1- The box and whisker plots indicated significant variability and the presence of outliers in errors linked to embedded items, block-outs, and bulkheads, as well as trade-placed tubes. Notably, positioning and dimension errors exhibited the highest variability, underscoring the need for stricter quality control measures in these areas.

Q2 - The heatmap of the correlation matrix revealed strong correlations among dimension errors, position errors, and complete omissions, particularly within the same component category. This suggests that enhancing dimensional accuracy reduces associated E&O.

Q3 - The bar chart emphasized the frequency of high-occurrence errors, particularly in embedded items and trade-placed tubes. These findings underscore the need for targeted quality control interventions to minimize errors and enhance construction accuracy and efficiency.

Identifying the three most common MEP rough-in E&O enables project managers to focus on supervision and quality control procedures, minimizing negative impacts on project timelines, quality standards, and costs. Ineffective supervision, especially among subcontractors, can lead to significant rework and delays. Therefore, improving planning, training, and quality management practices can enhance project outcomes [20]. Additionally, protecting completed work from damage prevents inefficiencies, and documenting E&O aids in establishing patterns and implementing corrective measures. The integration of technologies such as augmented reality (AR) can also improve accuracy and efficiency, highlighting important areas for future research.

E&O during MEP rough-ins can have cascading effects on project schedules, cost efficiency, and overall quality. Poor supervision, especially at the subcontractor level, often exacerbates these issues, leading to costly rework and delays. Therefore, actionable strategies are necessary to translate analytical insights into enhanced on-site practices.

- Improving dimensional accuracy through digital layout tools.
- Enhancing coordination and training for subcontractors involved in rough-in work.
- Establishing systematic quality checks for high-variability components like sleeves and embedded items.
- Leveraging technology, such as augmented reality (AR) or building information modelling (BIM) overlays, to validate placement before concrete pours.

These practical suggestions can assist project managers, contractors, and design professionals in applying findings directly to reduce E&O in MEP rough-ins.

This study offers a structured, component-based framework that links E&O categories with concrete slab MEP rough-in elements. By quantifying variability, identifying correlation patterns, and highlighting areas of high error frequency, the research provides a foundation for future field-validated studies and the development of technology-enhanced inspection systems. These insights support more consistent MEP installations and contribute to improved construction quality management practices.

LIMITATIONS AND FUTURE WORK

This study offers valuable insights into Errors and Omissions (E&O) in MEP rough-ins for concrete slabs; however, several limitations affect the generalizability and depth of the findings. First, the analysis relies on a small sample size, with responses reflecting the perceptions and recollections of construction professionals rather than direct field measurements. Consequently, the findings should be viewed as exploratory indicators rather than statistically representative outcomes. While the survey reached a diverse group of professionals, certain trades—particularly mechanical, electrical, and plumbing subcontractors—were underrepresented, which limits the ability to conduct subgroup comparisons or identify trade-specific patterns.

Another limitation is the reliance on self-reported data, which may introduce recall bias or subjective interpretations of error frequency. Although the descriptive statistical approach was suitable given the available data, it restricts the application of more robust inferential techniques that could further validate the relationships observed between components and error types. Additionally, the study did not include on-site observational data, physical measurements, or reviews of construction records that could help triangulate and verify reported error occurrences.

Given these limitations, several opportunities for future research emerge. conducting field-based studies to validate survey-identified trends. Additionally, developing controlled mockup slab environments will allow for experimental testing. Comparing traditional inspection methods with technology-based methods, such as augmented reality (AR).

Future research should explore longitudinal case studies to determine if targeted quality-control interventions effectively reduce recurring error types over time. Increasing the sample size and involving a wider range of trade professionals would improve generalizability and facilitate trade-specific or project-type analyses. Ultimately, combining empirical field data with the component–issue classification framework proposed in this study can help develop a more comprehensive predictive model for minimizing errors and omissions (E&O) during MEP rough-in activities.

REFERENCES

[1] G. Sibanyama, M. Muya, and C. Kaliba, “An Overview of Construction Claims: A Case Study of the Zambian Construction Industry,” International Journal of Construction Management, vol. 12, no. 1, pp. 65–81, Jan. 2012, doi: 10.1080/15623599.2012.10773185.

[2] Y. Guo, “Analysis on Concrete Construction Technology in Civil Engineering Construction,” J. Phys.: Conf. Ser., vol. 2011, no. 1, p. 012023, Sep. 2021, doi: 10.1088/1742-6596/2011/1/012023.

[3] P. E. D. Love, J. Zhou, C. Sing, and J. T. Kim, “Documentation errors in instrumentation and electrical systems: Toward productivity improvement using System Information Modeling,” Automation in Construction, vol. 35, pp. 448–459, Nov. 2013, doi: 10.1016/j.autcon.2013.05.028.

[4] B. Pang, F. Wang, J. Yang, S. Nyunn, and I. Azim, “Performance of slabs in reinforced concrete structures to resist progressive collapse,” Structures, vol. 33, pp. 4843–4856, Oct. 2021, doi: 10.1016/j.istruc.2021.04.092.

[5] ACI 117, “ACI 117 Specifications for Tolerances for Concrete Construction and Materials - ACI 117- (Reappoved - Studocu.” Accessed: Apr. 11, 2025. [Online]. Available: https://www.studocu.com/en-us/document/purdue-university-global/building-construction-for-fire-protection/aci-117-specifications-for-tolerances-for-concrete-construction-and-materials/44863475

[6] ACI 347, “347R-14 Guide To Formwork For Concrete | PDF | Specification (Technical Standard) | Concrete.” Accessed: Feb. 17, 2026. [Online]. Available: https://www.concrete.org/Portals/0/Files/PDF/CEU-347R-14.pdf

[7] J. B. P. D. Filho, B. M. Angelim, J. P. Guedes, M. A. F. De Castro, and J. D. P. B. Neto, “Virtual design and construction of plumbingsystems,” Open Engineering, vol. 6, no. 1, Dec. 2016, doi: 10.1515/eng-2016-0076.

[8] M. Salam, P. Forsythe, and C. Killen, “Exploring Interdisciplinary Collaboration in the Detailed Design Phase of Construction Projects,” Jul. 2019, pp. 761–772. doi: 10.24928/2019/0149.

[9] M. Al-Adhami, “Extended Reality Approach for Construction Quality Control,” 2019.

[10] J. Yang, M.-W. Park, P. A. Vela, and M. Golparvar-Fard, “Construction performance monitoring via still images, time-lapse photos, and video streams: Now, tomorrow, and the future,” Advanced Engineering Informatics, vol. 29, no. 2, pp. 211–224, Apr. 2015, doi: 10.1016/j.aei.2015.01.011.

[11] ACI 347, “ACI 347-04 Guide to Formwork for Concrete,” 2004.

[12] American Concrete Institute, “ACI Concrete Terminology,” 2013.

[13] J. P. Moehle, J. D. Hooper, D. J. Kelly, and T. R. Meyer, “Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors: A Guide for Practicing Engineers (NIST GCR 10-917-4),” 2016.
[14] S. Girgin, R. Fruchter, and M. Fischer, “A case study towards assessing the impact of mixed reality-based inspection and resolution of MEP issues during construction,” Journal of Information Technology in Construction, vol. 28, pp. 555–570, Sep. 2023, doi: 10.36680/j.itcon.2023.029.
[15] N. K. Muthumanickam, L. Boyd, and S. Pless, “Robotics for Systems Integration in Buildings: Pilot Study of Viable Approaches to Install Hygrothermal and Rigid Electrical Systems,” in Earth and Space 2024, in Proceedings. , 2024, pp. 1125–1142. doi: 10.1061/9780784485736.098.
[16] M. Bashir, F. Ahmad, T. Y. Lee, M. Shah, and M. Awang, “Potential Cost Savings Analysis of Building Information Modelling-Enabled Clash Detection,” Journal of Construction in Developing Countries, vol. 30, pp. 199–219, Jan. 2025, doi: 10.21315/jcdc.2025.30.1.8.
[17] R. B. Johnson and L. Christensen, Educational Research: Quantitative, Qualitative, and Mixed Approaches. SAGE Publications, 2020.
[18] L. Cao, M. F. Shamsudin, and A. A. Hassim, “Understanding the Key Types of Quantitative Research and Their Impact,” Journal of Postgraduate Current Business Research, vol. 9, no. 1, Art. no. 1, Sep. 2024.
[19] I. Etikan, “Sampling and Sampling Methods,” BBIJ, vol. 5, no. 6, May 2017, doi: 10.15406/bbij.2017.05.00149.
[20] Z. Irani and D. Edwards, “A Rework Reduction Model for Construction Projects,” Engineering Management, IEEE Transactions on, vol. 51, pp. 426–440, Nov. 2004, doi: 10.1109/TEM.2004.835092.