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Errors and Omissions in Concrete Structures Technology Solutions

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Concrete is an indispensable material in contemporary construction, used for various elements such as foundations, columns, beams, and slabs. Construction and design phases are prone to errors and omissions, which can lead to a wide range of negative consequences, resulting in delays, increased costs, compromised structural stability, and safety hazards. A significant part of the construction industry's efforts is directed toward enhancing efficiency and mitigating such issues. This study aims to identify errors and omissions in concrete structures and assess technologies and techniques that have the potential to prevent these issues. This study uses a three-phased qualitative content analysis and found the top three categories associated with concrete errors and omissions were: "Design- related, Formwork installation and execution, and Defective formwork and structural," which encompassed 70% of the identified problems. In addition, the research identified that the majority of the solutions identified could be identified as the theme of "Technological Tools."

Key Words: Concrete, Construction, Errors, Omissions, Problems, Formwork, Falsework, Shores Construction, Formwork

Introduction

The construction industry is crucial in shaping our world by building structures and infrastructure that cater to society's needs. Further, concrete is extensively used across multiple construction project types (Guo, 2021), and concrete slabs are a vital element in construction, providing stable foundations for various structures (PHRC, 2013). From the material design perspective, concrete has evolved significantly and has undergone a "transition from the allowable-stress design method, limit-state design method, to the performance-based design method in response to the evolution of materials, sophistication of experimental facilities, and advancement of computation skills" (Sakai et al., 2016). From the construction perspective, concrete is typically used using one of two methods: precast or cast-in-place.

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Precast concrete is cast in a factory or controlled setting and transported to the site for assembly. Meanwhile, cast-in- place concrete is poured into forms at the construction site. Both types have been adopted globally, and various factors dictate the implementation of one over the other. However, errors and omissions can take place during the design and/or construction phases:

- Errors and omissions during design occur due to human error, inadequate knowledge of concrete technology, or failure to follow design codes and standards.
- Errors and omissions during construction occur due to poor workmanship, improper materials handling, or inadequate quality control.

Historically, onsite errors are a part of the construction process, and the construction industry often spends a significant amount of time and money on rectifying mistakes. Accurate and timely monitoring of onsite construction operations is important for identifying project-specific issues and enabling practitioners to make project control decisions quickly and easily. However, current practices are still prone to errors and can be both time-consuming and costly (Yang et al., 2015). Redoing tasks that were not done correctly initially slows down projects and incurs extra costs. Further, a reduction in rework can enhance the safety performance. Therefore, given the tangible and intangible benefits of ensuring that concrete cast in place is devoid of errors, this research explores the literature regarding errors and omissions in concrete structures and assesses technologies and techniques that have historically been recommended to prevent the issues.

Literature Review

Numerous factors, such as poor working conditions, lack of knowledge, miscommunication, and others can cause concrete member and associated system errors and omissions. According to a survey of reported failures in concrete buildings under construction, almost half of the building's falsework failures were caused by deficiencies in regular vertical shores. One out of every two falsework collapses was also due to inadequate lateral bracing (Mosallam & Chen, 1990). The primary cause of these critical defects is human error (Baiburin, 2017). Most of the errors attributed to humans can be divided into unintentional and intentional.

- Unintentionally: includes human activities such as misreading a measurement or bumping a switch categorized (Rooney et al., 2002).
- Intentional: actions committed or omitted by workers who believe their actions are correct or better than prescribed (Rooney et al., 2002).

Human errors and omissions can arise from a multitude of factors, including working conditions, lack of knowledge, negligence, miscommunication, miscalculations, and financial constraints. These errors and omissions are often identified at a later project stage, requiring expensive revisions (Eden et al., 2000), and can impact project schedule, budget, and stakeholder profitability. Furthermore, minimizing errors and rework associated with the rework can improve safety, as construction projects show rework contributes to safety incidents (Love et al., 2018). These errors and omissions occur within the limits of current engineering knowledge (Galvão et al., 2021). At the same time, the holistic use of technologies such as Building Information Modeling (BIM) and augmented reality (AR) has the potential to reduce some of these errors with concrete.

Building Information Modelling (BIM) adoption and implementation across all project stages facilitates numerous benefits in numerous areas, including error detection and communication of errors, thereby reducing the likelihood of escalation (Wong & Fan, 2013). Further, the US construction industry has transitioned towards the implementation of BIM across multiple stakeholders (Fountain & Langar, 2018) (Langar & Pearce, 2014), which can potentially enhance communication and reduce errors. At the same time, some project stakeholders may lack the necessary skills and experience to deliver the required level of detail, leading to increased errors (Love et al., 2018).

Augmented Reality (AR) has been increasingly integrated with BIM in the Architecture, Engineering, Construction, and Operations (AECO) industry. The integration of AR and BIM offers a host of advantages, including enhanced visualization of construction sites and more efficient management of construction processes (Machado & Vilela, 2020). AR enhances BIM's visualization capabilities, which have been observed to be adopted by most stakeholders (Langar & Pearce, 2017), (Fountain & Langar, 2018) and can facilitate enhancing onsite accuracy.

Augmented Reality (AR) integrates the virtual and real world and enhances the real world by overlaying additional virtual information (Fuge et al., 2012). Numerous devices such as AR glasses, smartphones, tablets, and HoloLens facilitate the use of AR technology. AR has the potential to revolutionize onsite construction by providing various applications, such as improving communication and collaboration, enhancing project monitoring and documentation, and reducing risks throughout the construction process (Sivanesan et al., 2021). For example, improving the digital fabrication process using onsite visual holographic technology 3D provides contextual, scaled, and tangible descriptions of intuitive targets for onsite projects, unlike traditional 2D drawings (Song et al., 2021). AR can also reduce training time and mastery time by utilizing its powerful educational potential (Gudoniene & Rutkauskiene, 2019). The impact of integrating AR on error reduction has been a subject of growing interest. AR's real-time guidance and information overlay aims to enhance quality control, reduce errors, and improve the efficiency of construction processes (Kwon et al., 2014; Park et al., 2013). Across numerous project types, studies have consistently indicated that AR- assisted tasks reduce errors and improve task completion times.

Given that AR facilitates the integration of information into the real world that enhances the visualization capabilities and the project's cognition, resulting in reduced errors, improved safety, increased productivity, and others, the research aims to identify errors and omissions in concrete structures and assess technologies and techniques that have the potential to prevent these issues.

Methodology

The research used a content analysis method because it allows the performance of purely qualitative analysis to quantitative analysis. Content qualitative analyses are often used in grounded theorizing and case-based research to reduce interview data into theoretically meaningful categories (Reger & Kincaid, 2021). Content qualitative analysis involves collecting and analyzing textual data and provides an opportunity to gain a deeper understanding of a phenomenon, group, or impact (Sulbaran et al. Forthcoming). Thus, the qualitative content analysis for this research was spread over three phases to determine what errors or problems were encountered during Formwork and what techniques and technologies contribute to or address these issues. (Figure 1).

- Phase I – Establish Research Parameters: The first step, identifying the unit of analysis, was the errors and omissions in the concrete structures. The next step in this phase involved the selection of filters and keywords. The filters included the purposive selection of search platform, publication language (English in this case), the relevance of the document to the research (based on the review of the article), publication period (last ten years 2013-2023), and full-text availability to the research team. Web of Science was purposively selected as the search platform for its ability to generate a comprehensive review of peer-reviewed publications related to the discipline (Clarivate, 2022) and access to the researchers. Further, in the first phase, the research team also identified keywords for the research and included five sets of keywords (Table 1).

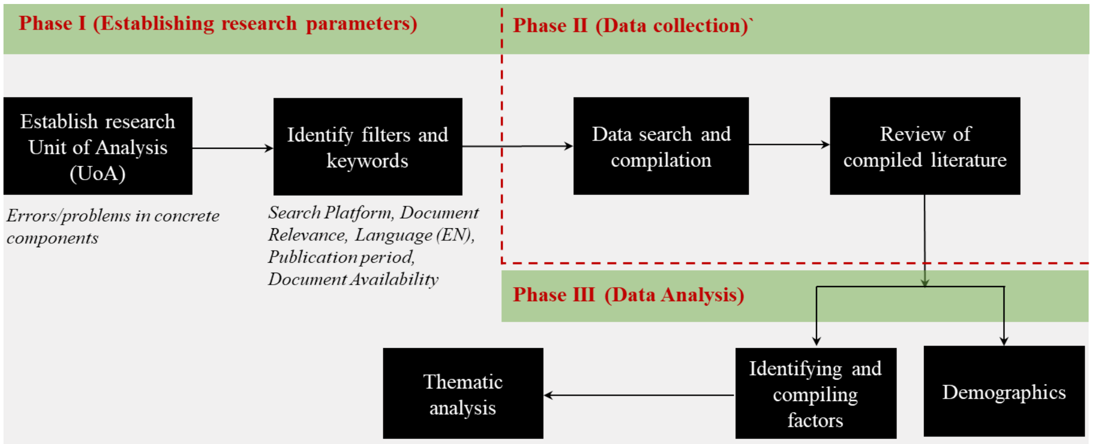

Figure 1. Phases of the Qualitative Content Analysis Method for this Research Table 1.

Table 1. Research search criterion.

Search Set Number	Search Set Criteria
1	All fields: *Concrete*; AND All Fields: *Construction*; AND All Fields: *Formwork*; AND All Fields: *Problems*
2	All fields: *Concrete*; AND All Fields: *Construction*; AND All Fields: *Formwork*; AND All Fields: *Errors.*
3	All fields: Concrete; AND All Fields: Construction; AND All Fields: Formwork; AND All Fields: Omissions
4	All Fields: *Construction*; AND All Fields: *Falsework*; AND All Fields: *Errors.*
5	All Fields: *Construction*; AND All Fields: *Shores*; AND All Fields: *Errors*.

- Phase II – Data Collection: The research team reviewed the literature based on the pre-established parameters (Phase I) and identified 123 peer-reviewed publications. The review of the compiled literature revealed that one research article emerged in multiple search sets, so the total number of identified publications using the five search sets was reduced to 122. All identified articles were downloaded and analyzed. The researchers also created a master spreadsheet to help apply the identified filters and determine the factors, Errors/problems, and technologies/techniques used to address these issues if mentioned. After the application of filters (publication language, article relevance, publication date, and document access) identified in the first phase, the final set of research articles analyzed for the research was reduced to 39.

- Phase III – Data Analysis: The researchers conducted a demographic analysis of the shortlisted publications to help identify publication types, their published areas, publication trends (dates), and others. In addition, the researchers also conducted a thematic analysis to identify the themes that emerged with error and omission types and the technologies used to solve them. Thematic analysis has been successfully used in research to identify hidden themes and has started to be used in the construction industry.

Result

About 30% (12) of the articles analyzed were peer-reviewed conferences, and 70% (28) were journal articles (Figure 1). The research also found interesting trends over the years, showing fluctuations in the recorded occurrences. Notably, there is a visible increase from 2014 to 2019, peaking in 2018, followed by a decline in 2020 and a subsequent rise in 2022 (Figure 2). The pandemic may have influenced the observed trends. The year 2020 saw a notable decrease in occurrences, which raises questions about its role in reducing the frequency of the events or incidents under consideration.

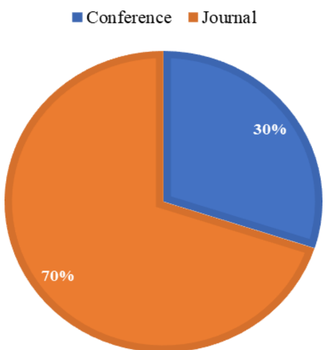

Figure 1: Study Demographics

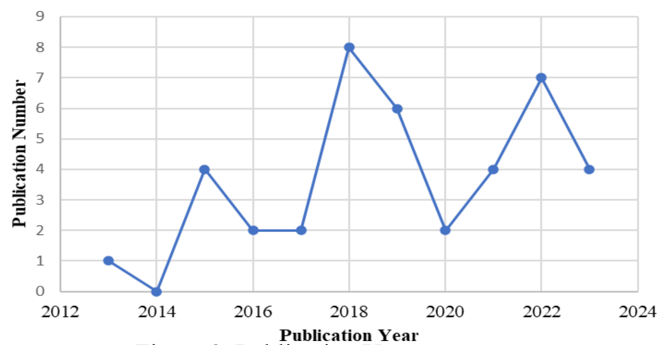

Figure 2: Publication Years

Based on the content analyses of the reviewed publications, fifteen issues related to design were identified, indicating significant challenges during the planning and design phase. The preparation of Formwork followed with five issues, highlighting the importance of meticulous preparation processes. Only 1 issue was reported regarding training-related concerns. Moderate challenges were identified in coordination and communication, with six issues. Formwork installation and execution presented 12 issues, emphasizing potential difficulties during the implementation phase. Equipment and material issues were relatively low, with only 2 and 1 issues, respectively. Defective framework and structural issues accounted for eight reported problems, suggesting a need for increased attention to quality control and structural integrity. This summary provides an overview of the varied challenges associated with different aspects of Formwork in construction, emphasizing the critical role of design and execution phases in ensuring successful outcomes.

The research team also conducted a thematic analysis of the solutions provided in the literature to solve the problems associated with errors and omissions with concrete. The researchers identified 24 distinct solutions based on the literature review that could be used to avoid errors and omissions (Table 1). Furthermore, the research team envisioned AR and BIM as significant strategies for the problems associated with concrete errors and omissions. However, very few publications did the same. Based on the analysis of the solutions identified in the literature, three thematic areas, "Optimization Modeling and Decision Support, Technological Tools, and Techniques and Materials," were identified (Table 2).

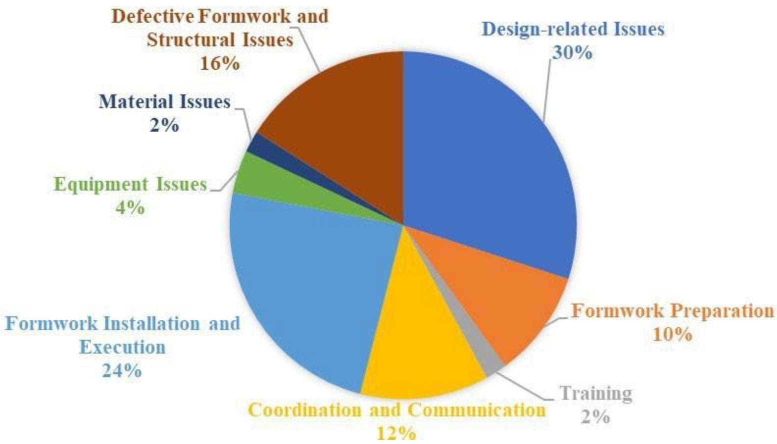

Figure 3: Distribution of Problems/Errors in Formwork in Construction

The "Technological Tools" theme identified 11 resources, including LINGO 14.0 Optimization Modeling Software, 3D scanning, BIM technology, RFID, and 3D printing, demonstrating various technologies used in formwork and construction projects. In the "Techniques and Materials" section, eight were highlighted, such as personalized Formwork with elastic membranes, aluminum formwork systems, and composite structures, showcasing innovative formwork design and construction approaches. Although "Technological Tools" encompassed most solutions (46%), as identified in Figure 4, the research did not identify AR as a potential solution to solve the problem with errors and omissions. Implementing AR on construction sites to solve the problems with errors and omissions of concrete can be paramount as it can overlay digital information on the real world, assist workers in visualizing design plans, identify potential issues, and provide real-time guidance, leading to significantly better outcomes with fewer errors.

Table 2. Themes for solutions

Overarching Themes	Repetition	Solutions based on the literature review
Optimizat ion Modeling and Decision Support	5	LINGO 14.0 Optimization Modeling Software
		Microsoft Excel Solver Tool for building optimization models
		Data analysis techniques for formwork selection in const. projects
		Decision support systems for formwork selection
		Mathematical model of the decision problem using classifier ensembles
nological Tools	11	3D scanning for Formwork
		SAP2000 software for understanding the effects of Formwork loads on exterior girders rotation
		BIM technology
		RFID (Radio Frequency Identification) Reader & tags in construction
		Smartphone Viewer Application for RFID and 3D models
		3D design technology and CNC shaping technology

		3D printing with Batiprint Fused Deposition Modeling (FDM) 3D-printed formworks Glass Fiber Reinforced Polymer (GFRP) & epoxy formwork 3D Printing
Techniques and Materials	8	Personalized formwork concept using elastic material membranes Composite structure combining tile vaulting and reinforced concrete Aluminum Formwork System (AFS) Pneumatic Formwork using inflatable structures Precast reinforced concrete shells Modular formwork systems development Development of a new composite system form (CSF): Composite (Aluminum + Magnesium) + steel + Film-coated plywood panel + rubber corner Composite structure: geotextile tubed SFRC

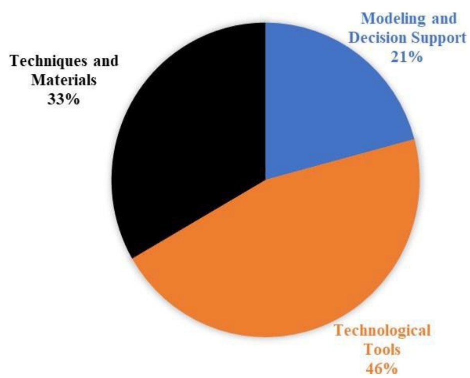

Figure 4. Technologies and Techniques in Formwork and Construction Projects

Conclusion

The research conducted a three-staged thematic analysis to identify errors and omissions in concrete structures and assess technologies and techniques that have historically been recommended to prevent the issues. Analysis of shortlisted literature on concrete errors and omissions indicates that the field is constantly evolving. Journal articles are the most common form of research, with fewer conference papers. In 2020, due to the COVID-19 pandemic, the trends observed emphasize the importance of further research to understand its impact on construction processes. The distribution of challenges in formwork processes underscores the need for careful planning and execution to achieve successful outcomes.

The construction industry is witnessing various advancements aimed at enhancing efficiency and quality in formwork and construction projects. This involves integrating diverse technological tools, innovative techniques, and materials into the construction process. Adopting innovative formwork technologies, such as polyurethane in air-supported fabric formwork, 3D printing, RFID technology, and BIM software, increases efficiency and sustainability in concrete construction. These solutions demonstrate a holistic integration of technologies being embraced to improve precision and effectiveness in formwork construction. Therefore, it is essential to keep up to date with the evolving technologies and methodologies to ensure successful formwork implementation in the constantly changing field of construction.

Future Work

The research identified limited use of BIM and AR to solve some of the issues with errors and omissions in concrete construction. One would assume that significant research exists that depicts the use of BIM and/or AR to solve issues with concrete errors. However, limited research exists. Therefore, one of the future research areas aims to determine how the Construction industry stakeholders have used BIM or AR to solve problems with concrete errors and omissions.

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