Development of an Innovative Automated Method for Identifying the Installation Sequence of Steel Structure Elements Using ETABS Model Information

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ABSTRACT

Accurate and detailed scheduling is a critical prerequisite for creating 4D models in construction projects. However, this process, heavily reliant on manual efforts, often results in a generalized and less-detailed schedule that ultimately fails to deliver the required accuracy and efficiency, potentially jeopardizing project success. This challenge becomes more pronounced with the increasing scale and complexity of projects, especially in steel structures, where the installation sequence of elements must be determined in a way that not only adheres to general installation rules but also ensures structural stability at all times. Despite the importance of this issue, the literature has paid limited and often fragmented attention to installation sequencing, leaving the process predominantly manual. To address this gap, this paper introduces an innovative automated method for identifying installation prerequisites and determining the optimal installation sequence for steel structure elements. The proposed method automatically extracts the necessary data from the ETABS model and, using a set of installation rules and real-time stability analysis, identifies the prerequisites for installing each element. The results demonstrate the success of the model in determining installation prerequisites for each element and, consequently, the installation sequence for the structure. Furthermore, the findings indicate that the proposed method, particularly in large-scale projects, not only improves the accuracy and speed of installation sequencing but also serves as a robust foundation for generating automated 4D models—an aspect that has been addressed to a limited extent in the existing literature.

KEYWORDS

Automation, Installation Sequence, Steel Structures, 4D Modeling, Building Information Modeling (BIM)

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1. Introduction

Construction projects increasingly demand precise scheduling, particularly for large-scale steel structures where complexity and scale challenge traditional planning approaches. Existing methods heavily depend on manual input, which hampers accuracy and increases inefficiencies. Moreover, ensuring structural stability during the installation process remains a critical challenge. Although Building Information Modeling (BIM) tools have facilitated advancements, limited attention has been given to automating detailed sequencing, leaving a significant research gap. This paper contributes to the field by proposing a novel automated methodology that integrates ETABS data and predefined installation rules to generate optimal sequences while preserving structural stability.

2. Methodology

The proposed methodology introduces an automated framework to determine the optimal installation sequence of steel structure elements. This framework leverages Building Information Modeling (BIM) data extracted from ETABS files and incorporates engineering rules to ensure structural stability during installation. The methodology includes the following steps:

- **Data Extraction from ETABS Models:** Automatically extract detailed structural information, including element geometry, connectivity, and load-bearing properties, from ETABS files. This data serves as the foundation for subsequent analyses.
- **Classification of Structural Elements:** Categorize elements based on their roles and properties, such as beams, columns, and bracings, to facilitate the prioritization of their installation.
- **Identification of Rigid Frames:** Analyze the structural model to identify rigid frames using Eulerian path algorithms. This step ensures efficient sequencing by recognizing interconnected elements that can be installed sequentially.
- **Adjacency Analysis:** Examine spatial relationships between elements to determine adjacency and interdependencies, which are crucial for accurate installation sequencing.
- **Application of Installation Precedence Rules:** Define and apply precedence rules based on structural stability and practical construction constraints. These rules are derived from engineering expertise and ensure that the installation sequence maintains stability at every stage.
- **Verification of Structural Stability:** Conduct moment-by-moment stability checks to guarantee that the structure remains stable during installation. This step ensures compliance with safety standards without overemphasizing the computational complexity of stability analysis.
- **Generation of Installation Sequence:** Combine the analyzed data and precedence rules to automatically generate an optimal installation sequence that aligns with structural stability requirements and practical constraints.

The methodology's automated approach reduces reliance on manual efforts, improves accuracy, and offers scalability for complex and large-scale steel structure projects.

3. Results and Discussion

The proposed methodology was implemented and tested on a 730-ton steel structure located in Tehran to evaluate its practical applicability and reliability. The automated framework effectively identified installation prerequisites and generated optimal sequencing for structural elements. The results demonstrated a significant improvement in scheduling precision and efficiency compared to traditional manual approaches. Specifically, the application of this method reduced the total project duration to 208 working days, emphasizing its potential to streamline construction timelines.

Figure 1 depicts the automated identification of installation prerequisites for various structural elements. The visual representation highlights how the methodology systematically classifies and organizes elements based on their dependencies and spatial relationships. This step ensures a clear understanding of the sequence required for stable and efficient installation.

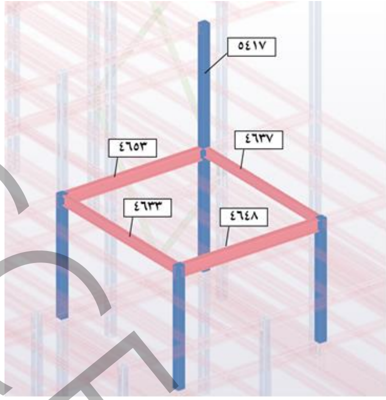

Figure 1. Element #5417 and its Installation Prerequisites in the 3D Space

Figure 2 presents the final installation sequence, integrating both precedence rules and stability checks. The sequencing not only adheres to engineering principles but also ensures structural stability at every stage of installation. The visualized sequence demonstrates how the method avoids potential conflicts and delays by accounting for all practical and structural constraints.

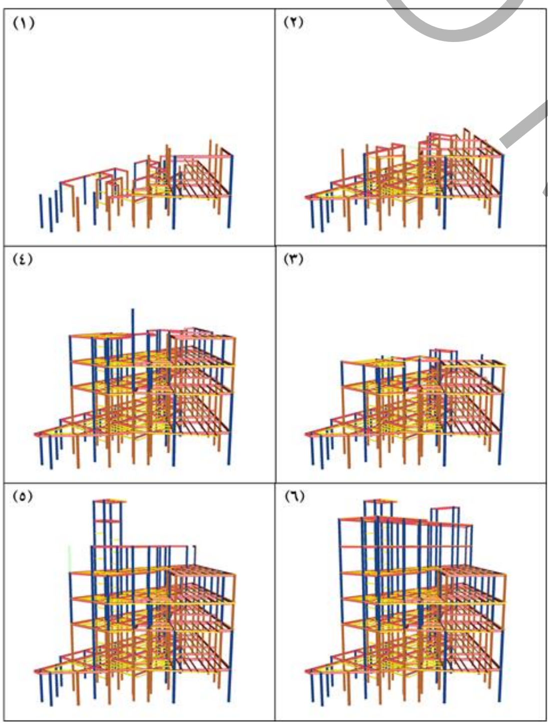

Figure 2. Snapshots of the Installation Sequence in the 4D Model

The automated approach's ability to maintain structural stability during installation is a critical advantage over traditional methods. By systematically incorporating stability analysis and sequencing rules, the methodology enhances project safety while optimizing resource allocation and scheduling accuracy. This combination of precision, safety, and efficiency underscores the value of the proposed framework, particularly for large-scale and complex steel structures.

4. Conclusion

This study introduces a robust framework for automating installation sequencing in steel structures, addressing challenges of manual processes and ensuring structural stability. The proposed method integrates ETABS data with advanced sequencing algorithms to optimize project planning and execution. Although the research demonstrates promising results, limitations include the unavailability of BIM models for some projects and the exclusion of hybrid or highly complex structures from analysis. Future work could expand the methodology to address these limitations and explore its application to diverse structural systems and larger datasets.

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