



Building Information Modeling enabled Cascading Formwork Management Tool



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ABSTRACT

Formwork systems are accountable for a significant share of the cost of reinforced concrete structures. The application of constructability principles to the design, selection and management of formwork systems in the preconstruction phase can significantly reduce the cost of reinforced concrete construction projects. Although many studies have developed tools and methodologies to automate the design and selection of formwork systems, few studies have explored the benefits of improving the process of managing formwork. The focus of this paper is on the use of BIM along with a cascading tool to maximize the return on formwork investment and improve the management of formwork. This paper presents an approach to utilize data drawn from the building information models coupled with a cascading algorithm to efficiently manage the formwork inventory on a construction project by generating a scheduled formwork reuse plan and calculating the minimum quantity of formwork required for the project. The paper discusses the use of BIM to extract data required for the cascading tool, working of the cascading algorithm and the development of the tool. The paper ends by presenting a case study where the developed tool was applied on a construction project in Cincinnati, Ohio and 13% savings in formwork material cost was reported.

1. Introduction

Building Information Modeling (BIM) is transforming the construction industry [1]. This transformation is a result of BIM's integration of project information to the 3D model, which provides more accurate data on building characteristics and specifications as compared to the traditional 2D Computer-Aided Design and Drafting (CADD) which is subject to workers' skill and is prone to error [2]. BIM can be used for a variety of construction applications including: (1) Quantity takeoff and cost estimation [3], (2) Inventory management [4], (3) Early identification of design errors through clash detections [5], (4) Construction planning and constructability analysis [6], (5) Onsite verification guidance and tracking of construction activities [4], (6) Offsite prefabrication and modularization [7], (7) Site planning [8], and (8) Better safety planning and management [9]. The paper makes the case that BIM can also be used for optimizing the use and management of formwork on reinforced concrete construction projects.

Formwork is a significant cost factor in reinforced concrete construction. Formwork can potentially account for as much as 15% of the total construction cost and 33% of the cost of the concrete structure

[10]. Disorganized management and handling of formwork systems can potentially result in an inefficient construction schedule and subsequently impact the total budget for construction.

On a typical formwork process, structural engineers design the concrete structure; concrete contractors then design the formwork by studying the shape and size of the concrete members. The contractors rely on their knowledge and experience to use the appropriate formwork materials and systems [11]. Once the formwork system is selected, the structure is divided into multiple phases of concrete pours. The number and size of phases depends on the availability of concrete, placing equipment and labor on site, limitations due to construction joints, cost of erecting and stripping forms and reuse and maintenance of forms between phases [12].

In many cases, even after the careful selection and planning of concrete phases, there is no formal strategy for optimizing the re-use of formwork between phases. When the formwork is taken off from concrete in one phase, it is usually taken to a temporary storage/inventory shelter on the site and may or may not be reused in another phase based on management's judgment and effectiveness. In this in-formal process, formwork is double handled and may be unnecessarily stored for long

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durations, which can damage the formwork, increase labor and crane hours, and result in overall poor formwork management [13].

To improve the formwork management process and optimize the reuse of formwork among construction phases, there is a need for a formal process that generates a scheduled formwork reuse plan based on the concreting phase schedule and calculates the minimum quantity of formwork required for the project. Such a formal process can minimize the time elapsed between the stripping and re-erection of forms without damaging them in the process [12]. This can also result in efficient use of material and reduce labor and equipment cost due to reduction of double handling of materials.

In this paper, we present a methodical approach to leverage data from a structural building information model and to use it with the cascading tool to generate a formwork schedule for the project and estimate the minimum formwork material quantity required, which can be reused throughout the project. This approach will improve the current un-automated practices on site and make the formwork management process more efficient. We anticipate that the research presented in this paper will help contractors and engineers optimize formwork management. The paper starts by reviewing previous research on formwork selection, design, management and BIM. The paper then discusses the methodology adopted including the use of BIM to extract the formwork material quantity take off data and project information from the building information models and the use of this extracted information with the developed cascading tool. The paper then presents a case study and compares results from the proposed process and current processes utilized by the concrete subcontractor of the case study project. The paper also discusses the potential benefits of the proposed approach, limitations and future research.

2. Literature review

The installation and disassembly of formwork, has a significant impact on the productivity of the concrete construction process as well as the productivity of other crafts such as mechanical, electrical, plumbing etc. [14]. Due to its significant impact on the overall construction process, the proper selection, management and planning of formwork system is critical for an economical and efficient construction. In this section, the background of research done in the field of formwork systems and BIM technology are discussed.

2.1. Management of formwork systems

Before the advent of sophisticated computer tools in construction engineering and management, the design, selection and management of formwork systems was a labor intensive, time consuming process that was considered more of an art than a science and relied on the construction engineer's design experience and engineering judgment [15]. With the emergence of computer applications in construction engineering, several researchers attempted to improve the formwork process by proposing methods to automate the formwork systems' design, selection and management process.

2.1.1. Formwork design and selection

One of the very early advances in the field of automating formwork design was made by Tah & Price [15]. They used computational analysis and data base management systems to develop a preliminary formwork design tool to assist experienced and inexperienced engineers. A reported limitation of this design tool was that it was intended to be used as a preliminary design tool and was considered inadequate for detailed designs. Hanna et al. [16] developed microcomputer-based expert systems to assist the formwork designers to select optimum formwork based on the expertise of formwork professionals. This tool utilized an expert system, which was developed by systematically capturing the expertise of people involved in all phases of the life of formwork from design, erection and concrete placement to

removal.

Other researchers used more complex approaches to optimize the formwork selection process, such as Artificial Neural Networks based expert systems to assist the process of vertical formwork selection [17] and horizontal formwork selection [18]. In addition, some studies suggested the use of probabilistic neural networks for the selection of vertical formwork systems [14]. Lee et al. [2] developed an automatic formwork layout tool using BIM based on a cost based formwork layout algorithm. However, a reported limitation of this study was its non-application on unconventional buildings. Elbeltagi et al. [19] used fuzzy logic for developing a model to assist formwork decision makers in selecting appropriate vertical formwork systems for construction projects with an average industry professional's satisfaction level of 77%. Shin et al. used Boosted Decision Trees (BDT) for the selection of formwork systems [20] and reported that the BDT performed better than the traditional process that relies on the experience and intuition of industry professionals. However, they also reported that the model was based on a rather small dataset and that a small number of projects were chosen to test the performance of the BDT, and they proposed a detailed examination of the quality of collected data set and its applications on tall building construction in order to utilize the model for actual buildings.

It is evident from the amount of research done towards the automation of design and selection of formwork systems, that scholars and researchers have realized the impact of formwork systems on construction. However in practice, in spite of the vast amount of previous research completed, the selection and design of formwork in the US still depends to a great degree on the subjective and intuitive opinions of the concrete subcontractor's supervisory personnel at the site [20], [19]. These opinions are affected by factors such as whether the formwork is owned by the contractor or rented, cost constraints, project's duration, contractor's experience and knowledge. Due to its dependency on human judgment, the result of the selection process may not be consistent, which adversely affects the cost and schedule of the project. This suggests that more work is needed for truly automating the formwork design and selection process.

2.1.2. Formwork planning and management

Previous research has predominantly emphasized selection of the formwork system and not formwork planning and management [21], [2] [22]. In order to increase formwork productivity and to control cost of formwork it is important to focus on formwork inventory management by optimizing the allocation of available resources and maximizing the return on formwork cost investment. Some studies have focused on constructability factors which influence formwork productivity and they concluded that management, repetition, standardization and consistency are the factors that impact formwork productivity, the most [23], [24]. Hurd [12] concluded that the sooner the formwork is stripped, the more economical and practical it becomes to schedule many reuses of formwork. In order to make a reinforced concrete project cost effective, it is crucial to use the formwork material economically and efficiently [25]. In other words, planning for maximum reuse of forms within the basic limitations of safety and quality of construction is one of the most important factors that lead to an economical project.

A predefined formwork repetitive reuse schedule can ensure maximum reuse of formwork systems and hence improve the productivity and cost effectiveness of the system. Although proper phase reuse and planning for the reuse schedule in concrete construction phases of the building is essential for a successful reuse of formwork [22], a limited amount of research has focused on repetitive use of formwork systems.

Huang et al. [21] used Cyclone to optimize the repetitive re-use of modular formwork systems on a high-rise building. They identified five formwork module reuse schemes including crane use and sharing. They defined a gang forming operation, which included different construction activities ranging from main flow of structural construction to steel

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