# Formwork System Selection in Building Construction Projects

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The formwork system (FWS) gives the geometry and strength required by the reinforced concrete (RC) structure to attain the desired form and structural design properties of the cured concrete.

Keywords: building construction project ; formwork system selection ; decision making

## 1. Introduction

The formwork system (FWS) gives the geometry and strength required by the reinforced concrete (RC) structure to attain the desired form and structural design properties of the cured concrete [1][2]. In addition, formwork-related activities such as erecting the FWS, placing the rebar, pouring the concrete, and stripping the FWS are performed continuously throughout the building construction project [3][4]. Therefore, the FWS can have significant effects on the construction project's time, cost, and quality performance [5][6][7][8]. In general, the FWS may account for up to two-thirds of the entire cost of the RC structural frame [9], and it can significantly affect the total duration of the project since it influences the floor cycle-time of building construction projects [10]. The planning and designing of the FWS can be a major challenge for construction professionals as they are both time-consuming and complex processes [11]. Moreover, the incorrect planning of the FWS may be a significant source of material and time waste in the later phases of the construction project [12]. Therefore, the selected FWS may also affect the sustainability performance of the RC building construction project [13]. In this regard, due to the high level of material waste in RC construction [14][15], the sustainability of the FWS has become an important factor in recent years [16].

The structural design and the selected FWS may affect an RC building construction project's constructability [17]. Revaluating the building's structural design in light of the available FWS alternatives may improve constructability and potentially lower the unit cost of the RC structure [18]. In other words, improving the constructability in RC building construction projects may depend on selecting the appropriate FWS [19]. Furthermore, formwork activities (e.g., erecting, stripping, or moving of the FWS) are considered especially dangerous for construction workers due to their association with a high level of construction accidents [20][21]. Hence, the FWS may also affect the safety performance of the RC building construction project. In building construction projects, labour productivity can be measured as a function of the floor cycle time of the FWS [22]. Since different FWS may have varying floor cycle times, labour productivity is another project performance factor affected by the selected FWS [23]. Consequently, selecting the appropriate FWS can save project costs and time, and it can be a critical component in successfully implementing an RC building construction project [8][24][25].

Since the early 1990s, several studies have been conducted to identify the FWS selection criteria and the FWS alternatives to solve the FWS selection problem [26]. The selection of the appropriate FWS depends on various compromising and conflicting criteria, some of which can be interdependent and interrelated [27]. Moreover, the widespread use of industrial FWSs (i.e., modular and reusable FWSs) and technical advancements in formwork engineering have led to the inclusion of new FWS selection criteria and new FWS alternatives for building construction projects [22][27][28]. Therefore, scholars and construction professionals have treated the FWS selection as a multi-criteria decision-making (MCDM) problem based on several FWS selection criteria and FWS alternatives, e.g., [29][30].

The FWS selection is a group decision-making process conducted by experts in the field of formwork engineering [1]. Therefore, consideration of the subjective judgments and the uncertainty in the collected data from these experts in the MCDM model may provide an improved and objective selection process [31]. Although previous studies greatly contribute to the FWS selection problem, they do not consider the subjectivity and uncertainty in the collected data from the decision-making team. The main objective of this research is not to develop a new MCDM methodology but to propose an integrated approach that employs the recently developed rough analytic hierarchy process (R-AHP) and rough evaluation based on distance from average solution (R-EDAS) methods to solve the FWS selection problem. Several studies have combined the AHP and EDAS methods to solve a specific selection problem, e.g., [32]. For instance, Stevic et al. [33] used an integrated fuzzy AHP-EDAS approach to evaluate suppliers in an uncertain environment. Similarly, Karatop et al. [34] utilized the fuzzy AHP and fuzzy EDAS methods to determine the best renewable energy alternative in Turkey. In addition, Toan et al. [35] combined the AHP and EDAS methods to evaluate video conferencing software alternatives and used grey numbers to integrate the subjective judgments of the experts in their case study. In this research's proposed approach, the subjective opinions of the experts are aggregated, and the uncertainty in the data is incorporated using the rough set theory and rough numbers. The R-AHP method is used to determine the rough weights of the FWS selection criteria, and the R-EDAS method is employed to evaluate and rank the FWS alternatives. In addition, a comparative analysis using other rough MCDM methods is proposed to ensure the stability and validity of the final rankings of the FWS alternatives. In order to illustrate the effectiveness of the proposed approach for the FWS selection problem, it was applied to a real-life building construction project in Turkey.

## 2. Formwork System Selection in Building Construction Projects

The selection of FWSs in building construction projects has been the focus of several studies from 1989 until 2022. The majority of these studies fall into two main categories: (1) studies that focus on identifying and/or ranking the quantitative and qualitative FWS selection criteria, e.g., [24][36], and (2) studies that propose solutions to select the most appropriate FWS, which is affected by various compromising and conflicting criteria, e.g., [10][37]. The studies related to the identification and/or ranking of FWS selection criteria have been summarized in a single body of knowledge in Terzioglu et al.'s [27] study, which is a critical review of the relevant literature for building construction projects. Since the main objective of this research is to propose an integrated MCDM approach for selecting FWSs, this section will focus mainly on studies that attempted to solve the FWS selection problem. Value engineering, knowledge-based guidelines, rule-based expert systems, neural networks (NNs), and several MCDM methods are among the proposed solutions for the FWS selection problem. The following is a brief review of these studies in chronological order:

Hanna and Sanvido [38] developed a knowledge-based systematic guideline, specifically for the contractor's formwork planner, to select vertical FWSs based on Hanna's factors and FWS alternatives [36]. In this research, five vertical FWS alternatives, including conventional FWS, ganged FWS, jump FWS, slip FWS, and self-raising FWS, were identified for building construction projects in the USA. Hanna et al. [26] presented a rule-based expert system to assist decision-makers and formwork design engineers in selecting vertical and horizontal FWS alternatives for building construction projects in the USA. This research considered traditional wood FWS, conventional metal FWS, flying truss FWS (i.e., Table FWS), column-mounted shoring FWS, and tunnel FWS as horizontal FWS alternatives. Kamarthi et al. [39] and Hanna and Senouci [40] proposed Neural Network (NN) models for the vertical and horizontal FWSs selection problem, respectively, using the previously identified factors and FWS alternatives. Abdel-Razek [41] utilized a value engineering approach to guide decision-makers in the FWS selection process for building construction projects. Elazouni et al. [42] proposed an integrated approach to estimate the acceptability of new horizontal FWSs (e.g., telescopic beam and prop FWS, telescopic beam and shore-brace FWS, shore-brace FWS, s-beam and prop FWS, drop-head FWS), by combining the Analytical Hierarchy Process (AHP) method with NN models. Based on previously developed NN models for the FWS selection problem, e.g., [40], Tam et al. [43] and Shin [44] introduced a probabilistic NN model and an artificial NN model, respectively, to select the most appropriate FWS. In Shin's [32] study, horizontal FWS alternatives such as aluminium panel FWS, conventional FWS, Table FWS, and drop-head FWS were identified as the most commonly utilized FWSs in Korea's high-rise building construction projects. Elbeltagi et al.'s [45] study for the selection of horizontal FWS (e.g., conventional FWS, Table FWS, shore-brace FWS, and drop-head FWS), and Elbeltagi et al.'s [29] study for the selection of vertical FWS (e.g., traditional FWS, panel FWS, single-sided FWS, crane-climbing FWS, and self-climbing FWS) both used a knowledge-based systematic guideline and fuzzy logic to determine the most appropriate FWS in building construction projects in Egypt. It should be noted that, in these studies, fuzzy logic was applied to convert linguistic input and output variables associated with FWS selection criteria and FWS alternatives, respectively, to their fuzzy forms. Shin et al. [10] employed a boosted decision tree (BDT) model to select horizontal FWSs in high-rise building construction projects in Korea, based on the most important FWS alternatives and factors affecting the FWS selection identified by Shin [44]. Several studies have proposed well-known MCDM methods to solve the FWS selection problem using experts' evaluations based on crisp numbers. For instance, Krawczyska-Piechna [46] proposed the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method to select the most appropriate FWS for building construction projects in Poland. Martinez et al. [47] proposed the Choosing by Advantages (CBA) method for the FWS selection problem in Ecuador. However, in these studies, information regarding the various types of FWS alternatives was not provided. Basu and Jha [37] applied the AHP method to solve the FWS selection problem in the Indian building construction sector, based on the FWS selection criteria identified by Hanna et al. [26]. Likewise, Hansen et al. [30]

employed the AHP method to select among two FWS alternatives (e.g., conventional FWS and aluminium FWS) based on Indonesia's most significant FWS selection criteria. Teja et al. [48] developed a fuzzy rule-based system to select vertical FWSs by combining fuzzy logic with the rule-based expert system introduced by Hanna et al. [26]. This research determined that traditional FWS, conventional FWS, panel FWS, crane-climbing FWS, self-climbing FWS, and plastic FWS are the most frequently utilized FWSs in the Indian building construction sector.

In summary, most studies addressing the FWS selection problem employed techniques such as rule-based expert systems, NNs, and other MCDM methods. However, no study has integrated the subjective judgments of the decision-makers into the FWS selection process or considered the vagueness in the collected data from the experts in their evaluation to select the most appropriate FWS. The FWS selection is a group decision-making process [29]. In addition, the early involvement of different stakeholder groups (e.g., the contractor and the formwork fabricator (FWF)) in the planning and design stages of the FWS may improve the time and the cost performance of a building construction project [49][50]. On the other hand, the perspectives and perceptions regarding the FWS alternatives and the importance level of FWS selection criteria of different construction professionals (i.e., experts in the decision-making team) may vary [51]. However, uncertainty arises when decision-makers have varying opinions on alternatives [52]. This might result from inadequate information or the different backgrounds of the decision-makers [52]. Therefore, the subjective judgments and the vagueness in data obtained from the experts should be considered when using MCDM methods for the FWS selection problem. In this regard, using the mathematical tools provided by uncertainty theories such as fuzzy set theory and rough set theory may improve the objectivity of the decision-making process [53][54]; in this case, for evaluating FWS alternatives. To the researchers' knowledge, no study involving MCDM methods to solve the FWS selection problem has incorporated uncertainty into the decision-making process.

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