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Methods for Modeling and Evaluating Construction Disputes: A Critical Review

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ABSTRACT Cost and time are the targeted outcomes of any successful construction project, and disputes over these two key factors constitute a major obstacle to successful project outcomes. As escalated levels of dispute are becoming increasingly unavoidable, the construction industry is aiming to develop dispute identification strategies to reduce and eliminate them during construction. However, existing research on construction disputes appears to give more consideration to dispute resolution than it does to avoiding conflict and preventing disputes from arising in the first place. This paper aims to minimize disputes during construction by addressing the causes of disputes during the pre-construction phase. As an integral part of ongoing research, it presents the results of a thorough study encompassing a critical review of previous research on construction disputes. Several conflicts and disputes are categorized and analyzed to allow for the future determination of their direct and/or indirect links to the pre-construction phase. This review also elaborates on the different methods of research adopted in the literature and the relevant research tools utilized. The research highlights the use of fuzzy logic coupled with structural equation modeling (SEM) as a recognized and valid modeling tool in construction projects, as it models and establishes an appropriate framework for dispute modeling and evaluation. The findings of this review therefore call for a further investigation of and deep research into the relationship between the characteristics of the pre-construction phase and the types of disputes and their likelihood of taking place during the construction phase itself. These findings can be utilized to develop an operational framework for predicting dispute occurrences during construction. The paper concludes by providing a developed hybrid fuzzy-SEM model to quantify the probability of dispute occurrence in construction projects, thereby enabling project stakeholders to predict, identify, and properly manage dispute occurrences during the pre-construction phase.

INDEX TERMS Dispute, construction projects, pre-construction phase, fuzzy logic, structural equation model (SEM), dispute resolution, hybrid.

I. INTRODUCTION

The construction industry has seldom been known to be complex and competitive in its inherent nature that considers and looks after the best interest for all its stakeholders, each from their own perspective seeking success and attainment of their goals [1]–[3], [4]. Due to the established levels of complexity among the different project stakeholders and the differences in views among the project contributors in what is usually a complex situation, conflicts are inevitable. Fenn [5] highlights that disputes in construction are unavoidable as the reasons for them are grounded in the intricacies of the industry's inherent functions. If conflicts and claims are not well handled, they ultimately become disputes. Much of the construction process literature contends in one way or another that the relationships between the parties in a construction project tend to be harsh and very often lead to conflict and litigation [1], [5]–[7].

Dispute are considered a key factor hindering the successful achievement of construction projects. They are also costly and time-consuming, and as such are of great concern to the industry. Thus, it is vital to have proper knowledge of the causes and effective management of disputes in order to complete construction projects within the stipulated time, budget, and quality [1], [3], [8]–[10], [11]. Studying the triggers of construction disputes is also essential for greater success in attaining construction project objectives [3], [8], [9], [12].

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While disputes are mostly foreseeable, their escalating frequency in the construction industry has led to a common interest of researchers worldwide in categorizing the generic aspects of conflicts, claims, and disputes, as well as their methods of resolution. [3], [8], [9], [12].

II. CONTRIBUTION TO THE BODY OF KNOWLEDGE

Many parties involved in construction projects are still unfamiliar with the methods and advances in evaluating construction disputes [13]. Meanwhile, some papers have attempted to review the issue of disputes [13]–[15]. However, there is a gap in this existing knowledge, as disputes are rarely addressed coherently and no ground rules or common approaches have been used to identify, evaluate, and address disputes. Also, as this review illustrates, disputes are predominantly identified and managed during the construction phase and rarely during the pre-construction phase.

Therefore, in order to enhance industry knowledge and collectively assess construction dispute causation and methods in a comprehensive manner, this paper attempts to critically review disputes and how the literature has approached this topic. It starts by giving a definition of disputes, as provided in the literature, then outlines how to evaluate the causes and the places in which disputes occur as well as the methods used to identify disputes as early as possible in any construction project. This paper concludes by proposing a preliminary step-by-step guideline for developing a framework and an associated dispute hybrid model to address the likelihood of disputes and assign them to their corresponding pre-construction phase where they originte. This proposed hybrid model attempts to cover the aforementioned gap in the existing knowledge. In the discussion section of this paper, the theoretical contribution of the proposed hybrid model is discussed in thorough detail to showcase the contribution of this paper to the body of knowledge.

III. REVIEW APPROACH AND METHODOLOGY

A review of the earlier relevant literature is a key part of any scholarly contribution to the body of knowledge [9]. A critical and comprehensive review of current and past research on construction disputes builds a sound fundamental knowledge base and offers strong insights for knowledge advancement in this area. As this critical review aids the process of conceptual and theoretical development regarding disputes, it identifies what areas of the topic have been covered, recognizes what previous research has contributed to knowledge advancement, and ultimately helps to identify possible future research needs to constructively contribute to the body of knowledge on disputes in the construction industry. Thus, it is possible to avoid repetition. For this review, the adapted methodology aims to present and evaluate the most relevant information found in articles, highly regarded journal publications, books, conference proceedings, and master's and Ph.D. theses and dissertations published between 1991 and 2020. This is done in order to critically summarize and evaluate the ideas and information presented in the literature as well as to obtain comprehensive knowledge and coverage of disputes and the previously used methods to identify, evaluate, and manage their occurrence and likelihood in construction projects.

This paper will therefore cover the sources of disputes as presented in the literature as well as the methods of identifying and evaluating disputes and their likelihood of occurring globally from the 1990s until the present. This represents an attempt to reflect on the research that has been done on disputes, assess it in terms of sources, findings, and methods, and ultimately propose a step-by-step framework and model to produce a newly developed assessment tool with which to evaluate disputes in a more proactive manner.

IV. DISPUTES DEFINITION IN THE LITERATURE

Disputes are mentioned in literature either distinctively from or synonymously with the terms conflicts and claims. As explained in [16], conflict occurs occurs when the same situation is seen differently by two parties. Conflict can also be defined as different objectives and attitudes held by several different parties [17]. Conflict is also defined by [18] as a "serious disagreement and agreement about something important." According to [19], conflict is as "an expressed struggle between at least two independent parties who perceive incompatible goals, scare resources, and interference from others achieving those goals," while [20] asserts that disagreement or a discrepancy of views and beliefs leads to conflict. A claim, in the literature, is defined by [21] as "an assertion of a right to money, property or a remedy," which he says in construction includes "extension of time." Likewise, [22] defines a claim as "a request for compensation for damages incurred by any party to a contract." Conflict management is therefore the process of identifying and addressing differences that, if left unresolved, could affect the project objectives [17].

As discussed by [13], a dispute is defined in the Oxford Dictionary as "Question[ing] the truth or validity of (a statement or fact), an argument, a disagreement between management and employees that leads to industrial action". Disputes are also defined as "any contract question or controversy that must be settled beyond the job site management" [23].

Specifically within the construction industry, [9], [20], and [24] describe disputes as situations in which a claim or assertion made by one party is rejected by the other party and the rejection is not accepted in return. The interrelationships between conflicts, claims, and disputes are shown in Figure. 1. As this figure illustrates, non-conflict issues can also cause claims and turn into disputes.

It is also worth noting that submitting and rejecting a claim leads to the initial evolvement of a dispute. Therefore, a claim is considered to be a request for reimbursement for losses and a dispute is seen as a consequence of a claim refusal or rejection by construction project parties.

V. SOURCES AND CAUSES OF DISPUTE

Research calls for mechanisms, strategies, and corresponding models to prevent disputes from arising or to reduce their

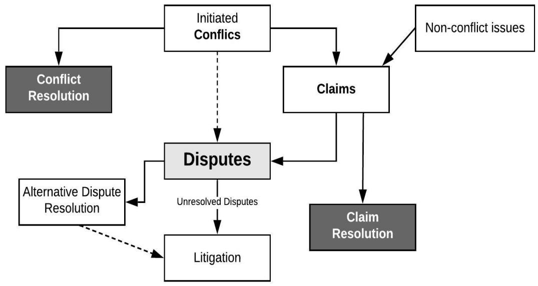

FIGURE 1. Conflicts, claims, and disputes (adapted from [24]).

occurrence in construction projects. Therefore, an understanding of the root conditions and causes of disputes must first be attained [5], [25]. A considerable number of studies (e.g. [6], [22], [24], [26]–[29]) have gone into substantial depth in order to determine the causes of construction disputes, their root sources, and the most appropriate dispute resolution processes or adapted models to minimize and resolve them.

Most of these research efforts advocate the early settlement of disputes to avoid time and monetary losses. However, according to survey findings in the literature, both dispute management and the application of the necessary framework for it take place either mostly or exclusively during the construction process.'' and not before that. This is notwithstanding the fact that early intervention can take place during the early stages of the pre-construction phase, as identified by [30], if the appropriate link has been established between that phase and the cause of the dispute.

When discussing the pre-construction stage, it is important to note that as discussed by [31], it includes several phases: the planning (pre-design) phase; design phase; and tendering and award phase. For the purpose of this review, the period preceding the construction phase is considered as the pre-construction phase, during which early intervention can limit and reduce the occurrence of later disputes.

Returning to the research into dispute causes, some of the reviewed studies only identified very limited categories or ignored some important groups in disputes, as [32] explains. Hence, there are few common ground rules to use in categorizing disputes, nor has a clear link been established between these dispute causes and the distinct project phases (mainly the pre-construction phase). While similarities exist within different studies, there is a significant level of uncertainty and contradiction with respect to the operationalization and meaning of the constructs within the literature on disputes [32]. To resolve this uncertainty, [33] suggests that the issues in a dispute must be unambiguously identified in all submitted claims. Their study employed two approaches, namely, the subject-matter approach and the diagnostic approach. The subject-matter approach is the most widely used; however, it does not capture the relative aspects of disputes. To cover this shortcoming, the authors also adopt a diagnostic approach, then propose a construction dispute structure created by integrating these two approaches. A different approach is taken by [33], who argues that construction disputes can be either contractual or speculative. The incompleteness of construction contracts is the common factor in both types, while task factors and people factors, respectively, distinguish contractual from speculative disputes (Fig. 2).

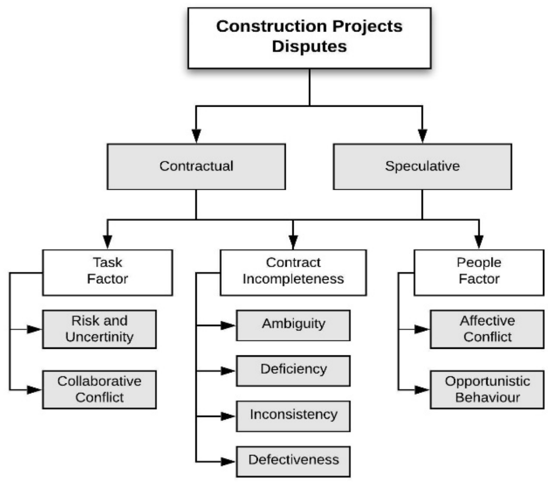

FIGURE 2. Conflicts, claims, and disputes (adapted from [33]).

Using a questionnaire survey performed on 61 projects in Hong Kong, [24] provides an effective review of disputes in construction projects, which identifies the common root causes as well as the immediate (proximate) causes. These causes can be identified or classified as subject matter dispute causes. Root causes recognized by [24] include client lack of information and decisiveness, inappropriate contract type, unclear risk allocation, unrealistic tender pricing, and unrealistic information expectations. The identified immediate or proximate causes included weak communication, inadequate briefs, erroneous design data, error in design documents, wear or slow client responses, inappropriate contract form, and inappropriate contractor selection. This study confirmed the need for further research to isolate the real source causes of preventable claims and disputes. Figure 3 provides a list of root and proximate causes of disputes.

As stated by [24], many of the root causes of disputes can be mitigated using various project management strategies and associated tools and techniques, particularly during the pre-construction phase. For example, errors in design documents can be minimized using design checks and audits. Errors in design and contractual documentation were also highlighted in this study and can be managed during pre-construction phase.

In a study of construction and infrastructure projects in Australia, [34] recognized nine key issues in disputes: scope variations, contractual clause interpretation, extension of time claims, site conditions, obtaining approvals, access to the site, design quality, late or incomplete information, and resource availability.

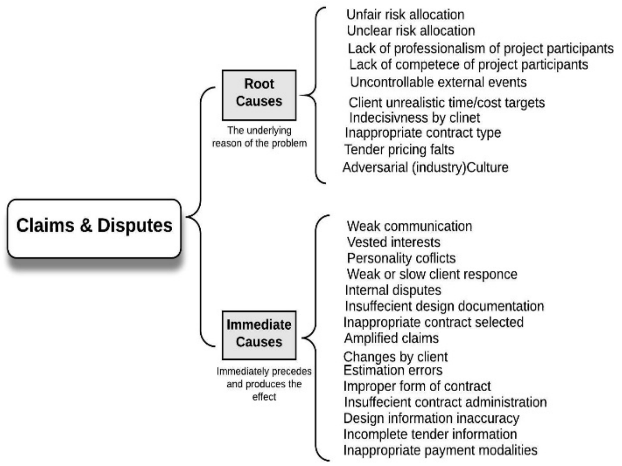

FIGURE 3. Root and immediate causes of disputes (adapted from [24]).

A study of disputes by [16] discussed the origins of different disputes and identified nine main categories. Disputes originated with management, the owner, the contractor, the nature of work, the work quality, the insurances and guarantees submitted by the contractor, site status, safety issues, the sub-contractors, and finally the workers.

A different categorization is offered by [35], who suggested that construction disputes can be classified based on three basic components, namely contract provisions, triggering events, and conflict.

An even simpler categorization is provided by [36], who recognized 33 dispute causes in the literature and congregated them under two categories: construction-related (24 causes) and human behavior-related (9 causes). Based on a questionnaire survey, the authors ranked the identified sources according to their importance and determined that the most significant sources in the human behavior category include parties' expectations and inter-party problems, and the construction category they include variation and delay in work progress.

In the UK, [28] evaluated claims and disputes through a survey of 28 quantity surveyors and 5 case studies. They concluded that disputes can be categorized into seven main types: contractual conditions, payments, variations to work, EOT, nomination, re-nomination, and information availability.

In a study of residential buildings performed by [37], the author recognized common direct and indirect (micro- and macro-level) dispute causes. A questionnaire survey of 120 contractors was conducted to evaluate the severity of 29 direct and 32 indirect causes. The analysis resulted in a determination of the top five. The top five direct dispute causes were owner progress payment delay, unrealistic contract period, change orders, poor work quality, and labor inefficiencies. The top five indirect dispute causes were inadequate experience of contractor, absence of proper communication between contract parties, contractor's ineffective planning and scheduling of projects, cash problems during construction, and poor estimation practices.

In a study of 24 construction projects and associated disputes in Canada, [22] determined six mutual dispute categories: premium time, equipment costs, financing costs, revenue loss, productivity loss, and site overhead. Another, similar study of 21 projects and 438 dispute events in the UK by [2] found disputes between construction parties to be mainly attributed to six causes: payment and budget, performance, delay in time, negligence, administration, and work quality.

In an effort to reveal the variables responsible for the occurrence of dispute problems, [38] named some of these variables as being related to the owner, the contractor, the consultant, a third party, and human behavior, or found that they were design- and/or contract-related. The authors concluded that management of such variables will lead to better and more efficient project completion.

In their extensive review of construction disputes, [39] conducted a preliminary examination of 20 projects, including semi-structured interviews with 50 various project participants, from which they recognized a set of dispute sources. The top 10 sources included poorly addressing the impact or effect of changes related to time and cost, EOT, escalation in price, payment failure in reference to contract conditions, suspension of work, defective work, tender evaluation, risk imposed by the contractor or owner, quality of work on-site, and hesitancy to pursue clarification of financial stability.

A study by [9] indicated that the main causes of disputes are non-completion, poor workmanship, EOT and loss and expense, lack of a proper contractual relationship, contract termination, design changes, work variation, construction manager employment issues, document clarifications, defects liability liquidated ascertained damages, and payment. In a study done by [3], the researchers classified dispute causes into seven categories based on their source or origin. These categories were related to the owner, the contractor, the design, the contract, human behavior, the project, and external factors. The study produced 28 different subcategories for the causes of dispute, and the authors recommended further examination. In their results, obtained using the Relative Importance Index (RII), "contractor-related disputes" had the highest relative importance value (0.301548). Design-related and contract-related disputes were rated second and third with values of 0.253987 and 0.259314, respectively. On the other hand, project-related and human behavior-related dispute causes scored the lowest RII, with values of 0.037032 and 0.026826, respectively. Yet while contractor-related disputes had the highest RII, the combined RII of contract- and design-related disputes is higher, at 0.51. Both contract- and design-related factors are both directly related to the pre-construction phase, indicating that the pre-construction phase plays a more significant role than the construction phase in dispute occurrence.

Table 1 summarizes the studies carried out over the past two decades to identify the causes of disputes in construction projects. This is a comprehensive list of examined studies and there is no level of commonality or comparison among them. Yet on the other hand, and as examined in this paper,

TABLE 1. Previous studies related to the causes of disputes in construction projects.

Author	Causes of Disputes
[22]	Six common categories of dispute: 1. Premium time 2. Equipment costs 3. Financing costs 4. Loss of revenue 5. Loss of productivity 6. Site overhead.
[28]	Five main categories of claims: 1. Extension of time 2. Variations in quantities 3. Variations in specifications 4. Drawing changes 5. Others. Seven main types of disputes: 1. Contract terms 2. Payments 3. Variations 4. Extensions of time 5. Nomination 6. Re-nomination 7. Availability of information.
[27]	Ten factors in the development of disputes: 1. Poor management 2. Adversarial culture 3. Poor communications 4. Inadequate design 5. Economic environment 6. Unrealistic tendering 7. Influence of lawyers 8. Unrealistic client expectations 9. Inadequate contract drafting 10. Poor workmanship.
[2]	Six areas: 1. Payment and budget 2. Performance 3. Delay and time 4. Negligence 5. Quality 6. Administration.
[40]	Poor design, change orders, weather, site conditions, late delivery, economic conditions, and increase in quantity.
[29]	Five primary causes of claims: 1. Unrealistic expectations by parties 2. Ambiguous contract documents 3. Poor communication between project participants 4. Lack of team spirit 5. Failure of participants to deal promptly with changes and unexpected outcomes.
[39]	10 factors most often leading to disputes: 1. Impact or effect of changes in respect to time and cost not properly addressed 2. Extension of time 3. Price escalation 4. Failure of payment as per condition of contract 5. Suspension of work 6. Defective work 7. Contractors' and employers' risk 8. Tender evaluation 9. Work quality 10. Reluctance to seek clarification of financial stability.
[38]	1. Owner-related 2. Contractor-related 3. Consultant-related 4. Third-party and human behavior-related 5. Design and contract-related.
[41]	1. Project management procedure: Change order, pre-award design review, pre-construction conference proceedings, and quality assurance 2. Design errors: errors in drawings and defective specifications 3. Contracting officer: Knowledge of local statues, faulty negotiation procedure, scheduling, bid review 4. Contracting practices: Contract familiarity/client contracting procedures 5. Site management: scheduling, project management procedures, quality control, and financial packages 6. Bid development errors: estimating error
[37]	The five most severe direct dispute causes: 1. Delay in progress payment by the owner 2. Unrealistic contract duration 3. Change orders 4. Poor quality of completed works and 5. Labor inefficiencies respectively. The five most severe indirect dispute causes: 1. Inadequate contractor experience 2. Lack of communication between construction parties 3. Ineffective planning and scheduling of project by contractor 4. Cash problems during construction 5. Poor estimation practices.
[42]	1. Variations to scope 2. Contract interpretation 3. EOT claims 4. Site conditions 5. Late, incomplete or substandard information 6. Obtaining approvals 7. Site access 8. Quality of design 9. Availability of resources.
[26]	Three root causes of disputes: 1. Conflict - Task interdependency differentiations, communication obstacles, tensions, personality traits 2. Triggering events - Nonperformance, payment, time 3. Contract Provision
[36]	Significant sources: 1. Construction-related: variation and delay in work progress 2. Human behavior-related: expectations and inter-party problems
[16]	Types of dispute under nine main categories of origin related to: 1. Management 2. Owner 3. Contractor 4. Nature of work 5. Quality of work 6. Insurances and guarantees submitted by the contractor 7. Site status 8. Safety issues 9. Sub-contractors 10. Workers.
[3]	Owner-related, contractor-related, design-related, contract-related, human behavior-related, project-related, and external factor-related
[24]	Root causes and proximate causes
[43]	Four sources of dispute: 1. Errors, defects, and omissions in the contract documents 2. Underestimating the real cost of the project in the beginning, 3. Changed conditions 4. Stakeholder involvement in the project.
[9]	1. Non-completion 2. Extension of time and loss and expense 3. Poor workmanship 4. No contractual relationship 5. Termination of contract 6. Variation 7. Employment of construction manager 8. Clarification of document 9. Design changes 10. Defects liability liquidated ascertained damages 11. Payment

one can attempt to to draw out a certain level of cohesion from these varied studies. The identified causes of disputes can be broadly categorized and subcategorized, which offers a common starting point for a more focused review, study, and evaluation of dispute causation.

Table 2 presents a summary of the literature reviewed in this study and the identified causes of construction disputes, adapted from the study done by [3]. This table can be further expanded to add more dispute subcategories under the designated categories.

VI. EARLY DISPUTE RESOLUTION AND AVOIDANCE

Much research on construction disputes focuses on resolution; that is, on what happens after the dispute has already taken place [9]. Although there is always a likelihood of conflicts and disputes occurring, it is still advantageous to identify imminent disputes as early as possible in any project phase. As the literature shows that it is cost- and time-intensive to resolve construction disputes, [44] suggested that knowing the conditions and dispute-related issues at the earliest possible time could to a great extent diminish the severity of claims and disputes.

In alignment with [44]'s claim, the American Arbitration Association (AAA) [45] manual presents a wide variety of early intervention and resolution methods. The manual also offers instruction for utilizing such methods at various stages of a construction project—from the early concept and design stages to on-site construction activities. This demonstrates that dispute prevention can start not only prior to construction but as early as the conceptual phase. The AAA manuals can be specifically tailored for a given project and can be used during all project phases.

TABLE 2. Categorized disputes in literature - adapted from [3].

Dispute Main and Subcategories		Authors	[17]	[22]	[23]	[24]	[2]	[19]	[38]	[41]	[39]	[31]	[40]	[21]	[11]	[7]	[3]	[32]	[34	[42]
A. Owner Related	A1	variations initiated by the owner			●			●				●	●		●	●	●	●		
	A2	change of scope			●	●		●	●						●	●	●	●		
	A3	late giving of possession						●									●			
	A4	acceleration						●									●			
	A5	unrealistic expectations		●		●		●		●				●		●	●	●		●
	A6	payment delays			●		●	●			●			●		●	●	●		●
B. Contractor Related	B1	delays in work progress			●		●	●	●			●			●		●	●		
	B2	time extensions	●		●			●					●		●	●	●		●	
	B3	financial failure of the contractor	●				●	●		●					●		●	●	●	
	B4	technical inadequacy of the contractor						●							●		●	●		
	B5	tendering		●				●			●				●		●	●	●	●
	B6	quality of works	●	●			●	●							●	●	●	●	●	●
C. Design Related	C1	design errors		●				●		●	●						●			●
	C2	inadequate / incomplete specifications						●			●						●			●
	C3	quality of design					●	●	●		●		●				●			●
	C4	availability of information			●			●					●				●			●
D. Contract Related	D1	ambiguities in contract documents			●	●		●	●	●	●					●	●		●	●
	D2	different interpretations of the contract provisions						●		●			●	●			●			●
	D3	risk allocation						●									●		●	●
	D4	other contractual problems		●	●		●	●							●	●	●	●		
E. Human Behaviour Related	E1	adversarial/controversial culture				●		●						●			●			●
	E2	lack of communication		●		●		●			●	●		●		●	●	●		●
	E3	lack of team spirit						●				●					●			●
F. Project Related	F1	site conditions						●	●				●		●		●			
	F2	unforeseen changes		●		●		●	●		●						●			
G. External Factors	G1	weather						●	●								●			
	G2	legal and economic factors		●				●	●								●			
	G3	fragmented structure of the sector						●									●			

These phases range from inception (early concepts through design and tender document preparation) through construction completion and project closeout. From this perspective, dispute prevention and resolution can start from a project's early inception, aiming to forestall and minimize potential litigation caused by disputes during the construction phase [45]. Furthermore, as [7] discusses, it is crucial to minimize and thus avoid litigation because litigation processes tend to be prolonged due to the insufficient experience and capability of the legal parties. Disputes are therefore a challenge to both the judicial process and to construction project stakeholders. Another argument for early intervention is that in observing the data gathered by this study thus far, one can see that many purported causes of claims and disputes result from activities occurring during the early planning, design, tendering, and award stages of project development, a stage that both [30] and [31] referred to as the pre-construction phase.

Looking at the different stages of a project from inception to completion (pre- and post-construction stages), provides a clear idea of not only the causes but also the phases during which each factor may contribute to disputes. This knowledge can facilitate early intervention for dispute resolution and a proactive dispute prevention strategy.

VII. DIFFERENT MODELING AND EVALUATION METHODS FOR DISPUTES AND DIFFERENT DISPUTE ELEMENTS

The most important and crucial part of a research study is a proper selection of methodology [46]. The body of knowledge and the available literature have identified various methodologies that have been adapted for use in construction management in general and in for disputes in particular. It has also identified relevant modeling and evaluation methods in dispute prediction that come from generalized study of this subject, as well as methods for evaluating the different elements of a dispute.

A. FUZZY SET THEORY AND FUZZY LOGIC IN DISPUTE MODELING AND EVALUATION

Over the past decade, "fuzzy techniques" have been widely used in the research area of construction engineering and management [47]. Fuzzy technique methodologies provide a viable tool for modeling subjective information, handling uncertainty where comprehensive data sets are not available for modeling. As explained by [47], the fuzzy set theory (FST) is a branch of modern mathematics introduced by [48] to model the vagueness intrinsic in human reasoning progression. Since then, fuzzy set theory has been used for complex problems that are not well defined due to the incomplete and inaccurate information that characterizes real systems [47]. The main role of fuzzy logic is quantifying the certainties and uncertainties of how much an element fits into a set. By employing fuzzy logic, it is possible to estimate system performance based on certain rules and in terms of the input variables. Fuzzy logic can be summed up in the following steps [40]–[47], [52]–[54]:

1) Fuzzification: The real variables are converted to linguistic variables using their attributes (fuzzy rules). For each real variable, there is a number of memberships that is equal to the number of attributes. In fuzzification, the crisp values of each variable are converted into a fuzzy variable.
2) Fuzzy inference: This defines the behavior of the system by applying the If/Then statement to the linguistic variables. The inference includes any combination

TABLE 3. Research on fuzzy set theory/fuzzy logic model in dispute-related and other similar construction projects topics.

AUTHOR (YEAR)	Fuzzy set theory/fuzzy logic model use in disputes modeling and construction-related studies
[55]	This was a study on the application of the fuzzy set theory on complex problems of building or facility satisfaction and productivity on a construction site. The study provided a basic framework for the utilization of the fuzzy set theory in the evaluation of construction risks
[56]	Described a system to test the concept of construction risk assessment by using linguistic variables. A limited number of risks were covered to allow for greater detail in the assessment; and the problems and benefits of linguistic variables were discussed
[57]	a fuzzy model was developed based on the knowledge extracted from practitioners in Hong Kong. The fuzzy system consists of four components: dispute identification, dispute analysis; dispute evaluation; and dispute control.
[35]	For the conceptualization of dispute, fault tree (FT) framework was used to evaluate system failures. a fuzzy FT model was employed by the authors to analyze the likelihood of construction disputes by using a hypothetical case.
[50]	Utilized fuzzy set theory for analyzing weather delay as a factor that causes litigation and disputes in projects was done by. First using a fuzzy logic model then by the selected delay analysis method (Time impact analysis) analyzed weather delays in construction projects.
[58]	Fuzzy sets approach was used to develop a likelihood evaluation system. The resulting Fuzzy Fault Tree model (FFT) graphically presents the antecedences and consequences of dispute artifacts. The proposed FFT dispute likelihood evaluation model provides an approach to identify the critical contributors that trigger construction disputes.
[53]	Identified the factors mostly affecting the construction cost in the construction industries in Tamil Nadu. The paper presented an application of fuzzy logic for developing cost overrun assessment model using and the model was validates using 4 case studies
[59]	Proposed a decision support tool for contractors before the bidding stage to quantify the probability of delay in construction projects in Turkey by using the relative importance index (RII) method incorporated into fuzzy logic.
[60]	This research is the extension of delay analysis techniques by using fuzzy logic method. In this study, the delay factors were ranked using Relative Important Index (RII) scale. The results derived from this model indicate a systematic and effective way for analyzing construction project delays.
[59]	Fuzzy set theory was used to provide strong and significant instruments for the measurement of ambiguities variables and provides the opportunity to meaningfully represented concepts. The validity of a proposed safety performance model, relationships between determinants of safety performance were analyzed in this study using the structural equation modeling (SEM). After validation of the model, a safety performance index assessment tool was developed.
[61]	The study presents a model for the evaluation of construction projects. The proposed model was based on a multi-criteria comparative analysis using fuzzy logic.

of the attributes of the input and output. This means that the inference phase determines the output of the system in terms of the linguistic variable by applying the IF/Then Rule. This kind of variable interaction provides a more flexible tool when dealing with such variables.

3) Fuzzy Rules: The rules are used for determining the system's overall performance. According to the determined fuzzy rules (elicited from expert judgment), a decision table should be formed to demonstrate the variables' effect on the topic under study. As indicated by [54], there are many fuzzy rule types that can be applied, yet the authors' Mamdani-style fuzzy rules have the advantage of being the most employed in the literature and are also intuitive, widely accepted, and well-suited to human feedback. On another level, fuzzy logic offers the possibility to modify the system's performance by adding new attributes for the real variables via their membership function and the corresponding rules without distracting the system. This flexibility is a pronounced benefit of using fuzzy logic. For example, by using project delay as an element in construction disputes, the probability of project delay occurrence can be computed in terms of the real input variables. This means that the probability of project delay is considered as an output variable (dependent variable). To return the output variable to its crisp value, defuzzification is employed.
4) Defuzzification: The attributes of the output variables are used to construct the rules for membership implementation. Then in the defuzzification phase, the output linguistic variable is converted into its crisp value and becomes a real variable. Figure 4 shows a generic illustration of a fuzzy logic system.

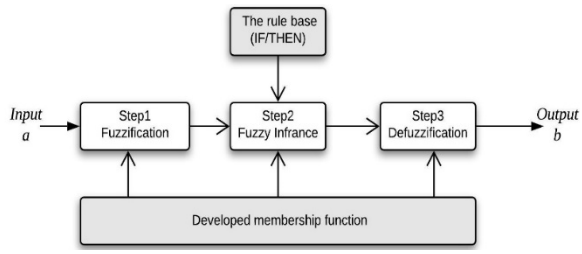

FIGURE 4. A fuzzy logic system (adapted from [53]).

Various authors have adapted several tools for modeling and evaluation of disputes. For instance, [35] adapted the fault tree (FT) framework to assess system failures for dispute conceptualization. The same authors also used a fuzzy FT model to analyze the probability of construction dispute occurrence in a hypothetical case.

In addition to disputes themselves, various elements of disputes have also been explored and their probability of occurrence assessed. Knowing that delay is one of the key elements in a dispute, [51] conducted a thorough study to quantify the probability of delay in construction projects in Turkey by utilizing the relative importance index (RII) method incorporated into fuzzy logic. In this study, the authors identified 83 delay factors and categorized them into 9 major clusters. An extensive literature review was conducted alongside interviews with experts from the construction industry. Table 3 provides a list of previous studies utilizing the fuzzy set theory/fuzzy logic to investigate construction projects and dispute-related topics and elements. As one can see based on this table, very few studies to date have utilized fuzzy set theory to model and evaluate disputes with an emphasis on their link to the design phase (pre-construction phase).

This review of fuzzy logic demonstrates that it can be used as an evaluation model because the performance of the system is a single value. In researching disputes, the output of fuzzy logic provides the probability of dispute occurrence; however, for a more conceptualized understanding of disputes, one must determine the weight of the real input variables and their impact on the probability of dispute. Hence, strong modeling, such as SEM, should be used because the literature perceives it to be a highly competent procedure [59], [62]–[64], [4]. This was further elaborated by [4], who applied the SEM approach to build a model that explained and identified the critical factors affecting infrastructure projects. Although fuzzy logic and SEM have been separately considered to have a pronounced application to construction project modeling, the literature has identified limited research into the use of fuzzy logic coupled with SEM for dispute modeling and evaluation.

B. STRUCTURAL EQUATION MODELING (SEM)

SEM, also known as the covariance structural model, is a multivariate analysis-based model that determines the latent variables that are unknown observable variables and determines the corresponding measurable indicators (errors) [4], [59], [62]–[64].

SEM studies the relationship between the latent variables and the measurement indicators, and it is considered a strong tool as it studies the relationship between the latent variables and determines the covariance between each pair of latent variables [59], [62]–[64]. Specifically, SEM provides the researcher with the flexibility to provide models for different relationships between multiple predictor and criterion variables, it allows for the construction of unobservable latent variables, it can model measurement errors for observed variables, and it can test theoretical and measurement assumptions against observed data [51], [52].

As discussed by [65], SEM represents a class of multivariate models that are utilized to determine a causal relationship between variables (exploratory modeling) or to investigate if a model is the most suitable for the data under study (confirmatory modeling).

In the study of disputes, SEM can be used to determine the relationship between the latent variables (non-observables) by plugging the probabilities of dispute causes, obtained using fuzzy logic, into the system as real variables. SEM can be used to determine a regression model for the dispute occurrence as an output variable in terms of the dispute causes as real variables [51], [52], [66], [67].

SEM-based procedures have considerable benefits over second-generation regression methods, such as principal components analysis, factor analysis, discriminant analysis, or multiple regression [51], [52]. SEM procedures also give researchers more flexibility to work with both real and

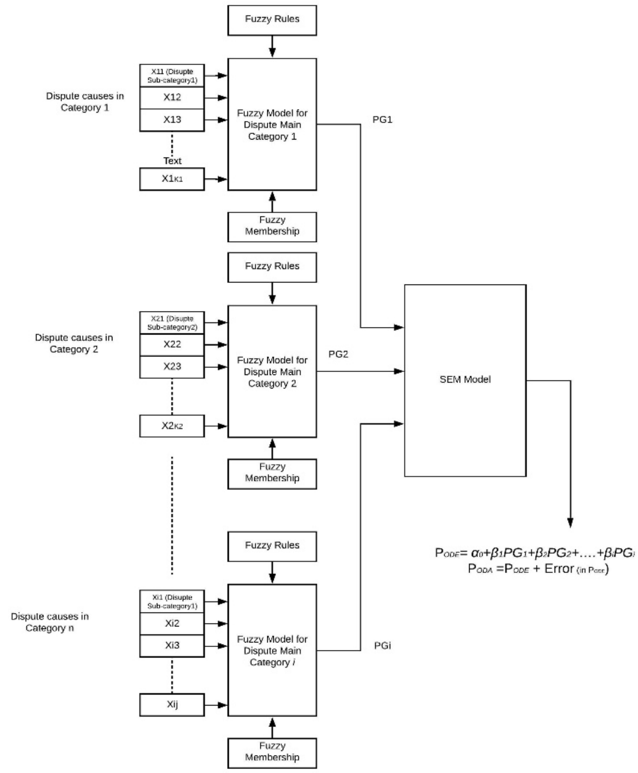

FIGURE 5. Hybrid fuzzy logic-SEM model for dispute probability evaluation.

theoretical data [59], [68], [65]. See Table 4 for examples from the literature in which SEM was utilized in disputes and in construction-related studies.

Most SEM analyses are done using a specialized SEM software program. The commonly used programs for SEM, in which multiple regression evaluation is performed in progressive phases, include LISREL, AMOS, DEPATH, EQS, Mplus, Mx, CALIS, and RAMONA [63], [67], [69].

VIII. DISCUSSION AND PROPOSED FRAMEWORK FOR DISPUTE EVALUATION BASED ON FUZZY LOGIC AND SEM

As this literature review demonstrates, some researchers have developed fuzzy logic models to evaluate the probability of disputes in construction projects, while other researchers have developed SEM models to evaluate construction-related topics and dispute occurrence based on multivariate covariance analysis and regression model development.

A few studies do combine both methods. Here we draw a preliminary framework for developing a new model to evaluate the dispute occurrence probability in traditional construction projects, a framework based on fuzzy logic incorporated with SEM. This study focuses on the dispute causes that can be addressed during the pre-construction phase of the project.

Figure 5 presents a block diagram illustrating the proposed hybrid fuzzy logic-SEM model. The following preliminary steps explain how the development of an operational

TABLE 4. SEM use in construction projects-related research.

Author (Year)	Examples of SEM use in construction projects-related research
[62]	In This research, a safety performance model was developed, validated, and the relationships between determinants of safety performance were analyzed using the structural equation modeling (SEM). After validation of the model, a safety performance index assessment was proposed.
[64]	Identify best practice relating to the effective management of materials in an urban, confined construction site, using structural equation modelling. Results analyzed using confirmatory factor analysis in the form of structural equation modelling.
[70]	Structural equation modelling (SEM) was utilized to decide the impact of internal stakeholders on project completion delay (PCD), which interpreted to the fact that influential factors related to internal stakeholders are capable of causing project completion delay
[71]	In a study to establish interdisciplinary linkages among knowledge areas of contracting, risk management, organizational behavior, and international EPC project delivery, the authors applied SEM to test the hypothesized relationships established in the conceptual model. Case studies were further used to validate and interpret the substantive meaning of the model
[15]	Review the importance of applying SEM for construction delay study.
[72]	In this study, A theoretical structural equation model representing the influence of four key latent variables on project delays in the Indian construction industry has been developed.
[73]	This study attempts to examine the relationship between the project cost and multiple influencing factors by using Bayesian SEM
[74]	A theoretical model demonstrated how construction resources affect cost overrun. The model is tested using structural equation modelling technique with Partial Least Square (PLS)
[75]	this paper presents the results of a structural equation model (SEM) for describing and quantifying the factors affecting contract disputes between owners and contractors in construction projects.
[76]	In this study, using the data from Turkish project in international markets employing structural equation modeling (SEM) techniques, risk paths were identified and the total effects of each vulnerability factor and risk path on cost overrun were assessed.
[77]	In this research, Structural equation modeling (SEM) of causes of delay in construction has been developed for describing and quantifying the influence of different causes. This study revealed that SEM is a strong tool for quantifying the relationships among investigated factors.

framework can be identified and a hybrid fuzzy logic-SEM model can be designed:

1- Construct a comprehensive categorized list of the main categories and subcategories of disputes based on the available literature and further literature synthesis as well as a review of more dispute causes, expanding on the current categories and subcategories of disputes as determined in this review and further literature to be reviewed. The resulting dispute subcategories are reordered in relation to the different stages of the pre-construction phase. This will form the basis for assessing pre-construction phase performance.
2- Determine the direct and indirect dispute categories and subcategories that result from the pre-construction phase.
3- Construct a fuzzy logic model coupled with the SEM-based procedure.
4- The main role of fuzzy logic is to determine the probability of dispute occurrences for each main category of dispute causes. Fuzzy logic considers the subcategories of dispute causes as real input variables. For each real variable, the attributes will be identified, and the corresponding memberships will be constructed; hence, the real variables are converted to linguistic variables.
5- For each main category, the IF/Then rules are applied to compute the probability of dispute occurrence as a function of the real input variable.
6- The fuzzy logic procedure is repeated for all dispute categories, and the corresponding dispute probabilities are computed.
7- The probabilities of dispute occurrence in all designated dispute categories obtained from the fuzzy logic are then plugged into the SEM model for factorization and path analysis.
8- The SEM model takes the dispute probabilities of the dispute groups as a real input variable. Then it converts them into a latent variable that is un-observable. The SEM also constructs measurable indicators for the latent variables.
9- The developed SEM model identifies the relationships among the latent variables, constructs a hypothesis, and performs a multivariate statistical analysis on these variables.
10- Finally, a regression model is developed by the SEM model to depict a relationship between the dispute occurrence as an overall system performance as a function of the real input variables.
11- It should be noted that the SEM model uses the latent variables and measurable indicators to bridge the overall system performance probabilities of the dispute cases' main categories. The overall output of the system should determine the weight of each dispute probability and its impact on the overall dispute occurrence probabilities in the pre-construction stage.

The hybrid fuzzy-SEM model uses the following notation:

X_{ij} = *Dispute subcategory j of dispute main category i where* $i = 1, 2, 3, \ldots, n$ *and* $j = 1, 2, 3, \ldots, k_i$

k_i = *Length of a subcategory for each dispute main category i*

P_{Gi} = *Probability of dispute occurrence resulting from dispute main category i after applying the fuzzy logic model.*

P_{ODE} = *The Estimated Overall Dispute probability of a project*.

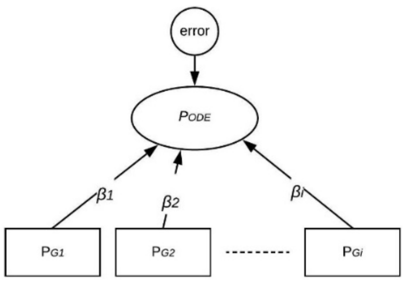

FIGURE 6. SEM model structure for predicting overall dispute probability.

From the above notations, it can be seen that the sizes of the main categories and corresponding subcategories vary according to the main category under study. For example, dispute main category 1 (owner-related) can have 6 dispute causes/subcategories, while main category 3 (design-related) has 4 dispute causes/subcategories. These subcategories can be further modified to include more subcategories as the next phase of research. Therefore, this designated subcategory length depends on each category and what it includes.

After the fuzzy logic model has been applied, the SEM model developed in this study is applied to predict the regression model for the overall dispute probability. Based on the dispute occurrence probabilities obtained from the main categories, the overall dispute probability is estimated and denoted as P_{ODE}. The estimated overall probability of dispute is given as a function of the probabilities of the main dispute categories. P_{ODE} is represented in the following equation:

$$P_{ODE} = \alpha_0 + \beta_1 P_{G1} + \beta_2 P_{G2} + \ldots + \beta_i P_{Gi}$$

where

$$\alpha_0 = \textit{intercept of the overall probability of disputes at the start of dispute causes}$$

and

$$\beta_i = \textit{the weight of dispute category } i.$$

However, SEM can compute the error in the estimated latent variables to investigate the validity of the model. Since the latent variables exhibit error, the estimated overall dispute probability has an error. This means that the actual overall dispute probability can be computed as a function of the estimated overall dispute probability and the error:

$$P_{ODA} = P_{ODE} + Error(inP_{ODE})$$

where P_{ODA} = the actual overall probability of dispute. The developed SEM model can be summarized as shown in Figure 6.

As Figures 5 and 6 show, this specifically designed hybrid fuzzy logic-SEM model is intended to predict the occurrence of disputes before they take place during construction. This hybrid model makes a strong theoretical contribution because it is based on the factual explanatory theory that disputes are likely to be prevented when addressed as early as possible in any project. Based on this theory, a general principle was developed by first identifying the dispute categories and subcategories while linking them to their relevant pre-construction phase. These categories and subcategories are the entries into the hybrid fuzzy logic-SEM model that can be employed to quantify the dispute likelihood in construction projects, thus enabling project stakeholders to proactively predict, identify, quantify, and properly manage the occurrence of disputes in advance during the pre-construction phase of their projects. This ultimately saves the expenditure of time and money—two of the most critical items in construction projects, and items that stakeholders seek to control—on disputes and resulting litigation. As such, a predictive model makes a valuable contribution to the field of construction disputes. However, this hybrid fuzzy logic-SEM model is not only applicable to a single dispute case or a specific project but rather has the merit and potential to serve as a general framework, providing insight into a wider class of phenomena related to dispute likelihood during the pre-construction phase of traditional construction projects, and this model can be considered theoretically robust.

IX. CONCLUSION AND FUTURE WORK

Disputes in construction projects are very common in the industry. In any project, then, dispute occurrence must be investigated thoroughly and as early as possible to evaluate the causes of dispute and link them to the pre-construction phase so that they can be reduced or eliminated before construction commences.

This paper therefore focuses on providing a critical review of disputes and publicizing the preliminary findings of the investigation. It covered sources of disputes as presented in the literature, including methods of identifying and evaluating disputes and their likelihood as well as the different tools used to assess construction disputes worldwide. Based on the findings of this review and the related discussion, a comprehensive dispute evaluation framework was developed by first developing a categorized list of main dispute categories and subcategories of disputes while considering their links or occurrences during the corresponding pre-construction phase. This paper then presented a model based on fuzzy logic incorporated with SEM (called the hybrid fuzzy logic-SEM model) that can evaluate the dispute occurrence likelihood in traditional construction projects. This model depicts a relationship between dispute occurrence as overall system performance and as a function of the real inpute variables. It makes a sound theoretical contribution because it is designed to potentially serve as a general framework for the study of dispute likelihood during the pre-construction phases of traditional construction projects.

Ultimately, the paper proposes that dispute modeling and evaluation can be conducted using a step-by-step framework and an associated hybrid fuzzy logic-SEM model. The outcome of the research is expected to provide a strong base for the future development of a detailed operational framework, and with proper programing, the hybrid fuzzy logic-SEM model could be applied to any traditional project worldwide. This will enable early dispute resolution and prevention before project construction starts, eventually targeting the proactive minimization or reduction of the rate of conflicts, disputes, and litigation occurrences in the construction industry, saving these projects time and cost and contributing to their ultimate success.

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