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Data-Driven Analysis Of Construction Bidding Stage-Related Causes Of Disputes

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Abstract: Construction bidding is a complex process that involves several potential risks and uncertainties for all the stakeholders involved. Such complexities, risks, and uncertainties, if uncontrolled, can lead to the rise of claims, conflicts, and disputes during the course of a project. Even though a substantial amount of knowledge has been acquired about construction disputes and their causation, there is a lack of research that examines the causes of disputes associated with the bidding phase of projects. This study addresses this knowledge gap within the context of infrastructure projects. In investigating and analyzing the causation of disputes related to the bidding stage, the authors implemented a multistep research methodology that incorporated data collection, network analysis (NA), spectral clustering, and association rule analysis (ARA). Based on a manual content analysis of 94 legal cases, the authors identified a comprehensive list of 27 causes of disputes associated with the bidding stage of infrastructure projects. The NA results indicated that the major common causes leading to disputes in infrastructure projects comprise inaccurate cost estimates, inappropriate tender documents, nonproper or untimely notification of errors in a submitted bid, nonproper or untimely notification of errors in tender documents, and noncompliance with Request for Proposals' (RFP) requirements. Upon categorizing and clustering the causes of disputes, the ARA results revealed that the most critical associations are related to differing site conditions, errors in submitted bids, unbalanced bidding, errors in cost estimates, and errors in tender documents. This study promotes an in-depth understanding of the causes of disputes associated with the bidding phase within the context of infrastructure projects, which should better enable the establishment of proactive plans and practices to control these causes as well as mitigate the occurrence of their associated disputes during project execution. **DOI: 10.1061/JMENEA.MEENG-5426.**

Introduction

Overview

The construction industry is considered a major contributor to the economic development of all nations. In the US, the construction industry represents about 7% of the total gross domestic product (GDP) (Fails Management Institute 2021). In 2021, the construction industry contributed $1,964.5 billion, approximately, which represented 4.7% of the overall US gross output (US Bureau of Economic Analysis 2022). Despite its major economic contributions, the construction industry is subject to various conflicts, claims, and disputes between contracting parties. Recently, the economic impacts of the COVID-19 pandemic as well as several political events have resulted in an increased number of claims, conflicts, and/or disputes within the construction industry, and will potentially continue to result in such issues in the future (Alsharef et al. 2021; Hanes 2022; Boyette 2022; Arcadis 2022). In fact, construction disputes can lead to unnecessary construction cost overruns, delays, and other related negative impacts (Kisi et al. 2020; Fenn et al. 1997). Globally, the average length of construction disputes is estimated to be 15.4 months with an average value of $52.6 million. In North America, the average length of construction disputes is estimated to be 16.7 months with an average value of $30.1 million (Arcadis 2022). Furthermore, the direct costs of construction disputes were estimated to vary between 0.5 to 5 percent of the total project cost (Love et al. 2010).

Such sizable monetary amounts and delays could be avoided or decreased by thoroughly investigating causation of disputes (Abdul Nabi and El-adaway 2022). Understanding the driving causes of disputes between the contracting parties is essential for the development of proactive measures toward an effective avoidance\reduction of the occurrence of disputes in construction projects (Kumar Viswanathan et al. 2020). Moreover, a study by Tanriverdi et al. (2021) investigated the causal mapping among causes of disputes to explore the emergence of construction disputes. It was found that the occurrence of construction disputes is typically not attributable to a single cause alone, but rather arises from a combination of various contributing factors/causes (Tanriverdi et al. 2021). That said, several research studies have studied the causation of disputes between different project stakeholders implementing different methodological approaches (Jahren and Dammeier 1990; Mitropoulos and Howell 2001). However, while a substantial amount of knowledge has been acquired about construction disputes and their causation, disputes continue to prevail and disrupt the construction process (Salami et al. 2023; Wang et al. 2022).

Research Need

Despite the valuable contributions of previous research on construction disputes, there is still a lack of research that examines

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the causes of disputes related to the bidding stage specifically and studies the associations among them. In fact, construction bidding is a complex process that involves several potential risks and uncertainties for all the stakeholders involved (Ahmed and El-adaway 2022). Such complexities, risks, and uncertainties, if uncontrolled, can lead to the rise of claims, conflicts, and disputes during the course a project, and large losses to involved construction firms. According to Finity (2022), construction businesses failed at nearly 1.5 times the rate of companies in other sectors over the last 10 years for various reasons including inaccurate bid decisions. In relation to that, Al-Tubayyeb (1989) and Ho and Liu (2004), among others, emphasized the strong tie between the bidding stage environment (i.e., bidding strategies, factors, uncertainties, and various related aspects) with the volume and magnitude of construction claims and disputes faced during the execution of the projects. Moreover, construction disputes are often being associated with the bidding process due to conflicting interests and differing interpretations of project requirements (Akintoye et al. 2003). Further, according to a study by Elsayegh et al. (2020), the underlying root cause of many construction disputes is often related to decisions made during the bidding stage of projects. Thus, it is crucial to examine the main causes of disputes related to bidding stage of construction projects and identify the critical associations that commonly lead to such disputes. This paper addresses this research need by exploring the causation of disputes related to the bidding stage and determining the critical associations among them.

In doing so, this paper would focus on bidding-related disputes within infrastructure projects because public infrastructure is a major component of the construction industry and is critical to every nation's socioeconomic progress. According to the US Bureau of Economic Analysis (2022), spending on public infrastructure reached over $353 billion in 2021. Moreover, the recent ASCE (2021) infrastructure report card highlighted that the total investment gap in infrastructure projects has increased from $2.1 trillion to about $2.59 trillion. In addressing this issue, the US president has signed into law a five-year, $1.2 trillion infrastructure bill. This infrastructure bill is considered the greatest investment, in nearly a century, in the US infrastructure (Zhang and Batjargal 2022). This sheds the light on the tremendous investments and the anticipated huge amounts of infrastructure projects that are needed for maintaining and expanding the deteriorating infrastructure assets. This should add to the bidding competitiveness between various contractors in the US construction market (Ahmed et al. 2022b).

In addition, given that the majority of infrastructure projects are being build using public funds, they are subject to the regulations of the public sector where competitive bidding is considered a legal requirement (US General Services Administration 2016) in order to ensure that taxpayers obtain the value for the money and protects the public against the squandering of public funds, and prevents abuses such as fraud, waste, and favoritism (Rowles and Cahalan 2015). Moreover, for contractor selection process, the most used bid allocation method is the low bid method (Ioannou and Awwad 2010) in which the lowest qualified bidder is awarded the contract following a competitive bidding process (Seydel 2003). Under the competitive bidding with the low bid method, it is argued that one of the main aspects that impact the realizable profitability and success of a contract is the firms' bidding-related decisions (Assaad et al. 2021). Moreover, such competitive environment in awarding of public infrastructure projects can create a dynamic where all parties are looking out for their own interests, which can lead to disagreements and disputes if not managed properly (Akintoye et al. 2003). As such and due to the aforementioned reasons, the authors considered infrastructure projects for investigating the causation of disputes related to the bidding stage.

Goal and Objectives

The goal of this paper is to investigate and analyze the causation of disputes as related to the bidding stage in infrastructure projects. To attain this goal, the associated objectives are to: (1) identify the key causes of disputes related to the bidding stage in infrastructure projects, and (2) determine the main connections and combinations between the causes of disputes that are linked to the bidding stage, which could result in potential disputes among the project stakeholders. By investigating the causes of conflicts in the bidding stage, the paper would pave the road toward the creation of proactive plans and procedures that will help control these bidding stage–related causes and reduce the likelihood of related disputes arising during the execution of the project.

Background Information

Previous Studies Relevant to Construction Disputes

Various research studies have tackled the issue of disputes in the construction industry. The majority of existing studies have focused on studying a specific aspect related to construction disputes, including: (1) dispute resolution methods, (2) causation of construction disputes, and (3) prediction of construction disputes. In relation to dispute resolution methods, there are numerous methods implemented for construction dispute resolution in the US. According to Abdou et al. (2016), litigation is considered the most commonly used method for dispute resolution. In that regard, Jagannathan and Delhi (2020) performed a systematic literature review to determine the factors that lead to the phenomenon of parties resorting to litigation. Due to the associated costs and delays with legal procedures, alternative methods for dispute resolution have been established including mediation, arbitration, and adjudication (Marques 2018; Rubin and Quintas 2003). However, there is still concern about parties turning to the court system to resolve their disputes (Brogan et al. 2018).

In relation to the causation of construction disputes, existing studies have tackled either disputes associated with to the construction industry in general (Diekmann and Girard 1995; Cheung and Pang 2013) or disputes associated with specific types of projects, geographical areas, and/or contracts (Ilter and Bakioglu 2018). For instance, Semple et al. (1994) analyzed 24 construction projects in Western Canada to find the causes of the corresponding construction claims and disputes. Cheung and Pang (2013) identified the key causes that can lead to disputes in construction projects and proposed a framework that differentiates two types of disputes: speculative and contractual. Moreover, Cakmak and Cakmak (2014) classified disputes into several types, including those that were connected to contracts, projects, contractors, owners, human behavior, design, and external factors. Kumar Viswanathan et al. (2020) developed a dispute causal model to study the interrelationships between the different dispute causes. Recently, Abdul Nabi and El-adaway (2022) identified 40 causes of disputes associated with modularization in the construction industry and analyzed the critical combinations among them.

In relation to the prediction of construction disputes, various researchers have focused on identifying risk factors that contribute to disputes and developing models that can accurately predict their occurrence. Previous research has employed various techniques, including data mining, machine learning, and statistical analysis,

to identify patterns and relationships between risk factors and the likelihood of a dispute occurring. For example, Chen and Hsu (2007) developed a hybrid model based on case-based reasoning (CBR) and artificial neural network (ANN) to predict the litigation likelihood in construction projects. Shin and Molenaar (2000) identified critical dispute characteristics for predicting disputes related to contractual change issues. Further, Mahfouz et al. (2018) utilized machine learning to develop a model that enables automatic extractions of knowledge and predicts the occurrence of differing site condition litigations. More recently, Ayhan et al. (2021) built a machine learning model for the prediction of the possibility of disputes in construction projects using empirical data via questionnaires with experts.

Although numerous studies and resources have been devoted to investigating and addressing construction disputes, the frequency and complexity of such disputes appear to be on the rise, indicating a persistent and growing issue within the industry (Wang et al. 2022; AAA 2018). Moreover, despite the variety of research on construction disputes, there is still a lack of research that examines the causes of disputes related to the bidding stage, specifically, and studies the associations among them. Monitoring and detecting causes of disputes in the early phases of the project are essential for the development of proactive plans toward efficient and effective avoidance/reduction of construction disputes and the resulting unnecessary costs and delays (Olantunji 2016). As previously highlighted, this paper tackles this area of research need by investigating the causes of disputes related to the bidding stage in infrastructure projects and studying the associations among them using network analysis, spectral clustering, and association rule analysis. In the following paragraphs, brief background information on network analysis, spectral clustering, and association rule analysis, as well as their relevance to this study are presented.

Network Analysis

NA is a mathematical method based on graph theory that examines networks while taking the interconnectivity of their components into account (Otte and Rousseau 2002). Networks are usually represented by nodes and linkages, which are usually identified based on the application of the method. NA analyzes the formed networks using various measurements and statistical methodologies to gain important insights from their structures. In doing so, degree centrality (DC) is a measure that is extensively utilized to quantitatively analyze the interconnectivity among the nodes of a network by calculating the number of linkages connected to each node (Freeman 1978). NA-based approaches have been utilized to investigate networks in various domains including social sciences, politics, sociology, healthcare, and business (Pow et al. 2012). In relation to construction engineering and management, some researchers utilized NA approaches to study interaction among project stakeholders as well as organizational behavior (Chinowsky and Taylor 2012; Li et al. 2019; Lu et al. 2020).

Apart from the traditional use of NA approaches in studying social behavior and ties among actors/individuals, various researchers have utilized such technique in other applications than social sciences such as scientometric analyses and/or identification of future research needs and directions in various domains (Cheng et al. 2020; Eissa et al. 2021). For instance, Woldesenbet et al. (2016) utilized NA to analyze and evaluate data with information and decisions, as well as identify critical aspects related to decision-making processes within the life cycle of highway infrastructure projects. Eissa et al. (2021) utilized NA approach to investigate and analyze the various applications of game theory in construction engineering and management (CEM) domains and provide directions for future research. In relation to that, NA has been proven efficient in analyzing the co-occurrence network in scientific research (Yang et al. 2012). In relation to that, Abotaleb and El-adaway (2019) highlighted the beneficial capabilities of using NA and its associated concepts to include: (1) facilitating quantitative analysis of associations between different factors in certain study fields, (2) comparing the importance of different factors relative to each other, and (3) identifying of understudied areas and knowledge gaps. In light of the above, NA is deemed appropriate for studying the interconnectivities between the identified causes of disputes and identifying the key causes among them. Measurement of interconnectivity (represented by the degree centrality measure) among the causes of disputes is essential to be able to determine the critical combinations between the causes of disputes, which is based on the interconnectivity level between the various causes. Further details are provided under the "Methodology" section of this paper.

Spectral Clustering

Spectral clustering is a technique based on algebraic graph theory (Shinnou and Sasaki 2008). Various studies highlighted the benefits associated with spectral clustering including: (1) providing a powerful tool for partitioning of networks resulting from NA, and (2) enabling partitioning of a group of factors (i.e., causes in this paper) into clusters based on their in-between interconnectivities' strength. In other words, spectral clustering splits the network's nodes resulting from NA into groups following the rule of increasing the connectivity between the nodes in the same cluster and decreasing it between the nodes in different clusters. Thus, spectral clustering has obtained an increased attention in recent studies as an innovative method for graph matrix partitioning (Jia et al. 2014; Janani and Vijayarani 2019) because partitioning a network graph into clusters facilitates an in-depth understanding of the structure of the network and implicit information as well as associations (Tanriverdi et al. 2021). That said, spectral clustering has been used for some research applications in the CEM domain. For instance, Zhou et al. (2019) utilized spectral clustering to analyze monitoring data of shield tunneling for better on-site management. Assaad and El-adaway (2021) used spectral clustering in their investigation of the critical combinations of safety fatality causes. In this paper, spectral clustering is used to categorize the identified causes of disputes associated with the bidding phase of the projects based on their in-between connectivity. Further details are provided under the "Methodology" section of this paper.

Association Rule Analysis

Association rule analysis (ARA) is a prominent association method to study the relationships and associations between several factors in a database (Joshi et al. 2018; Agrawal et al. 1993). According to Cheng et al. (2010), ARA enables discovering hidden rules or patterns in a data set and thus extracting meaningful information. For conducting the ARA, various algorithms can be applied including Apriori, Eclat, among others. The Apriori algorithm is considered the first algorithm for frequent pattern mining and the associated ARA (Fournier-Viger et al. 2019). Rahman et al. (2019) highlighted the advantages of the Apriori algorithm as follows: (1) easy to understand and implement, (2) effective in identifying frequent patterns and combinations, and (3) it needs comparatively less memory and computational complexity. In the CEM domain, various researchers have applied ARA approach using Apriori algorithm. For instance, Cheng et al. (2010) utilized ARA to investigate the relationships between the causes and effects

of accidents in the construction industry in Taiwan. Weng et al. (2016) applied ARA to study the characteristics of factors contributing to work zone crash casualties. Khalef and El-adaway (2023) used ARA to identify deficiencies in the body of knowledge related to the delivery of design-build projects. In this paper, ARA as well as the Apriori algorithm are implemented to identify the main associations among the categorized causes of disputes associated with the bidding stage, which could lead to disputes between the project stakeholders during the execution of the project.

Methodology

To attain the goal and objectives of this paper, a multistep research methodology was adopted, as shown in Fig. 1. The associated steps include data collection, NA, spectral clustering, and ARA. The previous section of this paper provided background information related to NA, spectral clustering, and ARA. Further detailed information pertaining to each methodological step is provided in the subsequent subsections.

Step 1: Data Collection and Network Analysis

Data Collection and Identification of Causes of Disputes

The authors collected actual case studies of litigations related to infrastructure projects in the US using Google Scholar case law search engine. In fact, Google Scholar was utilized because it can be easily accessed plus it includes a wide range of legal cases in various US courts. In addition, it was utilized by various published studies that focused on analyzing numerous contractual and legal aspects (Demachkieh et al. 2020; Vieira et al. 2021; Ahmed et al. 2022a). That said, the authors followed the subsequent systematic steps for data collection, which are summarized in Fig. 2:

- *Search*: The database search process using Google Scholar included the use of predefined keywords including "bidding," "infrastructure," and "construction project." The search focused on the past 10 years; specifically, the period between 2012 and August 2022 (the time of conducting the data collection process). A 10-year period is considered reasonable for identifying the recent challenges and obstacles faced by the participating parties in bidding for infrastructure projects. Moreover, the search covered both US state and federal courts. As such, this search led to the collection of 452 legal cases in various US courts.
- *Screening*: The authors performed a preliminary screening and assessment of the collected 452 legal cases to determine their fitness and relation to the scope of this paper. As such, 358 legal cases were excluded for one of the following reasons: (1) the cause of the dispute is not related to the bidding stage; (2) the dispute is not between the project stakeholders; (3) the project related to the dispute is not an infrastructure project; and/or (4) the legal case is duplicated.

The term "project stakeholders" refers to individuals or organizations who have an interest in the project, and whose participation and support can influence its success, including the owners, designers, contractors, subcontractors. For example, the case of Webb v. RV Wagner, I*nc*. (2013) appeared in the conducted keyword search. However, the case was between individuals (Crystal and Gary Webb) who experienced a motorcycle accident in the area of a bridge construction project, in which RV Wagner, Inc. was the general contractor. The dispute in this case is not between the project stakeholders and is not related to the bidding stage. Another example is the case of Showers Appraisals, LLC v. Musson Bros (2013) in which a property owned by Showers Appraisals, LLC experienced flood damage, where Musson Bros. was conducting sewer removal and installation as a contractor for the Wisconsin Department of Transportation (DOT). Showers Appraisals, LLC claimed this damage happened due to negligence on the side of Musson Bros. in performing its work. Again, the dispute in this case is not between the project stakeholders and is not related to the bidding stage. Accordingly, such cases were excluded from the collected data.

- *Selection*: Ultimately, the remaining 94 legal cases were selected and considered for the identification of causes of disputes related to the bidding stage in infrastructure projects.

Upon selection of the legal cases, the authors conducted a manual content analysis of the selected 94 legal cases. The manual content analysis was carried out in a manner similar to that established by Neuendorf (2002) and Krippendorff (2004). According to Abdul Nabi and El-adaway (2022), such manual review and analysis of the selected legal cases should increase the accuracy and specificity of the identification of causes of disputes related to the bidding stage as well as ensure that the selected legal cases are related to the scope of this paper. The following are the main steps

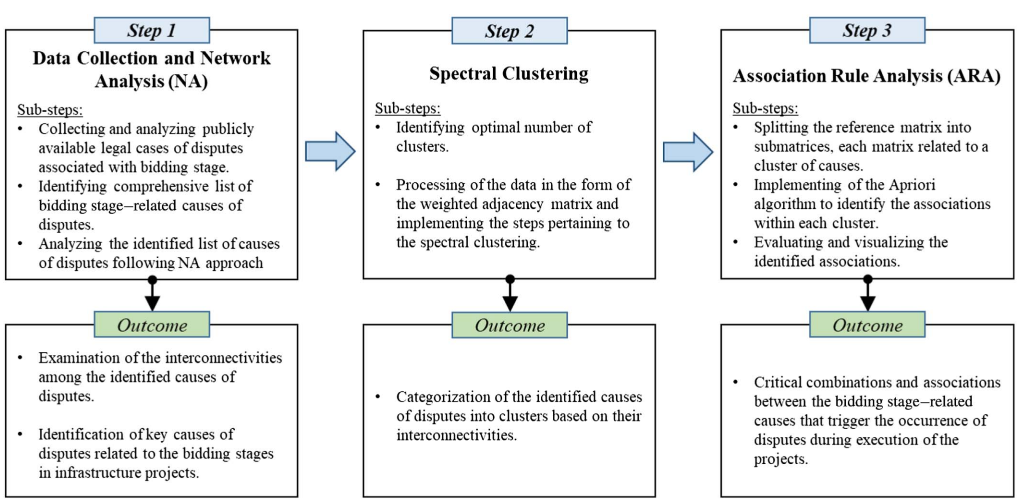

Fig. 1. Research methodology.

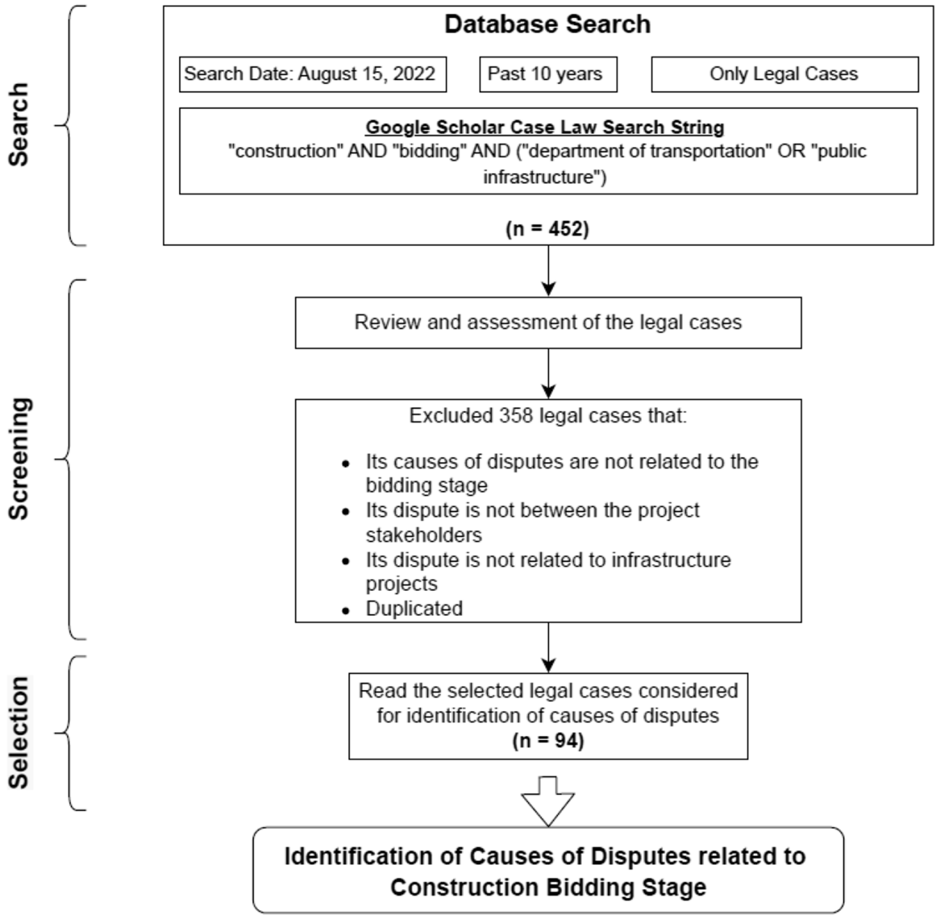

Fig. 2. Followed steps for data collection.

followed for identification of the causes associated with disputes in the selected legal cases:

- First, the authors manually and independently read the files related to the legal cases, in detail, without using any content analysis software. The authors independently followed an inductive approach in order to identify the causes of disputes based on the review and analysis of the legal cases. The employment of several coders reduces bias, which could affect the objectivity and accuracy of the results (Krippendorff 2004). Thus, such an approach in conducting the manual content analysis shall aid in the avoidance of single subjective judgment (Tinsley and Weiss 1975).
- Second, the authors independently recorded their identified causes of disputes using Microsoft Excel. For instance, in the case of Geosport Lighting Systems, LLC v. City of Bossier City, Louisiana (2021), Geosport was the lowest bidder on a public bid for lighting at various sports fields owned and operated by the city. The tender documents specified that bidders must use Musco lights or a product that met/exceeded the requirements listed in the documents. The submitted bid by Geosport was based on its own lights rather than Musco's and claimed that its lights were functionally equivalent to Musco's. However, the city required bidders not using Musco lights to include a revised electrical distribution plan signed by a licensed Louisiana electrical engineer. Geosport did not comply with this provision claiming that it required expending a significant amount of money and time in order to bid, which was prohibited by the Louisiana Public Bid Law. As a result, the city deemed Geosport's bid as nonresponsive and claimed that the bid was incomplete and lacked required information, even after declaring that Geosport's bid was the lowest. This conflict was a matter of dispute. Upon careful study of the case document, the authors determined that the leading causes for this dispute, associated with the bidding stage, between Geosport and the city were change or nonexecution of contract award, noncompliance with Request for Proposals' (RFP) requirements, and rejection of a bid. These causes were clearly stated throughout the case file. The aforementioned was an example of one of the analyzed legal cases and clarifies the criteria upon which the authors identified the causes of disputes. Moreover, the authors aggregated identical/similar causes of disputes during the process of reviewing and analyzing the selected 94 legal cases.
- Third, the authors compared the developed lists of causes of disputes. In the event of disagreement, another review cycle is carried out until an agreement is reached. Overall, a total of two review cycles were conducted. An example of a disagreement among the developed lists of causes by the two authors was that one of the lists did not include "collusive bidding" as one of the causes of disputes. It was considered within the cause "breach of legal requirements." However, after conducting the second review cycle, the authors agreed to include "collusive bidding" as a stand-alone cause of dispute associated with the bidding stage because it was clearly stated in some disputes such as the case of Cheeks v. Ft. Myer Const. Corp. (2014). Ultimately, the authors identified a comprehensive list of 27 causes of disputes that are related to the bidding stage in infrastructure projects. The identified list of 27 bidding stage–related causes of disputes will be shown in the "Results and Analysis" section.

Implementation of NA

Upon selection and reviewing the legal cases, the authors performed NA to study the co-occurrence and interconnectivity among the identified bidding stage–related causes of disputes. Studying the interconnectivity among the causes is important to examine dispute causation in infrastructure projects. First, the authors constructed a reference matrix R, which maps the analyzed legal cases with the identified list of bidding stage–related causes of disputes. More specifically, the rows in the matrix R represent the identified 27 causes of disputes, and the columns represent the analyzed 94 legal cases. If the cause of the dispute is referred to a legal case, the value of its corresponding cell will be 1; otherwise, it will be 0. Fig. 3 shows a descriptive example of the structure of a reference matrix. Let C_i denote an identified cause of dispute, N denote the number of the causes of disputes (27 causes). Further, let L_j denote an analyzed legal case, and J denote the total number of the cases (94 legal cases). As such, the resulting reference matrix R has a dimension of 27×94. For example, in Fig. 3, the analyzed legal case L_{j+1} mentioned the causes C_i and C_N; thus, their corresponding cells have values of 1 whereas the remaining cells (causes) under the analyzed legal case L_{j+1} have values of 0.

Second, the authors constructed a weighted adjacency matrix A, following Eq. (1), through multiplying the reference matrix R by its transpose and then entering zeros for all the diagonal values in the resulted matrix. Where $A_{N\times N}$ is an adjacency matrix of size $(N \times N)$, where N equals the total number of identified causes of disputes (in this paper, $N = 27$); $R_{N\times J}$ is a reference matrix, where J equals the total number of the analyzed legal cases in the corresponding matrix; i is the index of the matrix rows; and j is the index of the matrix columns. In the resulting adjacency matrix A, the matrix columns and rows represent the identified causes of disputes, while the entries of the matrix represent the level of co-occurrence among each pair of causes in the analyzed legal cases

$$A_{N\times N} = \begin{cases} R_{N\times J} \times R^T_{N\times J} & \text{for } i \neq j \\ 0 & \text{for } i = j \end{cases} \tag{1}$$

Upon construction of the adjacency matrix A, the authors developed a network graph, in which the nodes represent the causes of disputes, and the edges represent the interconnectivity among them. In analyzing the network graph, the authors adopted DC as the NA measure to quantitatively analyze the identified causes of disputes according to their frequency of inclusion, co-occurrence, and interconnectivity. DC is calculated for each identified cause of disputes based on the entries of the adjacency matrix A following Eq. (2). Where DC_i is the DC for cause i; and $a_{i,j}$ is the value of the corresponding cell in row i and column j of the adjacency matrix A

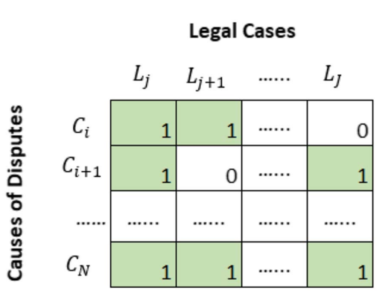

Fig. 3. A descriptive example of the structure of a reference matrix.

$$DC_i = \sum_{j=1}^{N} a_{i,j} \tag{2}$$

Step 2: Spectral Clustering

As previously highlighted, spectral clustering is implemented in this study as an innovative technique for graph matrix partitioning, because partitioning a network graph into clusters facilitates an in-depth understanding of the structure of the network as well as implicit information and associations. The following subsections provide illustration of the steps followed for performing spectral clustering in this paper.

Determination of the Optimum Number of Clusters

To perform the spectral clustering analysis, it is essential to calculate the optimum number of clusters k for the causes of disputes associated with the bidding stage on infrastructure projects. Since the developed network is a representation of the adjacency matrix A, the authors used the matrix A to identify the number of clusters k. In doing so, the authors utilized the elbow method. The elbow method is one of the most used techniques for the determination of the optimum number of clusters due to its simplicity, accuracy, and fast convergence. The elbow method computes the distortions' values for different numbers of clusters (Kodinariya and Makwana 2013). As such, the appropriate number of clusters k is determined so that adding another cluster has no significant contribution to the modeling of the data.

Implementation of Spectral Clustering Algorithm

Upon construction of the adjacency matrix A and determination of the optimum number of clusters k, the authors employed the spectral clustering algorithm following the steps illustrated in Ng et al. (2002) and Von Luxburg (2007). In general, the spectral clustering algorithm is a combination of graph theory as well as k-means clustering to perform clustering of a data set (Ng et al. 2002). That said, the steps pertaining to the implementation of the spectral clustering algorithm are as follows:

- First, the authors determined the DC value for each of the identified 27 causes of disputes using Eq. (2). Then, the authors constructed a degree matrix D that has dimensions of $(N \times N)$, following Eq. (3). In fact, the degree matrix D is the diagonal matrix for the DC values

$$D = \text{diag}(DC_i) = \begin{cases} DC_i & \text{for } i = j \\ 0 & \text{for } i \neq j \end{cases} \tag{3}$$

- Second, the authors determined the normalized symmetrical Laplacian matrix L_{sym} that has dimensions of $(N \times N)$, following Eq. (4)

$$L_{\text{sym}} = I - D^{-\frac{1}{2}}(A)D^{-\frac{1}{2}} \tag{4}$$

where $I = N \times N$ identity matrix; $A = N \times N$ adjacency matrix of reference matrix R; and $D = N \times N$ degree matrix.

- Third, the authors computed the eigenvalues and eigenvectors of the normalized symmetrical Laplacian matrix L_{sym} following Eq. (5). There exists N eigenvalues and N eigenvectors for the normalized symmetrical Laplacian matrix L_{sym}

$$L_{\text{sym}} \cdot e = \lambda \cdot e \quad \text{with} \quad |L_{\text{sym}} - \lambda \text{I}| = 0 \tag{5}$$

where e = eigenvectors; λ = eigenvalues; and $I = N \times N$ identity matrix.

- Fourth, upon determination of the optimum number of clusters k, the k largest eigenvectors of the normalized symmetrical

Laplacian matrix L_{sym} were calculated and arranged in columns to create a matrix U_k. The k largest eigenvectors are corresponding to the k largest eigenvalues.

- Fifth, a Y_k matrix was established by normalizing the rows of the U_k matrix, following Eq. (6)

$$Y_{ij} = \frac{u_{ij}}{(\sum_1^k u_{ij})^2} \tag{6}$$

- Ultimately, let y_i be the vector associated with the ith row in the matrix Y_k. Considering each vector y_i represents a point in R^k, the authors clustered these points into k clusters using k-means clustering method. Performing of the k-means on the matrix Y_k instead of the adjacency or the reference matrices enables obtaining more optimal results in relation to clustering the identified 27 causes of disputes based on the strength of their interconnectivities.

Step 3: Association Rule Analysis

Upon classifying the 27 causes of disputes into their respective clusters, the authors utilized ARA to determine the most critical associations and combinations among the causes of disputes within each cluster. First, the authors divided the reference matrix R into k submatrices $(R_1, R_2, \ldots, R_m, \ldots R_k)$. Each submatrix R_m contains the causes of disputes included in the mth cluster. Then, on each submatrix R_m, the authors applied the Apriori algorithm to determine the key associations and combinations between its causes of disputes.

Implementation of the Apriori Algorithm

This subsection explains the steps pertaining to the implementation of the Apriori algorithm. In relation to that, let $C = \{C_i, \ldots\ldots, C_j\}$ be the set of causes of disputes included in the mth cluster. Let $S = \{s_a, \ldots\ldots, s_n\}$ represent the set of selected legal cases, and s_a represents the causes of disputes highlighted in the case such that $s_a \subseteq C$. For example, if case a highlighted the causes C_i, C_j as the causes of its dispute, then the legal case a can be represented as the following set of causes of disputes $s_a = \{C_i, C_j\}$. Accordingly, the associations or combinations among the causes of disputes can be represented as $C_i \sim C_j$, where $C_i, C_j \subseteq C$, and $C_i \cap C_i = \emptyset$. Accordingly, all potential combinations and associations among the causes of disputes in each cluster are determined.

Thereafter, the authors applied the most utilized measures to evaluate and quantify the identified potential associations and combinations. These measures are: (1) support, (2) confidence, and (3) lift. The support value indicates how frequently a combination of causes appears in the data set (Liu et al. 2018). The confidence value reflects the predictability of a combination of causes (Liu et al. 2018). The lift value measures the correlation among the causes within a combination (Chen et al. 2020). These measures are calculated following Eqs. (7)–(10). It is worth noting that Eq. (7) determines the support for a cause of disputes separately, while Eq. (8) determines the support for an association or a pair of causes of disputes

$$\text{Support}(C_i) = \frac{\text{No. of legal cases that contain } C_i}{\text{No. of all legal cases in the cluster}} \tag{7}$$

$$\text{Support}\,(C_i \sim C_j) = \frac{\text{No. of legal cases that contain } C_i \text{ and } C_j}{\text{No. of all legal cases in the cluster}} \tag{8}$$

$$\text{Confidence}\,(C_i \sim C_j) = \frac{\text{No. of legal cases that contain } C_i \text{ and } C_j}{\text{No. of legal cases that contain } C_i} \tag{9}$$

$$\text{Lift}\,(C_i \sim C_j) = \frac{\text{Support}\,(C_i \sim C_j)}{\text{No. of legal cases that contain } C_i \times \text{No. of legal cases that contain } C_j} \tag{10}$$

Assessment of the Identified Associations

As previously highlighted, the Apriori algorithm identifies all potential combinations and associations among the causes of disputes within each cluster. To obtain meaningful results, the authors utilized the support, confidence, and lift measures by setting threshold values for each in order to filter all potential associations toward the determination of the strong and significant ones (Liao and Perng 2008). That said, the following steps were implemented:

1. One-itemsets are generated for each cause of disputes. Thereafter, the support for each cause of disputes (i.e., one itemset) is determined, following Eq. (7), and checked against a minimum threshold value σ of 0.01 for the support (i.e., $\sigma = 0.01$; and $Support\,(C_i) \geq \sigma$). This support's threshold value is considered since it is recommended in various previous studies that applied ARA to determine meaningful associations (Verma et al. 2014). Accordingly, if the support of any one-itemset for any cause of disputes is less than the minimum threshold value for the support (i.e., $\text{Support}\,(C_i) < \sigma$), then the corresponding cause of disputes is filtered out. The remaining one-itemsets are considered for the next step of the implemented Apriori algorithm.
2. Upon filtration of the one-itemsets (i.e., causes of disputes) according to their support values, different items (i.e., causes of disputes) are combined with the identified one-itemsets from the first step. Accordingly, all possible associations have been gathered in the form of q-itemsets, where $q \geq 2$ (Abdul Nabi and El-adaway 2022). Then, for each q-itemset, the support is determined following Eq. (8), checked against the aforementioned minimum threshold value σ of 0.01, and filtered accordingly. The remaining q-itemsets are considered for the next step of the implemented Apriori algorithm.
3. For each of the remaining q-itemsets, its confidence is calculated, following Eq. (9), and checked against a predefined minimum threshold value δ of 0.75 (i.e., $\delta = 0.75$; and Confidence $\geq \delta$). Thisconfidence threshold value is recommended in various applications of ARA (Hosseini et al. 2018). Accordingly, the confidence of any q-itemset must be greater than the minimum threshold value for the confidence (i.e., Confidence $<$ δ), otherwise, it will be filtered out. The remaining q-itemsets are considered for the next step of the implemented Apriori algorithm.

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Table 1. Used Python and R packages and libraries

Programming language	Package/library	Purpose	Reference
Python programming language	Pandas	Data preprocessing and analysis	McKinney (2010)
	NumPy	Mathematical computing	Oliphant (2006) and Van Der Walt et al. (2011)
	Matplotlib	Visualization and graphing	Hunter (2007)
	Seaborn	Visualization and graphing	Waskom et al. (2018)
	Scikit-Learn	Implementing the k-means clustering	Pedregosa et al. (2011)
R programming language	Arules	Implementing the Apriori algorithm for ARA	Hahsler et al. (2011)
	ArulesViz	Visualization of the associations	Hahsler and Chelluboina (2011)

4. For each of the remaining q-itemset, its lift is calculated, following Eq. (10), and checked against a predefined minimum threshold value α of 1 (i.e., $\alpha = 1$; and $Lift \geq \delta$). This lift's threshold value is considered since it is recommended in various previous studies (Verma et al. 2014). Accordingly, the lift value of any q-itemset must be greater than the minimum threshold value for the lift (i.e., Lift $> \alpha$), otherwise, it will be filtered out. Ultimately, the remaining q-itemsets are considered strong and significant associations between the identified causes of disputes.

Following the aforementioned steps for assessment of the associations, the authors were able to distinguish the strong and significant associations between the identified causes related to the bidding stage, which could lead to potential disputes between the project stakeholders.

Software Used

The analysis conducted on this paper was implemented using Python programming language (Oliphant 2007; Millman and Aivazis 2011), Gephi software (Bastian et al. 2009), as well as R programming language (Gardener 2012). For Python and R programming language, the authors utilized Project Jupyter and RStudio, respectively, as the Integrated Development Environments (IDE) for these programming languages (Perez and Granger 2015; Allaire 2012). More specifically, the authors implemented the steps pertaining to NA using Python programming language and Gephi software. For spectral clustering, the authors utilized Python programming language. For the ARA, the authors utilized R programming language. Various open-source packages and libraries have been utilized within both Python and R programming languages. Table 1 shows the used packages and libraries and their purpose under each programming language.

Results and Analysis

Bidding Stage–Related Causes of Disputes

As highlighted in the "Methodology" section of this paper, the authors considered 94 legal cases for the identification of causes of disputes related to the bidding stage in infrastructure projects. In general, infrastructure projects can be classified into 10 categories: (1) Transportation infrastructure, (2) Water and sewage infrastructure, (3) Educational infrastructure, (4) Recreational infrastructure, (5) Government infrastructure, (6) Commercial infrastructure, (7) Energy infrastructure, (8) Telecommunications infrastructure, (9) Healthcare infrastructure, and (10) Public safety infrastructure (CFI 2022). Table 2 shows the number of cases associated with each type of infrastructure projects. In addition, the Supplemental Materials show the analyzed legal cases, their characteristics, and the type of the infrastructure project associated with each case.

Table 2. Type of infrastructure projects and the corresponding number of cases

Type of project	Number of cases
Transportation infrastructure	62
Water and sewage infrastructure	14
Educational infrastructure	11
Recreational infrastructure	5
Government infrastructure	1
Commercial infrastructure	1
Energy infrastructure	0
Telecommunications infrastructure	0
Healthcare infrastructure	0
Public safety infrastructure	0

In general, the analyzed legal cases showed disputes between various contracting parties; however, the majority of disputes were between the client and the general contractor (70 out of 94 cases). In addition, the analyzed legal cases covered various methods of project delivery, including design-bid-build, public-private-partnership, among others; however, the majority are contracted under design-bid-build. The analyzed legal cases covered various bid evaluation methods, including the low bid method, best value method, low bid with cost-plus-time method, and an innovative method based on performance and monetary value evaluation, among others. Overall, the majority of the analyzed legal cases were delivered following the low bid method (49 out of 94 cases). In fact, this is expected because as previously highlighted, the majority of infrastructure projects are built using public funds and subject to the terms of the Federal Acquisition Regulation (FAR), where awarding the contract to the lowest responsible and responsive bidder is a legal requirement (US General Services Administration 2016; Ahmed et al. 2022b).

To this end, based on the conducted manual content analysis of the 94 legal cases, the authors identified 27 causes of disputes associated with the bidding stage in infrastructure projects. Table 3 shows the identified causes of disputes, their descriptions, and number of analyzed cases associated with each cause. Compared to previous studies related to the causation of construction disputes (Semple et al. 1994; Chan and Suen 2005; Ilter and Bakioglu 2018; among others), the following causes are considered unique in its direct relation to the bidding stage: (1) C1: Change or nonexecution of contract award, (2) C5: Rejection of a bid, (3) C7: Unfair evaluation of bids, (4) C11: Collusive bidding, (5) C20: Unclear bid evaluation method, (6) C25: Unbalanced bidding, and (7) C26: Bid withdrawal.

Results of the NA

Upon identification of the bidding stage–related causes of disputes and construction of reference matrix R that maps the 27 identified

Table 3. Identified causes of disputes associated with the bidding stage

Code	Cause of dispute	Description	Number of cases
C1	Change or nonexecution of contract award	Refers to a situation where the construction contract is awarded to a bidder, but for some reason, the contract is later changed or not executed. This can be a cause of dispute between the parties involved, including the owner, the winning bidder, and other bidders who may have submitted proposals for the project.	18
C2	Conflict of interest	Refers to a situation where a bidder has a competing interest or relationship that could potentially influence the awarding of the contract. This can be a cause of dispute if it is discovered that the bidder did not disclose this conflict or if the conflict is perceived to have influenced the awarding of the contract, leading to challenges to the fairness and transparency of the bidding process.	3
C3	Change in regulations	Refers to a situation where the regulatory environment affecting the project changes after the bidding process has started. This can be a cause of dispute if the change results in additional costs or delays for the project, and there is disagreement over which party is responsible for bearing these costs. It is important for contracts to have clear provisions for dealing with regulatory changes and the associated costs and delays.	6
C4	Noncompliance with RFP requirements	Refers to a situation where a bidder fails to meet one or more of the requirements specified in the RFP. This can be a cause of dispute if the noncompliance is discovered after the contract is awarded, leading to challenges to the fairness and integrity of the bidding process or resulted in additional costs or delays to the winning bidder.	39
C5	Rejection of a bid	Refers to a situation where a bidder's proposal is not accepted by the owner, typically due to the bid being nonresponsive or nonconforming to the RFP requirements. This can be a cause of dispute if the bidder believes that their proposal was unfairly rejected, either due to errors or inconsistencies in the evaluation process or due to bias or favoritism on the part of the owner.	33
C6	Breaching of legal requirements	Refers to a situation where a bidder or owner fails to comply with legal requirements that are relevant to the bidding process. This can include failure to comply with procurement regulations or failure to obtain required licenses or permits (e.g., Disadvantaged Business Enterprise (DBE) program).	30
C7	Unfair evaluation of bids	Refers to a situation where the owner or evaluators unfairly or improperly evaluate the bids submitted by bidders. This can be a cause of dispute if the affected bidders believe that their proposals were not evaluated fairly or that the evaluation criteria were applied inconsistently or unfairly.	40
C8	Inappropriate tender documents	Refers to a situation where the tender documents issued by the owner are incomplete, inaccurate, or otherwise inappropriate, making it difficult or impossible for bidders to submit responsive and compliant bids or it can lead to incurred costs and delays by winning bidder.	31
C9	Inaccurate project cost estimates	Refers to a situation where a bidder's estimate of the project cost is inaccurate or incomplete, leading to misunderstandings or disagreements over the budget for the project. This can be a cause of dispute if the bidder's estimate is significantly lower than the actual cost of the project, and the bidder is unable to perform the work within the budget, leading to claims, disputes, or even project termination.	38
C10	Differing site conditions	Refers to a situation where the site conditions at the construction site are different from what was expected or specified in the contract documents. As such, the winning bidder based on a submitted bid that did not take into consideration the differing site conditions may incur additional costs or delays during execution of the project, which can potentially lead to disputes.	17
C11	Collusive bidding	Refers to a situation where two or more bidders collude to submit noncompetitive bids, artificially inflating the prices and reducing the competition. Collusive bidding is illegal and can be a cause of dispute if the owner discovers the collusive behavior and may result in the cancellation of the tender process and legal or administrative actions against the colluding bidders.	7
C12	Disclosure of confidential information	Refers to a situation where confidential information related to the project or the bidding process is disclosed to a third party without the owner's authorization. This can be a cause of dispute if the affected bidders believe that their competitive position has been compromised by the unauthorized disclosure, leading to challenges to the fairness and transparency of the bidding process.	4
C13	Inaccurate bill of quantities	Refers to a situation where the bill of quantities in the tender documents, which provides a detailed breakdown of the items and quantities of work to be completed, is incomplete, inaccurate, or unclear. This can lead to disputes over the scope of work and the associated costs, as well as confusion over the technical specifications and the quantity of the materials to be used.	11
C14	Nonproper or untimely notification of errors in tender documents	Refers to a situation where a bidder discovers an error or ambiguity in the tender documents, such as the bill of quantities or technical specifications, but fails to notify the owner in a timely or proper manner. This can be a cause of dispute if the error leads to misunderstandings or disputes over the scope of work or the associated costs, and the bidder claims that they were misled or disadvantaged by the error.	29
C15	Noncompliance with FHWA requirements	Refers to a situation where a bidder fails to comply with the requirements of the FHWA, which is responsible for overseeing the construction of highways and other federally funded transportation projects. This can be a cause of dispute if the noncompliance leads to delays or other issues that affect the project's completion or the safety of the public.	3
C16	Restrictions on the use of specific subcontractors/suppliers	Refers to a situation where the owner imposes restrictions or requirements on the bidders regarding the use of certain subcontractors or suppliers in the performance of the work. This can be a cause of dispute if the bidders feel that the restrictions are unreasonable or unfairly limit their ability to compete for the project, or if they believe that the selected subcontractors or suppliers are not qualified or suitable for the work.	2
C17	Informal nonwritten agreements	Refer to situations where the owner and bidder (or a bidder and its subcontractor) make verbal or informal agreements, such as side deals, that are not included in the formal written contract. This can be a cause of dispute if there is a disagreement over what was agreed to, or if one party claims that the other did not fulfill its obligations under the informal agreement.	3

Table 3. (*Continued*.)

Code	Cause of dispute	Description	Number of cases
C18	Unlawful interference with contract or business expectancy	Refers to situations where a third party, such as a competitor, interferes with the bidding process or with the contractual relationship between the owner and the successful bidder. This can be a cause of dispute if the interference results in financial harm or loss of the contract for the successful bidder.	1
C19	Unclear permits acquisition plan	Refers to a situation where the owner does not have a clear plan or timeline for obtaining the necessary permits for the construction project. This can be a cause of dispute if the bidders are uncertain about the permitting requirements or timeline, which can affect their ability to accurately estimate the costs and schedule for the project.	2
C20	Unclear bid evaluation method	Refers to a situation where the owner has not clearly defined or communicated the criteria and process for evaluating the bids or how the winner will be selected. Such unclear bid evaluation processes may be perceived to be unfair; it can erode confidence in the process and lead to disputes between the owner and the bidders.	1
C21	Inaccurate project schedule estimates	Refers to a situation where a bidder provides inaccurate or unrealistic estimates of the time required to complete the project in their bid. This can be a cause of dispute if the bidder is ultimately awarded the contract and then fails to meet their schedule commitments.	15
C22	Improper selection of subcontractors	Refers to a situation where the general contractor selects subcontractors based on improper criteria, such as personal relationships or other factors unrelated to the subcontractor's qualifications, requriements of RFP (if any), experience, and ability to perform the work. This can lead to disputes if the subcontractors ultimately fail to meet their contractual obligations, resulting in delays, cost overruns, and other problems.	5
C23	Submission of defective bid bond documents	Refers to a situation where a bidder submits a bid bond that does not meet the requirements set forth in the bidding documents. Defective bid bond documents can result in disputes if the owner rejects the bidder's submission and awards the contract to another bidder. The bidder may argue that the bid bond met the requirements, while the owner may claim that the bond was defective or inadequate.	3
C24	Design errors and changes	Refers to situations where errors or omissions in the design documents cause changes to the project during construction. These changes can result in disputes if the owner and contractor disagree on the cost and responsibility for making the necessary changes, which later can result in additional costs and delays.	4
C25	Unbalanced bidding	Refers to a situation where a contractor submits a bid that is significantly lower than the actual cost of performing some parts of the work, but significantly higher for other parts of the work. Unbalanced bidding can be a concern for owners, as it can result in increased costs or disputes during construction.	4
C26	Bid withdrawal	Refers to a situation where a bidder decides to withdraw their bid after the submission deadline, which can result in questions about the fairness of the bidding process and potentially lead to legal action if it is not allowed by the regulations to withdraw a submitted bid after the submission deadline.	2
C27	Nonproper or untimely notification of errors in a submitted bid	Refers to a situation where a bidder identifies a mistake or uncertainty in their bid but fails to inform the owner appropriately and promptly. This lack of notification may lead to disputes due to misunderstandings or additional costs that are typically associated with errors in submitted bids.	32

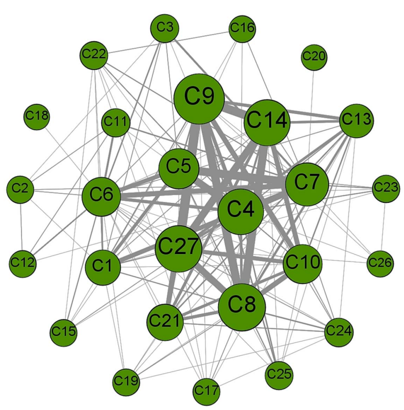

Fig. 4. Network graph corresponding to the reference matrix R.

causes of disputes with the 94 analyzed legal cases, the authors performed NA to study the co-occurrence and interconnectivity among the identified causes of disputes. Visualization of network graph facilitates understanding of the structural relationship between the causes, identification of similarities and differences in the degree of centrality, as well as obtaining holistic insights on the key causes of disputes (Cambridge Intelligence 2020). That said, Fig. 4 shows the corresponding network graph, which consists of 27 nodes and 137 edges. In Fig. 4, the nodes represent the causes of disputes, while the edges represent the co-occurrence and interconnectivity between each pair of causes of disputes. In addition, in Fig. 4, the node's size is an indicator of the value of DC of the corresponding cause of dispute. The bigger the node's size implies that the corresponding cause has a higher DC value, which means that this cause of disputes was frequently referred to in the analyzed legal cases and it is highly interconnected with other causes of disputes. Moreover, the thickness of the edge between any pair of causes of disputes indicates the level of interconnectivity between the two causes of disputes. The thicker the edge implies that the connected pair of causes highly co-occurred in the analyzed legal cases. As such, this visualization enables identification of the key causes of disputes associated with the bidding stages in infrastructure projects.

That said, Fig. 4 shows that the most common causes of disputes in the analyzed legal cases related to the bidding stage in infrastructure projects include C9 (inaccurate project cost estimates), C8 (inappropriate tender documents), C27 (nonproper or untimely notification of errors in a submitted bid), C14 (nonproper or untimely notification of errors in tender documents), and C4 (noncompliance with RFP requirements). Moreover, as it can be observed from Fig. 4, some nodes/causes are highly interconnected, while others are less interconnected or even not connected

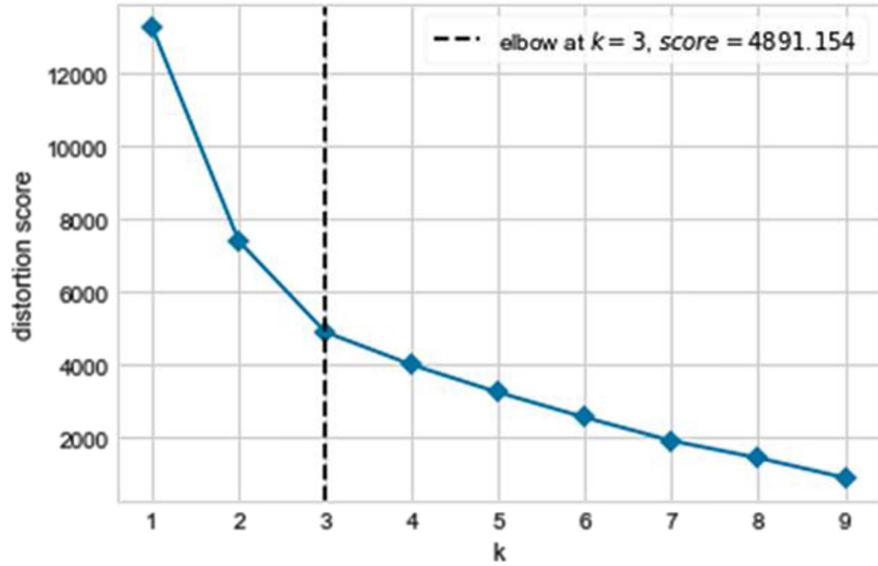

Fig. 5. Results of the distortion score versus number of clusters using the elbow method (k = number of clusters).

Table 4. Results of the spectral clustering

Cluster	#	Description
Cluster 1	C4	Noncompliance with RFP requirements
	C3	Change in regulations
	C10	Differing site conditions
	C11	Collusive bidding
	C13	Inaccurate bill of quantities
	C15	Noncompliance of FHWA requirements
	C16	Restrictions of the use of specific subcontractors/suppliers
	C18	Unlawful interference with contract of business expectancy
	C23	Submission of defective bid bond documents
	C24	Design errors and changes
	C27	Nonproper or untimely notification of errors in a submitted bid
Cluster 2	C7	Unfair evaluation of bids
	C9	Inaccurate project cost estimates
	C12	Disclosure of confidential information
	C17	Informal nonwritten agreements
	C19	Unclear permits acquisition plan
	C21	Inaccurate project schedule estimates
	C22	Improper selection of subcontractors
	C25	Unbalanced bidding
Cluster 3	C1	Change or nonexecution of contract award
	C2	Conflict of interest
	C5	Rejection of a bid
	C6	Breaching of legal requirements
	C8	Inappropriate tender documents
	C14	Nonproper or untimely notification of errors in tender documents
	C20	Unclear bid evaluation method
	C26	Bid withdrawal

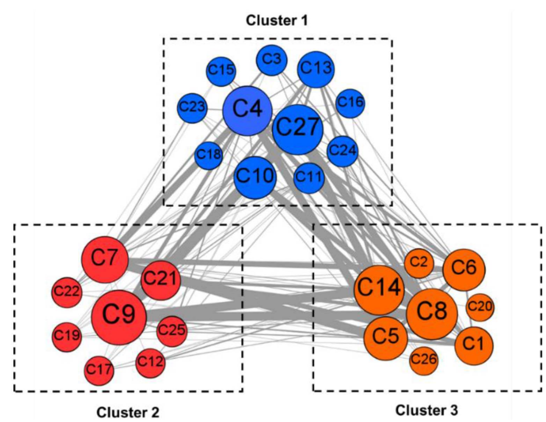

Fig. 6. Clustered network graph.

at all. As such, spectral clustering as well as ARA were implemented in this paper to group the identified causes of disputes according to their interconnectivity and determine the main associations and combinations of causes that could potentially lead to disputes between the project stakeholders.

Clustered Causes of Disputes

In the implementation of spectral clustering to group the identified 27 causes of disputes, the authors obtained the optimum number of clusters utilizing the elbow method. Fig. 5 presents the results pertaining to the elbow method, where the optimum number of clusters k is 3. Accordingly, the steps, described in the "Methodology" section, pertaining to the implementation of spectral clustering were performed with the recommendation of three clusters. Table 4 and Fig. 6 present the results of the performed spectral clustering.

Results of the ARA

Upon development of the three clusters of causes of disputes, the authors applied ARA to identify the most critical associations among the causes of disputes within each cluster. The following subsections present the results of the ARA in terms of the key associations associated with each cluster.

Key Associations in Cluster 1

As previously highlighted in the "Methodology" section, all potential associations among the causes of disputes in Cluster 1 were determined and then filtered according to the predefined thresholds

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for the support, confidence, and lift (0.01, 0.75, and 1, respectively). Accordingly, a total of seven key associations were determined in Cluster 1 between six causes of disputes: (1) C27: Nonproper or untimely notification of errors in a submitted bid, (2) C10: Differing site conditions, (3) C24: Design errors and changes, (4) C13: Inaccurate bill of quantities, (5) C4: Noncompliance with RFP requirements, and (6) C23: Submission of defective bid bond documents.

For instance, in the case of Scafar Contracting, Inc. v. City of Newark v. Malcom Pirnie, Inc., A/K/A Arcadis US, Inc. (2022) that involved a water and sewage infrastructure, Scafar Contracting won the bid for constructing a combined sewer overflow facility after submitting the lowest offer in response to the City of Newark's request. The proposed work was to remove 7,000 tons of nonhazardous soil and 10,000 tons of hazardous soil, with quoted prices of \$22/ton and \$123/ton, respectively. The city accepted the bid, and the parties signed a contract that incorporated the terms and specifications of the RFB. However, disagreements arose during the project when Scafar faced differing soil conditions and claimed that its costs for installing a cofferdam at the site and testing and disposing of the excavated material greatly increased and generated delays. Further, Scafar alleged that the city possessed better knowledge about the soil conditions but did not reveal them. This disagreement was a matter of dispute. Upon careful study of the case document, the authors determined that the leading causes for this dispute associated with the bidding stage were C4: Noncompliance with RFP requirements, C8: Inappropriate tender documents, C9: Inaccurate project cost estimates, C10: Differing site conditions, C13: Inaccurate bill of quantities, C14: Nonproper or untimely notification of errors in tender documents, C21: Inaccurate project schedule estimates, and C27: Nonproper or untimely notification of errors in a submitted bid. All these causes collectively led to the disagreement between the general contractor and the owner in this case and contributed to the rise of this dispute.

Fig. 7 shows the identified seven key associations in Cluster 1. It is imperative to note that the shade of the arrow representing the association indicates the significance of the association. The more intense the color of the arrow, the more significant and frequent its corresponding association in Cluster 1. Accordingly, it can be noticed that the most critical association in Cluster 1 involves the following causes of disputes: C27: Nonproper or untimely notification of errors in a submitted bid; C10: Differing site conditions; C4: Noncompliance with RFP requirements; and C13: Inaccurate bill of quantities. This identified association possesses a support value of 0.0106, a confidence value of 1, and the highest lift value of 8.55. These values indicates that this combination of causes of disputes is likely to occur (confidence is equal to 1). Moreover, a lift value of $8.55 > 1$ indicates that this association is of value in terms that the combinations of these four causes of disputes exist more often than anticipated (IBM 2019; Yao et al. 2019).

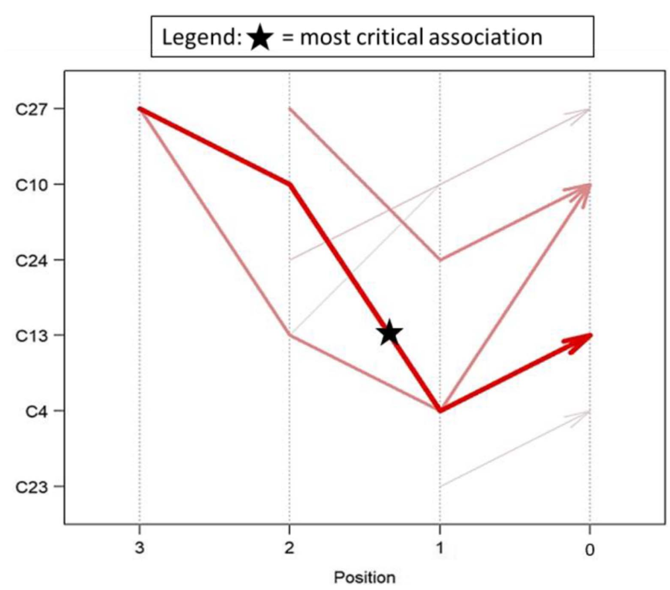

Fig. 7. Key associations in Cluster 1.

As such, this critical association reflects mainly two themes/aspects: (1) experiencing differing site conditions, as well as (2) having errors in submitted bids are warning signs of the rise of disputes between the project stakeholders. That said, project stakeholders should exert all measures at the bidding stage to avoid the occurrence of disputes related to these two aspects (e.g., contractors to ensure the correctness of their submitted bids; project stakeholders to ensure the correctness of the reports related to site investigation and to allocate responsibilities and risks clearly and efficiently among them). Further discussion of these two critical aspects is provided under the subsequent subsections.

Differing Site Conditions. A differing site condition (DSC) refers to the situation when the contractor faces a site condition that substantially differs from what normally experienced in the area of the project or from the conditions that are specified in the contract (Long et al. 2015). DSCs can result in cost and schedule overruns if they were not properly considered at the time of bidding. In fact, disputes resulted from DSCs are common, basically because of misinterpretation of site visit requirements, geotechnical reports, DSC-related contractual provisions (Chen and Liew 2003; Mahfouz et al. 2018). As such, contractors may be forced incorporate higher contingency values in their bids to account for the anticipated cost overruns and delays that may occur as a result of DSCs (Cushman et al. 2000). To avoid such scenarios, DSC clauses are included in construction contracts in order to achieve effective allocation of DSC-related risks among project stakeholders (Hanna et al. 2014).

There are mainly two types of DSCs: (1) Type 1, and (2) Type 2. A DSC of Type 1 refers to the subsurface condition that is substantially different from what is specified in the tender documents (Callahan 2005). For example, a DSC of Type 1 can be the quantity of rock that is substantially larger than what is indicated in test borings (Feldman and Keyes 2011). On the other hand, a DSC of Type 2 refers to the site conditions that are substantially different from what can be anticipated as per the location of the project and its nature (Callahan 2005). For example, a DSC of Type 2 can be the existence of corrosive groundwater at the location of the project (Amarasekara et al. 2018). In general, claims related to DSCs of Type 2 are difficult to be proven and usually result in disputes among project stakeholders.

Several researchers have investigated the issue of DSC-related disputes in the construction industry and recommended/developed different strategies to aid in its mitigation (Hanna et al. 2014; Mahfouz et al. 2018; Amarasekara et al. 2018; among others). For instance, in the study conducted by Amarasekara et al. (2018), it was found that the most suitable strategies for mitigation and avoidance the rise of disputes related to DSCs include: (1) application of new technologies for preparation of geotechnical reports, (2) employment of experienced contractor and consultant on the conditions at the location of the project, (3) involvement of qualified personnel for preparation of geotechnical reports, (4) conducting site visits and careful inspections by contractors prior to submitting their bids, and (5) referring to all drawings and documents related

to site conditions by contractor and consultant. Experiencing such measures/strategies prior to bidding on projects shall aid contractors in avoiding the rise of disputes related to DSCs during execution of the projects.

Errors in Submitted Bids. According to Kamil et al. (2018), English law contract generally identified the type of error/mistake to be either: (1) common mistake, where the mistake has been committed by both parties, (2) unilateral mistake, where the mistake has been committed by only one party, or (3) mutual mistake, where the mistake has been committed intentionally by both parties. By errors in submitted bids, the authors meant unilateral mistakes by the contractor in preparation of its submitted bid. Under the common law principles, the doctrine of unilateral mistake states that "If only one party is mistaken, the mistake is a 'unilateral mistake' of law. One may rescind for a unilateral mistake of law only if the other party knows of, but does not correct, and takes advantage of or unfairly obtain the benefit of the rescinding party's mistake of law" (Stimmel-Law 2022). A contractor with a mistaken bid may be seeking to rescind before any performance and recover a bid deposit. In that regard, Dyer and Kagel (1996) highlighted that most states' regulations accept the withdrawal of low submitted bids for public projects, without penalty, if they contain arithmetic errors. The definition of arithmetic errors is very broad and not well structured; thus, contractors can benefit from this to withdraw in the case of any error within their submitted bids (Ahmed 2015).

In general, errors in submitted bids in public projects can be due noncompliance with RFP requirements, the Federal Highway Administration (FHWA) requirements, and/or project's specifications, etc. Kamil et al. (2018) studied common mistakes of contractors during tendering based on law cases gathered from the Supreme Court of Canada. It was found that the most frequent errors during bidding are: (1) mistake in bid calculating, which will be discussed separately in next subsections, (2) wrong assumption in information, (3) clerical error, and (4) errors that are related to documents. In identifying the contributing factors, it was found that they are ordered as follows: (1) competitiveness and desire in winning the bid, (2) negligence of the contractor in submitting the bid and making assumption, (3) high reliance on the budget and information provided by the client, (4) incomplete/inaccurate information in tendering, (5) lack of communication, and (6) external factors (Kamil et al. 2018).

Moreover, nonproper or untimely notification by contractor of errors in its submitted bid might lead to a dispute between the involved project stakeholders. On the other hand, rejecting a submitted bid by the client due to an error within the bid could be a matter of dispute between the involved parties. As such, contractors are recommended to exercise careful judgment in preparation of their bids and check for any discrepancy before the submission. For instance, in case of ambiguity in tender documents, the contractor should request clarification before placing its bid. Moreover, in case of identifying any error after submitting a bid, it should be promptly communicated to the client. On the other hand, clients are encouraged to notify bidders of any error they acknowledged in their submitted bids. An approach is to check for major difference in received bids from contractors. Overall, building upon correct and accurate bids falls in the mutual interest of all project stakeholders and aids in avoiding the rise of unnecessary and costly disputes.

Key Associations in Cluster 2

Upon filtration of all potential associations among the causes of disputes in Cluster 2 according to the predefined thresholds for the support, confidence, and lift, two key associations were determined in Cluster 2. As shown in Fig. 8, these two key associations are between three causes of disputes: (1) C21: Inaccurate project schedule estimates, (2) C25: Unbalanced bidding, and (3) C9: Inaccurate project cost estimates.

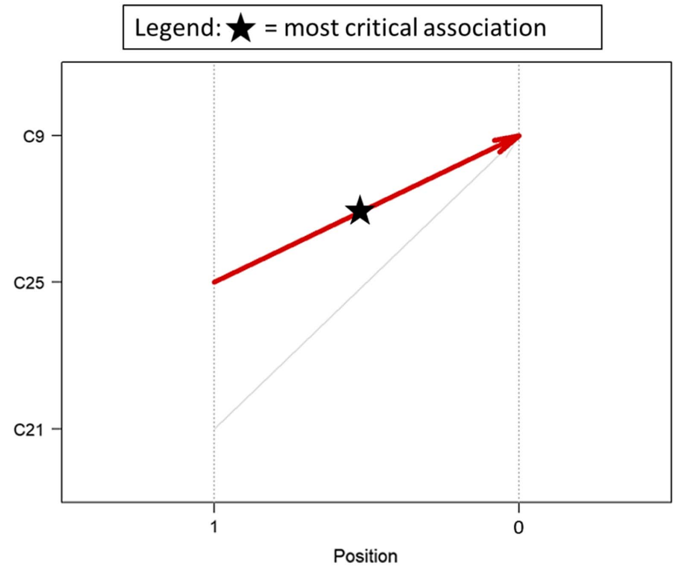

Fig. 8. Key associations in Cluster 2.

For instance, in the case of Montana Construction, Corp. v. Jersey City Municipal Utilities Authority (2021) that involved water and sewage infrastructure, Montana Construction was the lowest bidder for that project. However, Jersey City Municipal Utilities Authority (JCMUA) considered Montana's bid as nonresponsive, rejected it, and awarded the contract to the second lowest bidder. The reason was that JCMUA's project engineer, and an outside counsel reviewed submitted bid by Montana and agreed that it is unbalanced bid. Under the tender documents, JCMUA reserved the right to reject unbalanced bids. On the other hand, Montana Construction did not agree with the JCMUA's decision; thus, this disagreement was a matter of dispute. Upon careful study of the case document, the authors determined that the leading causes for this dispute associated with the bidding stage were C4: Noncompliance with RFP requirements, C5: Rejection of a bid, C6: Breaching of legal requirements, C9: Inaccurate project cost estimates, and C25: Unbalanced bidding. The combination of all these causes resulted in a conflict between the owner and the general contractor in this instance and played a role in the escalation of this disagreement and the dispute.

To this end, and as shown in Fig. 8, the most critical association in Cluster 2 involves the following causes of disputes: C25: Unbalanced bidding; and C9: Inaccurate project cost estimates. This identified association possesses a support value of 0.0426, a confidence value of 1, and lift value of 2.47. These values indicates that this combination of causes of disputes is likely to occur (confidence is equal to 1). Moreover, a lift value of $2.47 > 1$ indicates that this association is of value in terms that the combinations of the associated two causes of disputes exist more often than anticipated (IBM 2019; Yao et al. 2019).

As such, this critical association reflects mainly two themes/aspects: (1) submittal of unbalanced bids, as well as (2) having errors in cost estimation and/or noninclusion of contingency costs. That said, project stakeholders should exert all measures at the bidding stage to avoid the occurrence of disputes related to these two aspects (e.g., contractors to avoid submission of unbalanced bidding and clients to employ mechanisms to detect unbalanced

bidding; contractors to ensure the accuracy of their cost estimation practices and to continuously update and improve them). Further discussion of these two critical aspects is provided under the subsequent subsections.

Unbalanced Bidding. Unbalanced bidding is the practice of pricing some project items during the bidding process in a manner that does not represent their construction cost estimates plus a reasonable amount for overhead costs and profit. In fact, unbalanced bidding is a common practice in competitive bidding for public projects, where opportunistic contractors aim to win the project by being the lowest, only apparently, and target gaining more profits after being awarded the project (Jiang et al. 2019; Su et al. 2020). Such practice can lead to financial risks of encountering higher costs by the clients, impact the reliability of the bidding process, and increase the potential for disputes (Manzo and Tell 1997). Basically, a submitted unbalanced bid can be either a mathematically unbalanced bid or a materially unbalanced bid (Alhyari and Hyari 2022). A mathematically unbalanced bid contains one project item or more (unit price or lump sum) that are priced in a manner that does not represent their construction cost estimates plus a reasonable amount for overhead costs and profit. A materially unbalanced bid is basically a mathematically unbalanced bid that raises concerns about whether its selection would result in the lowest overall cost to the client (Missouri DOT 2021).

The issue of unbalanced bidding received great attention in research work and established regulations associated with public projects considering its detrimental impact on the execution of projects and its resulting disputes among project stakeholders. More recently, Alhyari and Hyari (2022) investigated the bidding regulations of various DOTs, and accordingly, identified the mechanisms followed for detection of unbalanced bids as well as presented response mechanisms to unbalanced bidding in public procurement. As per Alhyari and Hyari (2022), state DOTs and public agencies are utilizing the following mechanisms for the detection of unbalanced bidding practices: (1) comparison between the item rates included in the submitted bid and the corresponding engineer's estimate, (2) quantity verification among all the bidders, and (3) calculation of interests as to the expected payments. Furthermore, some researchers developed models and frameworks to aid agencies/clients in detection of unbalanced bidding such as Polat et al. (2018), Hyari et al. (2016), Nikpour et al. (2017), among others. However, the issue of unbalanced bidding still exists and leads to various disputes among project stakeholders.

In response to unbalanced bidding, Alhyari and Hyari (2022) highlighted some response mechanisms to handle unbalanced bidding practices including : (1) rejection of unbalanced bids, (2) banning the bidder from bidding on the project, (3) partial payment in case of front-loading, (4) setting maximum limits on the price of early planned items, (5) increasing performance security amount, (6) modification of contract/tender documents to explicitly prohibit exploiting errors in bidding documents, (7) negotiation of price (with narrower limits) in case of excessive changed quantity, and (8) inclusion of contractual conditions requiring the bidder to notify the client of any inaccuracies discovered in the bidding documents. The implementation of such mechanisms shall aid in avoiding unwarranted risks to clients and maintaining the integrity of the process of competitive bidding in public procurement. Overall, contractors should not exercise the unbalanced bidding practice considering its associated disadvantages as well as its detrimental consequences not only to the contractor, but also to all project stakeholders.

Errors in Cost Estimates. The construction sector is fraught with difficulties and uncertainties that can derail any project. Approximately, 80% of projects surpass their initial budget (Ahmed et al. 2021). Some of these encountered additional costs can be attributed to the errors in cost estimation at the time of bidding (Ahmed et al. 2022b). In relation to that, Ahmed et al. (2016) investigated the issue of the winner's curse in construction bidding and proved its existence. The winner's curse is the situation where the winning of the construction contract had submitted bid less than the actual cost executing the project. Excessive experience of a construction firm of the winner's curse issue might contribute to its failure or bankruptcy (Andersen 2022). To avoid such dilemma, Dyer and Kagel (1996) highlighted that general contractors in the US usually utilize one of the following mechanisms: (1) withdrawing their bids, (2) bidding higher for their portion of the project as a result of their subcontractors' low bids, and (3) conducting tough negotiations in pricing of change orders during the execution of the project to recover for the losses encountered due to errors in cost estimation. Generally, these mechanisms are considered ineffective; especially change orders as it leads to adversarial relationship between project stakeholders and increase the potential of disputes.

That said, many researchers investigated the issue of actual cost estimation and promoted models and frameworks to aid contractors with cost estimation processes. For instance, and not limited to, Akintoye and Fitzgerald (2000) identified the main causes of errors in cost estimation to be insufficient time for preparation of cost estimates, lack of knowledge of construction processes by cost estimation team, poor tender and contract documents, as well as large range of subcontractors' prices. Further, Chua and Li (2000) highlighted that contractors need to carefully consider adding contingency portion within their cost estimation to account for unforeseen occurrences. Ahmed et al. (2022b) presented game-theoretic framework to aid contractors in handling uncertainties associated with actual cost estimation. In addition, various research efforts underlined best practices for efficient cost estimation, including improved communication and knowledge sharing among various teams within the organization; proper staffing of cost estimation team; implementation of risk management within the cost estimation process; use of available cost estimation software; among others (Sridarran et al. 2017; Holm and Schaufelberger 2021). Overall, contractors should exert all efforts to promote enhanced accuracy within their cost estimation processes through implementation of best practices as well as applicable cost estimation frameworks and models.

Key Associations in Cluster 3

In Cluster 3, seven key associations were determined. These seven key associations are between five causes of disputes: (1) C5: Rejection of a bid, (2) C8: Inappropriate tender documents; C1: change or nonexecution of contract award; C6: Breaching of legal requirements, and (3) C14: Nonproper or untimely notification of errors in tender documents. For instance, in the case of Suburban Maintenance and Construction, Inc. v. Ohio Department of Transportation (2016), Suburban Maintenance and Construction (SMC) claimed that the provided tender/contract documents by Ohio Department of Transportation (ODOT) were ambiguous and as a result of that SMC was required to do additional work not included in its bid price for the contract work; thus, incurred additional cost. On the other hand, ODOT claimed that the provided tender/contract documents were clear, and SMC should perform all project work as per the bid price. This conflict was a matter of dispute. Upon careful study of the case document, the authors determined that the leading causes for this dispute, associated with the bidding stage, between SMC and ODOT were C8: Inappropriate tender documents, which resulted in inaccurate project estimates from the contractor, as well as C14: Nonproper or untimely notification

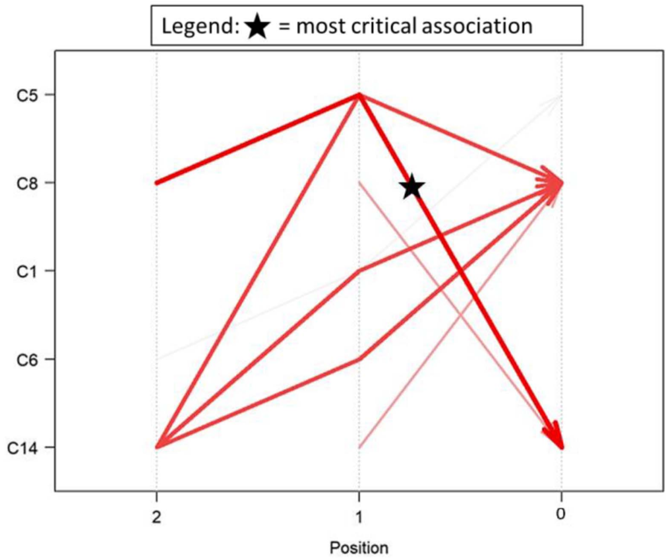

Fig. 9. Key associations in Cluster 3.

of errors in tender documents from both the contractor and owner sides.

To this end, and as shown in Fig. 9, the most critical association in Cluster 3 involves the following causes of disputes: C8: Inappropriate tender documents; C5: Rejection of a bid; and C14: Nonproper or untimely notification of errors in tender documents. This association possesses a support value of 0.0106, a confidence value of 1, and lift value of 3.24. These values indicates that this combination of causes of disputes is likely to occur (confidence is equal to 1). Moreover, a lift value of 3.24>1 indicates that this association is of value in terms that the combinations of these three causes of disputes exist more often than anticipated (IBM 2019; Yao et al. 2019).

As such, this critical association reflects mainly one theme/aspect: preparation of a bid based on tender documents or specifications that contain errors. Project stakeholders should exert all measures at the bidding stage to avoid the occurrence of disputes related to this aspect (e.g., clients or their representatives to ensure the accuracy, clarity, and correctness of the tender documents and/or specifications; contractors to clearly examine the tender documents and/or specifications and report any errors to the responsible party). Further discussion of this critical aspect is provided under the subsequent paragraphs.

In relation to errors in tender documents, the bidding stage of construction projects usually requires extensive exchange of documents and information as clients typically give contractors a set of documents that form the basis of the contract upon project award (Laryea 2011).

According to Smith (1986), tender documents are defined as the information supplied to the contractor about the contract, project conditions, etc., upon which the contractor can price the project as accurately as possible. Tender documents typically contain design, drawings, and specifications to reflect the expectations of the clients. The level of provided details differs based on the method of project delivery (e.g., design-build, design-bid-build, etc.), the procurement method (e.g., lump sum, unit price, etc.), size of the project, among other factors (Smith 1986).

Many researchers have studied the quality of tender documents as well as its impact on project performance and the magnitude of construction claims and disputes. According to Akintoye and Fitzgerald (2000) and Liu and Ling (2005), the quality of tender documents is often subpar in practice. The main causes of errors in tender documents are lack of consistency, being prepared by incompetent staff, acceptance of low fee for design and preparation of tender documents, and short time available for preparation, among others (Dosumu et al. 2017). The prominent issues with tender documents include missing or wrong information, insufficient degree of detail, as well as uncoordinated and contradicting information. (Brook 2004). Furthermore, poor tender documents can lead to errors in cost estimates, greater margins, as well as claims and disputes (Smith and Bohn 1999).

Contractors usually responds to problems in tender documents by: (1) pulling out of the bidding process, (2) having clarification meetings with clients; (3) submitting queries for more information and clarifications, and/or (4) increasing the monetary amount of contingency to account for the risks associated with poor tender documents (Laryea 2011). From the client's perspective, Laryea (2011) highlighted that for enhancement of the quality of tender documents, clients should identify and describe their expectations for the project clearly, allocate a reasonable tender period, and practice risk sharing. Moreover, Jaffar et al. (2011) emphasized the necessity of having a single point of responsibility for the coordination and management of the exchange of tender documents. In addition, conducting design audits and reviews can aid reducing errors in tender documents (Love et al. 2010). Overall, clients should exert all efforts to enhance the quality of tender documents, while contractors should communicate with the client in case of identifying any error/ambiguity within tender documents.

Research Contributions

This study provides substantial theoretical additions to the body of knowledge. First, it identified a comprehensive and distinct list of causes of disputes associated with the bidding stage in infrastructure projects. Second, it determined the key associations among the bidding stage–related causes that can lead to potential disputes. As such, this study promotes an in-depth understanding of the causes of disputes associated with the bidding stage of infrastructure projects. The provided knowledge can inform future research in CEM domain, specifically related to the bidding phase of projects, to tackle the identified critical aspects and combinations of causes of disputes.

In addition, this study has practical and managerial implications to practitioners in the construction industry. By identifying the causes of disputes associated with the bidding phase of infrastructure projects, practitioners can develop proactive plans and practices to mitigate the occurrence of disputes during project execution. For instance, the study revealed that inaccurate cost estimates and inappropriate tender documents were major common causes leading to disputes. Practitioners can address and mitigate these causes by enhancing the accuracy of their cost estimates and ensure that tender documents are appropriate, clear, and comprehensive. Furthermore, the study's findings can also inform the development of contractual provisions that address these causes and minimize the risks associated with them. Ultimately, the study's insights can help project stakeholders avoid costly disputes, enhance project performance, and improve the efficiency of construction project management.

Conclusion and Recommendations

It is essential to promote a better understanding of disputes and their causation as related to construction bidding in infrastructure projects. This paper thoroughly studied 94 legal cases and

identified a comprehensive list of 27 causes of disputes that are related to bidding stages in the infrastructure projects associated with the studied legal cases. Further, the authors implemented NA, spectral clustering, and ARA to quantitatively categorize/cluster the identified causes of disputes and identify the main associations within each cluster of causes. Accordingly, the 27 causes of disputes were grouped into three clusters. Moreover, the major critical combinations within each cluster are as follows: (1) Cluster 1: nonproper or untimely notification of errors in a submitted bid, differing site conditions, noncompliance with RFP requirements, and inaccurate bill of quantities, (2) Cluster 2: Unbalanced bidding, and inaccurate project cost estimates, and (3) Cluster 3: Inappropriate tender documents, rejection of a bid, and nonproper or untimely notification of errors in tender documents. The occurrence of such associations within a bidding stage of an infrastructure project is an indication of the increased probability of a dispute between project stakeholders.

In addition, the authors discussed each of the identified critical associations and recommended practices that can aid in mitigating the rise of disputes during the bidding stage in infrastructure projects, including: (1) involvement of qualified personnel, conducting of site visits, and incorporation of technologies in preparation of geotechnical reports, (2) implementation of careful judgment and checks by contractors in preparation of their submitted bids to ensure that the construction contract and awarding are based upon correct and accurate bids, (3) allocation of efficient policies and utilization of effective measures to handle unbalanced bidding practices, (4) implementation of best practices and applicable frameworks and models by contractors to improve the accuracy of their cost estimates, and (5) enhancement of the quality of tender documents through design audits and reviews, recruitment of experienced staff for coordination and management of the exchange of tender documents, among other effective practices. Implementation of such practices shall aid in the reduction of disputes during the execution of projects.

The research conducted in this paper possesses some limitations and recommendations for future research work. First, the presented results are based on the utilized techniques in this paper (i.e., spectral clustering and Apriori algorithm for ARA). Future research can use other clustering techniques, such as k-means clustering, or other algorithms for ARA, such as Eclat algorithm. The obtained results can be compared to the results observed in this paper. Further, future research is recommended to: (1) develop surveys/conduct interviews to obtain insights from practitioners in regard to the identified critical combinations of bidding stage–related causes of disputes, and accordingly (2) develop detailed guidelines for project stakeholders that enables them to mitigate the rise of disputes associated with construction bidding stage. Ultimately, the obtained results in this paper are based on the collected data within the reasonable period of the last 10 years. If the period of search is expanded, more legal cases would be collected, and it may reveal additional bidding stage–related causes of disputes and critical combinations. Future research is recommended to expand the period of search (e.g., 20 years) and examine the change in bidding stage–related causes of disputes and associated combinations over time.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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Supplemental Materials

Tables S1 and S2 are available online in the ASCE Library (www.ascelibrary.org).

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