The Application of Bayesian Network Analysis in Demystifying Construction Project Subcontracting Complexities for Developing Countries

Abstract

Purpose: This study addresses a gap in subcontractor management literature by focusing on previously unexplored complexities surrounding subcontractor management in developing countries. While past studies concentrated on selection and relationships, this study delves into how effective subcontractor management impacts project success.

Design/methodology/approach: This study employed the Bayesian Network analysis approach, utilizing a meticulously developed questionnaire survey refined through a piloting stage involving experienced industry professionals. The survey was ultimately distributed among participants based in Accra, Ghana, resulting in a response rate of approximately 63%.

Findings: The research identified diverse components contributing to subcontractor disruptions, highlighted the necessity of a clear regulatory framework, emphasized the impact of financial and leadership assessments on performance, and underscored the crucial role of main contractors in Integrated Project and Labour Cost Management with Subcontractor Oversight and Coordination.

Originality: Previous studies have not considered the challenges subcontractors face in projects. This investigation bridges this gap from multiple perspectives, employing Bayesian network analysis to enhance subcontractor management, thereby contributing to the successful completion of construction projects.

Keywords: Bayesian Network Analysis, Construction Industry, Construction in developing countries, Main Contractor-Subcontractor Relationships, Subcontractor Management.

1. Introduction

According to Osei-Asibey et al. (2021), the construction industry is mainly reliant on projects involving main contractors (MCs), subcontractors (SCs), suppliers, consultants, and clients, all of whom significantly influence the project's outcome. A subcontractor is an individual or organisation that enters into a contract with the main contractor to undertake certain tasks as part of the overall project and may be responsible for designs or the supply of labour, materials, equipment, and tools (El-Kholy, 2019). Traditionally, the main contractor is awarded a substantial portion of construction projects, while other activities are sublet to specialist contractors to enhance productivity and mitigate risks such as financial, completion, and quality risks (Debelo and Weldegebriel, 2022). The performance of subcontractors directly affects project success, with evidence suggesting that subcontracting can constitute up to 40% of the total cost of typical building projects in Ghana (Kadan, 2016). In well-developed construction economies like Australia and the UK, subcontractors handle 80% to 85% of all construction work (Williams, 2015). In certain projects, the portion of work performed by subcontractors may rise as high as 90% (Rajput and Agarwal, 2015; Mudzvokorwa et al., 2019). Despite recent trends toward off-site construction and vertically integrated organizations, Arashpour et al. (2018) noted that the construction industry's reliance on subcontracting is unlikely to change.

In many construction projects, some contractors bring together contractors who specialise in certain trades or services to deliver complex projects and act as general contractors (GCs) or construction managers. As a result, the general contractor serves as the project coordinator, while subcontractors handle most of the actual work (Polat, 2015). Focusing on core competencies is a common way to lower operating costs worldwide (Biruk et al., 2017). In most circumstances, main contractors use subcontractors to reduce costs, shorten project timelines, and share risk, but these objectives are not always guaranteed (Polat, 2015). In most cases, contractors' goals for using subcontractors are cost savings, time savings, and risk sharing, but there are some drawbacks (Karaman and Sandal, 2022; Polat, 2015).

Although the importance of subcontractors is widely acknowledged, most previous research on subcontractors has concentrated on subcontractor selection (Fagbende et al., 2011), evaluating and monitoring subcontractor performance and contractor-subcontractor relationships (Debelo and Weldegebriel, 2022). Developing a subcontractor selection model, monitoring subcontractor performance, or improving the main contractor-subcontractor relationship will not always result in successful subcontract work. Mbachu (2008) asserted that the main contractor's and the consultant's ability to achieve a project within the stipulated time, at the quality prescribed, and within budget is contingent to a large extent on the subcontractor's performance. Thus, a concerted effort of the main contractor in managing the subcontractors' operations will be necessary to attain projects within a reasonable cost and time frame.

Subcontractor-related challenges represent a primary risk within global construction projects (Yoke-Lian et al., 2012). Main contractors identify poor construction quality as a foremost issue when collaborating with subcontractors (Rajput & Agarwal, 2015). This inadequacy stems from subcontractors' failure to implement quality assurance and control programs, adhere to job safety regulations, and execute proper project planning, leading to project delays (Marzouk et al., 2013). Additionally, non-compliance with contract conditions stands out as a significant hurdle in subcontractor relations (Al-Tmeemy, 2018). Many subcontractors exhibit deficient management practices, particularly concerning cash flow management (Yoke-Lian et al., 2012). Main contractors distinguish between specialist subcontractors—such as those specializing in concrete and tiling—who often possess robust business management systems, and generalist subcontractors. This disparity highlights the lack of well-established management systems among inexperienced subcontractors (Adros & Abidin, 2019).

Existing literature on subcontractor management predominantly centres on developed nations, potentially overlooking critical insights and perspectives from developing countries, thereby constraining a comprehensive global understanding of this domain. Furthermore, the examination of contractual intricacies, legal disputes, and resolution mechanisms within subcontracting relationships represents an underexplored area that warrants deeper analysis. The adoption of methods such as Bayesian Network Analysis remains conspicuously absent in shedding light on issues such as payment delays, change orders, and scope creep. This study aims to bridge this gap by delving into these uncharted territories within subcontractor management literature. Thus, this study aims to unravel and propose strategies or solutions for the complex, critical challenges in subcontractor management. To achieve this goal, three objectives were set: (1) to determine the critical challenges in subcontractor management, (2) to ascertain the factors influencing cost and time performance of subcontractors, and (3) to categorize the identified factors from objectives 1 and 2 into themes that better explain the intricate dynamics in managing subcontractor relations, performance, and project contributions.

2. Literature review

2.1 Evolution and trends in Subcontracting Practice in Construction

Subcontracting, a long-standing practice, has evolved into a conventional method for project delivery, particularly for specialized works (Debelo and Weldegebriel, 2022). The increasing trend in subcontracting can be attributed to technological, political, social, and economic changes (Polat, 2016; Rodrigo and Perera, 2017). While main contractors bear legal responsibility for building projects, they heavily rely on subcontractors, specialists, and suppliers to execute the work (Akal, 2022). Contractors opt for the vicarious performance of subcontractors due to specialization, workload reduction, and risk mitigation (Abdullahi, 2014). However, this practice, while advantageous, carries inherent risks, given that the overall performance of the contractor hinges on the subcontractors' effectiveness.

Manu et al. (2013) noted that subcontracting serves as a means to negotiate lower labour costs, expedite tasks, outsource less rewarding or hazardous work, and promptly adapt to changing product market demands. By allocating construction tasks to different specialists, each trade can be executed in a cost-effective manner. Subcontractors encompass three types, each undertaking specific project tasks: a) trade subcontractors, like carpenters or painters, specializing in particular trades; b) specialist subcontractors, engaged in activities such as tunnel boring, post-tensioning, and pile foundation work; and c) labour-only subcontractors, supplying skilled and unskilled labour to the primary contractor (Ramalingam, 2020). Subcontractors contribute expertise by providing personnel, materials, equipment, tools, and designs for the execution of specific procedures. The selection of subcontractors in the construction industry is typically a complex decision, often reliant on managers' intuition and experience (Biruk et al., 2017; Palha et al., 2019).

The research gaps from the studies above purport that decision-making significantly impacts contractors' competitiveness negatively, especially subcontractor selection practices. The selection of subcontractors is paramount due to their critical role in project success and influence on the primary contractor's competitiveness (Mambw et al., 2020). Managing subcontractors is crucial as they undertake 80–90% of project activities (Deep et al., 2022; Polat, 2016). However, a comprehensive understanding of the various phases and sequence of activities in the management process remains lacking.

2.2 Management structure of subcontracting

The management procedure (structure) in subcontracting refers to how the general contractor sublets aspects of the project (works) to the subcontractor (Hui et al., 2008; Tang et al., 2021).

Two parameters are used to explain management arrangements: (i) the degree to which work is distributed among various subcontractors and (ii) the percentage of the volume of work that is subcontracted in monetary terms (Brahm and Tarziján, 2014). Although subcontracting decisions may be made in every single task, a holistic map of subcontracting arrangements in a project will generate insight into how firm strategy is supported by project architecture (Petro, 2019). Substantial subcontracting reduces the main contractor's control over the project, leaving more room for relational risks. Construction complexities are expected, and it is imperative to distinguish between the extent of subcontracting and the dispersion of subcontractors. This approach offers a more complex and subtle impact on organisational structure in subcontracting than conventional techniques (Brahm and Tarziján, 2014). Subcontracting arrangements in projects are a subsidiary of overall organisational boundary research that receives very little interest in the strategy and organisation literature compared to outsourcing, integration, and other related research branches (Chen et al., 2022; Tarziján and Brahm, 2014; Tan et al., 2017).

Previous studies have reported little about the determinants of subcontractor diffusion, notwithstanding providing valuable insights into the degree to which the project is subcontracted. Construction management researchers have identified concerns regarding the main contractor's capabilities and the project's features, constituting a significant proportion of influencing factors Typically, main contractors are responsible for providing, managing, and coordinating subcontractors along with the construction process activities. Despite this, the impact of governance capabilities remains largely unknown. Moreover, disputes in subcontracting decision-making often arise due to the strategic approach adopted by the general contractor (Tang et al., 2021). While project complexity has been extensively studied among project attributes, the project goal has been overlooked despite being the primary link between the project and the general contractor (Tang et al., 2021). Both the project's objective and the subcontractor's capabilities can significantly affect subcontracting management and the capabilities of the general contractor.

2.3. Contributing factors causing subcontractor management challenges

The factors influencing the relationship between contractors and their subcontractors on construction sites have been the subject of inquiry by many researchers (Hartmann and Caerteling, 2010; Chalker and Loosemore, 2016; Omotayo et al., 2022). Relationships between subcontractors and contractors are often strained and prone to conflicts due to a lack of fairness and misunderstandings (Ganiyu et al., 2021). Studying the factors affecting them is necessary to minimize these conflicts. Controlling these factors will ultimately improve the relationship between contractors and their subcontractors, consequently enhancing performance. To coordinate the subcontractors' work effectively, the main contractor must have a detailed understanding of each subcontractor’s tasks (El-Kholy, 2019; Tang et al., 2018). Ceric et al. (2021) established that the gap between main contractors and subcontractors negatively impacts site productivity.

Othman (2007) examined interface problems between main contractors and subcontractors, identifying poor communication, insufficient on-site information, inadequate supervision, the master-slave syndrome, and a lack of management systems as primary issues. Artto et al. (2008) concluded that top variables influencing the contractor–subcontractor interface include project management and planning concerns, operational relationships, financial aspects, work quality, and project complexity. Ganiyu et al. (2021) observed that several contractor firms hadn't integrated the creation of a subcontracting plan into their company procedures, attributing this to a possible lack of necessary personnel. Additionally, project-specific issues like unclear scopes of work and tight project schedules often hinder the implementation of subcontracting plans (Yin et al., 2014).

Conflicts often arise between main contractors and their subcontractors due to industry complexity and improper project management (Mahamid, 2017). According to Hartmann and Caerteling (2010), issues such as trust, quality, cost, and management can significantly impact this relationship. Lack of communication, poor planning, and inadequate management are identified by Mahamid (2017) as key factors influencing the contractor–subcontractor interface. Tayeh (2009) conducted a study in the Gaza Strip, discovering that problems stem from various issues, including assigning work to new subcontractors without informing the originals, financial constraints of the main contractor, delayed payments, contract conditions, schedule deviations, and construction quality. Alinaitwe et al. (2009) emphasized how inspection delays impede productivity, causing interface issues. Marzuki et al. (2019) highlighted that unclear drawing details contribute to problems between contractors and subcontractors.

Malla and Delhi (2022) noted that issues at the contractor-subcontractor interface stem from a lack of experience, resulting in inflexibility when adapting to new environments. Rivera et al. (2020) indicated that significant factors contributing to time delays in road construction projects, from the owner's perspective, include poor communication among construction parties, inadequate resource management, delays in project commencement, insufficient inspections, and rework. These delays often lead to interface problems between main contractors and their subcontractors. Debelo and Weldegebriel (2022) highlighted that the contractor–subcontractor relationship is a cornerstone for any successful construction project. The results of this study will facilitate proposing recommendations to enhance the contractor–subcontractor relationship in developing countries.

2.4 The application of Bayesian network analysis in built environment research

Evidence exists on using Bayesian Networks in several research fields, including built environments (Hon et al., 2021). Delgado-Hernandez and Palacios-Navarro (2023) utilised the Bayesian Network (BN) for built environment research to identify methods for enhancing client satisfaction in the construction industry. Likewise, Bakshan et al. (2017) employed a BN to establish behavioural causality models that ensure better building waste management. Zhang et al. (2020) analysed the load data of the pile foundation using the BN approach to obtain the design resistance input parameters. Sanchez et al. (2020) created a project management maturity model using BN to reduce project cost overruns. Wei et al. (2020) examined the chronology of risks in a smart city and modelled diffusion risks using BNs. Koseoglu Balta et al. (2021) demonstrated the possibility of risk prediction using the model of interdependencies between risk factors, constructing a risk network, predicting delay, and aiding decision-makers in developing outlay risk mitigation strategies for tunnel projects.

Among the areas of construction management research where Bayesian approaches have been applied are: project information management (Luo et al., 2019); materials management (Liu et al., 2020); design management (Hu and Castro-Lacouture, 2019); environment management (Bakshan et al., 2017); and stakeholder management (Sunindijo and Maghrebi, 2020). Moreover, Hon et al. (2021) reported on the applications of BN relating to safety management, risk assessment (also see Leniak and Janowiec, 2019; Wu et al., 2015b), contract management, process control, project cost management, and quality management. More precisely, Flores et al. (2021) employed the BN approach to pinpoint and analyse the best management strategies to improve the performance of window and door openings vulnerable to wind-driven rainfall ingress during tropical cyclones and strong storms. In keeping with this idea, Chakraborty et al. (2016) demonstrated a novel use of BN as a management tool for choosing between options in the railway transport sector. Finally, and more recently, Leu et al. (2023) created a BN model for forecasting project cost overruns.

Subcontractor management research and practice can benefit significantly from the application of Bayesian Network (BN) techniques, as they are well-suited to handle situations characterized by high degrees of uncertainty and complexity (Phan et al., 2016). According to Chan et al. (2018), BN techniques typically combine both subjective and objective data for monitoring, diagnosis, prediction, and establishing quantifiable relationships among variables. Given the frequent challenge of gathering flawless and complete sets of data in construction projects (Zhang et al., 2016), BN techniques are particularly useful for handling imperfect data (Leu and Chang, 2015). BNs, specifically, can more easily convey the intricacies of subcontractor management environments by utilizing Directed Acyclic Graphs (DAGs) to illustrate the interactions between variables (Baudrit et al., 2019). Consequently, BNs have been increasingly utilized in CM research fields such as schedule delay probability prediction (Luu et al., 2009), safety compliance (Al-Kasasbeh et al., 2022), and risk assessment of cost overruns (Islam et al., 2019).

In contrast to more conventional approaches like artificial neural networks (ANNs), BNs exhibit remarkable adaptability in terms of their capacity to receive inputs, produce outputs (Khanzadi et al., 2017), challenge preconceived notions in light of new research, and integrate a variety of evidence sources. Finally, to assist with management decisions, the BBN can be easily integrated with decision-analytic tools (Uusitalo, 2007). Thus, the statistical analysis applied Bayesian network analysis to deal with complexity of subcontractor management challenges.

3. Research methods and materials

The research employs a deductive approach involving the collection of quantitative data using survey questionnaires, for measuring and confirming variables identified from literature. The population of the study could not readily be determined due to the lack of official data on organizations or contractors' engagement of subcontractors in Ghana, as the subcontracting model is still evolving. In situations where the target population cannot be enumerated or distinctly identified (i.e., lacking a sampling frame), Zhao et al. (2014) advocate for the application of nonprobability sampling methods. Therefore, snowball and purposive sampling techniques were employed to identify 130 relevant participants. Hill (1998) recommended that a minimum of 30 participants is considered sufficient for survey-based research. In line with the positivist's philosophical worldview, the quantitative research design was chosen for this study. According to Hakansson (2013), survey-based research is a commonly utilized technique within the positivist paradigm.

A 5-point Likert scale was employed, with 1 and 5 symbolising 'strongly not significant' and 'very significant', respectively. The completed questionnaire was distributed through social media, email, and hand-delivered to participants in Ghana. The surveys were exclusively disseminated in Accra, Ghana. Out of 140 questionnaires disseminated, 88 valid responses were received, resulting in an approximate response rate of 63%. The collected data were analysed using Bayesian network analyses. Notably, the methodological choices involving survey questionnaires and purposive sampling were designed based on the need to effectively capture, measure, and analyse the complex phenomena associated with subcontractor management in the construction industry. This approach aims to fill the identified research gap.

3.1 Data collection instrument and participant profile.

The draft questionnaire underwent piloting among a dozen respondents who bore analogous traits to the study participants. Notably, eight pretest participants possessed at least ten years of experience in Subcontractor management in Ghana. This was essential to ensure the questions' clarity, consistency, and pertinence. For example, it was noted that the language used was too technical, prompting improvements to enhance clarity and comprehension. Subsequently, necessary adjustments were made to refine the final version in alignment with the study's objectives before formally administering the questionnaire in Ghana. The final version of the closed-ended questionnaire was divided into three parts. The first section was designed to gather information about respondents' background characteristics and project attributes. The second section focused on challenges in subcontractor management, while the third section delved into factors influencing subcontractor cost and time performance. A total of 65 variables, segmented under six components, were extracted from the literature review on factors affecting subcontractors' cost and time performance. These components encompass project-related factors, contract documents and management-related factors, and factors relevant to project staff, project managers, main contractors, and subcontractors.

>>>Insert Table 2<<<

Table 3 provides a breakdown of the attributes "Org" (organisation of the respondents), "ProfB" (Professional background), and "TypSP" (type of subcontracting projects) across different levels. For each attribute, the frequency and per cent representation and cumulative per cent are displayed for each level. The "Org" attribute has three levels. Level 1 consists of 19 instances, making up about 21.591% of the total, Level 2 has 26 instances (29.545%); and Level 3 has 43 instances, making up the largest portion at 48.864%. Cumulatively, these cover

100% of the attribute. "ProfB" has four levels, with Level 1 comprising 29 instances (32.955%). Levels 2 and 3 have 19 instances (21.591% each), while Level 4 consists of 20 instances (22.727%). Together, they also make up 100% of this attribute. "TypSP" has five levels. Level 1 dominates with 39 instances (44.318%). Levels 2 through 5 each contain just 1 instance (1.136% each). This suggests "TypSP" is heavily skewed towards Level 1. The three attributes would be used in the network and Bayesian analysis in section 4.

4. Analyses

4.1 Data Reliability analyses using Cronbach alpha and Guttman's λ2's tests

Reliability analyses using Cronbach's alpha and Guttman's λ2 are vital statistical tools that measure the internal consistency or reliability of a set of scale or test items. These measures offer insights into the extent to which these items correlate, providing a reliable outcome for the research. Despite sometimes underestimating reliability, Cronbach's alpha has proven its effectiveness in various contexts, including psychophysiology and social sciences (Malkewitz et al., 2023). Guttman's λ2, on the other hand, complements Cronbach's alpha by handling potential measurement errors, thereby enhancing the reliability of the findings (Isernia et al., 2023). Guttman's λ2 and λ6 are coefficients that measure internal consistency reliability in psychometrics. While both use item variance information, λ2 only considers the covariances, making it more restrictive. Conversely, λ6 includes higher-order dependencies and is less conservative, potentially overestimating reliability in large samples (Oosterwijk et al., 2017). These tools are instrumental in establishing confidence in the data's reliability, making them indispensable in empirical research. The reliability analyses were conducted to ensure the data met the expected standards for Bayesian network analysis.

>>>Insert Table 3<<<

Table 3 provides an overview of the reliability statistics for various items (CL1 to PD9), using three different measures: Cronbach's α, Guttman's λ2, and Guttman's λ6. Focusing on values above 0.6 showing strong reliability, all items from CL1 to CL10 display consistently high reliability across all three measures, implying these items are reliable in this specific context. The same holds for items PR8, MC1 to MC15, and others scattered throughout the table. Higher values of these coefficients suggest that the items are more internally consistent. Notably, there is a visible drop in values for some items (such as, PR1 to PR7, CDM1 to CDM12, PS1 to PS6, and PD1 to PD9), which can imply lower reliability or inconsistency.

4.2 Bayesian network analyses

4.2.1 Sparsity network analysis

Table 4 presents a summary of network analysis for five different networks for the specialisation of subcontractors. Each network has 14 nodes, and the table reports the number of non-zero edges and sparsity for each network. The first network has 65 non-zero edges out of 91 possible edges, resulting in a sparsity of 0.385. The second network has 42 non-zero edges out of 91 possible edges, resulting in a sparsity of 0.538. The third network has 51 non-zero edges out of 91 possible edges, resulting in a sparsity of 0.440. The fourth network has 48 non-zero edges out of 91 possible edges, resulting in a sparsity of 0.473. The fifth network has 43 non-zero edges out of 91 possible edges, resulting in a sparsity of 0.527. Sparsity measures how many edges are present in the network relative to the total number of possible edges. A higher sparsity indicates the network is more densely connected, while a lower sparsity indicates the network is sparser. The networks have sparsity ranging from 0.385 to 0.538, indicating moderate to sparsely connected. The number of non-zero edges in each network is also reported, which measures the overall strength of the connections between nodes. The inclusion criteria of $BF_{10}>10$ was used as the inclusion criterion for the variables in the network.

>>>Insert Table 4<<<

The general form of the joint probability distribution in a Bayesian network is as follows: Given a set of variables X1, X2, ..., Xn, the joint probability distribution for these variables can be written as:

P(X1, X2, ..., Xn) = Π P(Xi | Parents(Xi)) (1),

where Parents(Xi) represents the parent nodes of Xi in the Bayesian network, this equation follows from the chain rule of probability and the assumption of conditional independence that is central to Bayesian networks.

Given this, the relationships for the network can be modelled as:

Commercial/office buildings:
*P(SC10, MC4, SC11, PR8, PM3, CL1, SC9, MC10, CL3, MC6, PD3) = P(SC10) * P(MC4 | SC10) * P(SC11 | SC10, MC4) * ... * P(PD3 | SC10, MC4, SC11, PR8, PM3, CL1, SC9, MC10, CL3, MC6)………………………………………………………………………….. (2)*
(Assuming that the order of variables represents the dependencies).

Hotel retail/shopping centres:
*P(CL3, MC10) = P(CL3) * P(MC10 | CL3) ……………………………………………. (3)*

Consultancies:
*P(CL1, CDM11, PS6, SC10, PM3, MC4, SC11, PD3, PR8) = P(CL1) * P(CDM11 | CL1) * P(PS6 | CL1, CDM11) * ... * P(PR8 | CL1, CDM11, PS6, SC10, PM3, MC4, SC11, PD3)..(4)*

Main contractors:
*P(SC10, CL6, MC10, SC9, PM3, SC11, MC4, PD3, CL1, CDM11, MC10, MC6) = P(SC10) * P(CL6 | SC10) * P(MC10 | SC10, CL6) * ... * P(MC6 | SC10, CL6, MC10, SC9, PM3, SC11, MC4, PD3, CL1, CDM11, MC10) ………………………………………………. (5)*

Construction project managers:

$$P(CL6, SC11, MC6, CL1, PD3, MC4, CL3, PS6, SC10) = P(CL6) * P(SC11 \mid CL6) * P(MC6 \mid CL6, SC11) * \ldots * P(SC10 \mid CL6, SC11, MC6, CL1, PD3, MC4, CL3, PS6) \ldots\ldots\ldots\ldots(6)$$

Architect's view":

$$P(PM3, PS6, PD3, CDM11, MC10, PR8, CL1, CL3) = P(PM3) * P(PS6 \mid PM3) * P(PD3 \mid PM3, PS6) * \ldots * P(CL3 \mid PM3, PS6, PD3, CDM11, MC10, PR8, CL1) \ldots\ldots\ldots\ldots(7)$$

Quantity surveyors:

$$P(MC10, PR8, CL1, MC6, SC11, PD3, CL6, PM3, MC4) = P(MC10) * P(PR8 \mid MC10) * P(CL1 \mid MC10, PR8) * \ldots * P(MC4 \mid MC10, PR8, CL1, MC6, SC11, PD3, CL6, PM3) \ldots(8)$$

Civil and structural engineering respondents:

$$P(PM3, CL3, MC6, CL1, SC10, CL3, PS6, SC9) = P(PM3) * P(CL3 \mid PM3) * P(MC6 \mid PM3, CL3) * \ldots * P(SC9 \mid PM3, CL3, MC6, CL1, SC10, CL3, PS6) \ldots\ldots\ldots\ldots(9)$$

>>>Insert Figure 1(a) to (f)<<<

>>>Insert Figure 2(a) to (c)<<<

>>>Insert Figure 3(a) to (d)<<<

Under the organisation category, each network has 14 nodes, and the number of non-zero edges varies across the networks. Network 1 has 49 non-zero edges out of a possible 91, giving a sparsity of 0.462. This suggests a moderate connectivity level between the nodes in this network, with about half of the possible edges present. Network 2 also has 49 non-zero edges out of 91, giving the same sparsity of 0.462 as Network 1. This suggests that the connectivity pattern in Network 2 is similar to that in Network 1. Network 3 has 57 non-zero edges out of 91, giving a sparsity of 0.374. This suggests that the nodes in Network 3 are less connected compared to Networks 1 and 2, with only about a third of the possible edges present. The sparsity of a network is an important indicator of its structure and connectivity. A high sparsity indicates a sparser network, with fewer edges connecting the nodes, while a low sparsity indicates a denser network, with more edges connecting the nodes. Networks 1 and 2 have similar sparsity in this case, while Network 3 is less sparse.

Within the network plots from Figures 1 to 3, the values in blue have the strongest relationship within the nodes, while the red values have the weakest relationship. Hence, in Figure 1, Commercial/office buildings exhibit a strong relationship between SC10, MC4, SC11, PR8, PM3, CL1, SC9, MC10, CL3, MC6 and PD3. Similarly, hotel retail/shopping centres have a strong network between CL3 and MC10. Other projects, such as Government office buildings, Residential and hospital development, have extremely sparse relationships between the factors.

Figure 2 has three (3) networks for the organisation involving consultancies, main contractors and subcontractors. In Figure 2a, the consultancies section demonstrates strong relationships between CL1, CDM11, PS6, SC10, PM3, MC4, SC11, PD3 and PR8. Figure 2b, focusing on main contractors consists of SC10, CL6, MC10, SC9, PM3, SC11, MC4, PD3, CL1, CDM11, MC10 and MC6. Figure 2c highlights relationship involving CL1, CDM11, MC10, CL6, MC4, CL3, SC10, SC9, MC6, MC10, and PD3. Figure 3 consists of network plots for the professional affiliation of subcontractors. In Figure 3a, representing construction project managers, connections are observed among CL6, SC11, MC6, CL1, PD3, MC4, CL3, PS6 and SC10. Figure 3a, focused on the architect's view of the variables, links PM3 with PS6, PD3, CDM11, MC10, PR8, CL1 and CL3. Figure 3c pertaining to quantity surveyors, connections exist between MC10, PR8, CL1, MC6, SC11, PD3, CL6, PM3 and MC4. Lastly, Civil and structural engineering respondents linked PM3, CL3, MC6, CL1, SC10, CL3, PS6, and SC9 in Figure 3d.

4.3 Bayesian network plot for important variables

Based on the study's perspectives—subcontracting project type (Perspective 1), organization type (Perspective 2), and respondents' professions (Perspective 3)—Table 5 presents the significant codes found in the Bayesian network analysis. The objective of Table 5 is to identify the most influential factors and construct a causal network map for subcontracting. From Table 5, only seven (7) factors emerge as dominant in the Bayesian network.

>>>Insert Table 5<<<

>>>Insert Figure 4<<<

Figure 4 represents a dataset reflecting varying levels of importance or occurrence as perceived across three different perspectives (Perspect1, Perspect2, and Perspect3) for a range of code indicators (CL1, CL3, CL6, PR8, CDM11, PS6, PM3, MC4, MC6, and MC10). Each cell in the table illustrates the proportion (in percentage) that each code contributes to each perspective. In perspective 1, codes CL3 and MC10 are distinct with the highest proportion of 22.22%, indicating their importance or prevalence in this perspective. In contrast, codes CL6 and PS6 did not appear, as shown by their 0.00% values. For perspective 2, codes CL1, CDM11, and MC4 all hold a 13.64% proportion, suggesting equal importance or occurrence in this view. However, code CL3 and PR8 share the least contribution, with only 4.55%. In perspective 3, codes CL1, CL3, and PM3 contribute the highest proportions (15.38%), implying higher importance or prevalence than other codes. The minimum contribution in this perspective is from CDM11, with 3.85%. Figure 4 presents a comparative assessment of how these codes are weighed or perceived across three perspectives. Such a comparison could provide an insightful understanding of the relative importance, prevalence, or focus on these coded aspects in different contexts or views.

Figure 5 comprehensively summarises critical factors affecting subcontractor operations and performance across three perspectives. Each combination of factors represents a unique theme.

These resultant themes allow us to better comprehend the complex dynamics in managing subcontractor relations, performance, and project contribution.

>>>Insert Figure 5<<<

In Perspective 1, which focuses on the type of subcontracting project, the combination of legal disputes, lack of safety, and delay in drawing completion yields the thematic conclusion of "*Subcontractor Project Disruptions"*. This label suggests that these factors can cause disruptions or delays in project timelines and significantly impact the project's overall success. It underscores the need for proactive measures to mitigate such risks, including effective legal contract management, robust safety protocols, and timely completion of drawings. In Perspective 2 (type of organisation), the synthesis of government policy, payment method, and the presence of qualified supervisory staff culminates in the theme of "*Regulatory and Operational Framework for Subcontractor Management"*. This implies that these factors collectively shape the legal, financial, and operational environments in which subcontractors operate. This perspective emphasises the importance of staying updated on regulatory changes, setting up appropriate payment methods, and ensuring skilled supervision for effective subcontractor management. Perspective 3 (profession of respondents) encompasses factors that ensure the subcontractor's price aligns with the quality of work, financial ability and strength, and management-level leadership, yielding the theme "*Financial and Leadership Evaluation for Subcontractor Performance"*. It emphasises the need for a balanced financial assessment, leadership competency, and quality control in determining subcontractor performance. The final theme is *"Integrated Project and Labour Cost Management with Subcontractor Oversight and Coordination"*. Each of the four (4) themes identified through the analysis will be highlighted for their implications on subcontracting below.

5. Discussion

5.1 Implications of findings for subcontractor decision support

5.1.1 Subcontractor Project Disruptions

Abdullahi (2014) extensively reviews the practice of subcontracting in the construction industry, illuminating numerous complexities that could potentially engender project disruptions. One crucial aspect underscored in the study is the implication of legal disputes on subcontractor performance. Subcontracting agreements often form a convoluted legal landscape, potentially leading to disputes that obstruct project progress (Arditi & Chotibhongs, 2005). Legal conflicts arising from nebulous contract terms or disagreements over responsibilities can result in substantial delays and resource misallocation. The dearth of stringent safety measures can contribute to unanticipated interruptions, exacerbating the already precarious construction process. The consequential accidents or regulatory penalties threaten personnel and cause significant project delays, escalating costs, and diminishing productivity.

Delays in completing drawings represent another profound issue in subcontracting. Karim, Marosszeky, and Davis (2006) highlight that delays in providing design details can generate cascading effects on project timelines. The delay could lead to a sequence of disruptive events, with the subcontractors unable to initiate their work, thereby stalling overall project progress. Omotayo et al. (2022) allude to the pivotal role of trust in subcontractor payment and valuation practices. The prevailing distrust between contractors and subcontractors, particularly in the UK's private projects, often stems from discrepancies in contract administration and payment practices, further compounding the challenges of subcontracting. These issues underscore the multifaceted nature of subcontractor project disruptions and the concomitant need for robust management strategies.

5.1.2 Regulatory and Operational Framework for Subcontractor Management

Hartmann and Caerteling's work (2010) forms a compelling departure point for discussing the regulatory and operational framework for subcontractor management. In a review of procurement practices, they elucidate the interplay between trust and price, positing it as a key factor in establishing an effective management structure. Central to this interplay is the role of government policy. A well-crafted, clear policy provides the regulatory framework for fostering trust and cost-effectiveness, which is crucial for maintaining a healthy subcontractor relationship.

Additionally, Hui et al. (2008) delved into the dynamics of managing interdependence in complex projects. Their exploration emphasises the significance of a structured payment method. A transparent and fair payment system, designed considering the operational nuances of construction projects, can go a long way in enhancing subcontractor management. Such a system can aid in avoiding contractual disputes, fostering trust, and ultimately, improving project outcomes. Olatunji et al. (2016) offer an in-depth examination of subcontracting options in the construction sector, highlighting the role of qualified supervisory staff in subcontractor management. Proficient supervision ensures adherence to project standards, timelines, and safety regulations. Consequently, it becomes a cornerstone of an effective operational framework, contributing to more efficient management and successful project delivery.

5.1.3 Financial and Leadership Evaluation for Subcontractor Performance

Tang et al. (2021) underscored a crucial foundation for understanding the interplay of financial considerations and governance capabilities in subcontracting. They demonstrate the impact of a general contractor's governance capabilities on the organisational arrangement of subcontracting. One critical aspect highlighted is ensuring that subcontractors' prices align with the quality of their work. This pricing-quality balance underpins the value-for-money principle central to construction project success. Disparities between price and quality can lead to potential financial inefficiencies, compromising the overall project's cost-effectiveness and potentially impacting the construction sector's financial health. The role of subcontractors' financial ability and strength becomes particularly prominent in the study by Tan et al. (2017). Their empirical examination of subcontractor-main contractor relationships in Hong Kong elucidates how subcontractors' financial robustness directly impacts the main contractor's competitiveness. The financial stability of a subcontractor guarantees the continuous provision of services, reducing project risks related to bankruptcy or underperformance. Therefore, a thorough financial evaluation of subcontractors is vital to effective subcontractor performance management.

The prominence of leadership at the management level is accentuated in both studies. Strong leadership facilitates effective coordination, communication, and control, fostering an environment conducive to project success. Thus, assessing the leadership capabilities of subcontractor management can provide invaluable insights into their potential performance, with significant implications for project execution and the broader construction sector.

5.1.4 Integrated Project and Labour Cost Management with Subcontractor Oversight and Coordination

Fagbenle et al. (2011) shed light on the influential factors in selecting subcontractors, pointing towards a structured system for effective monitoring and support. The main contractor's role is crucial in selecting suitable subcontractors and facilitating a conducive environment for their successful operation. The support provided can manifest in different forms, such as technical advice, provision of resources, and enabling timely and clear communication. Subcontracting performance in road construction projects accentuates the main contractor's need for rigorous follow-up mechanisms. Regular checks on progress, quality, safety, and other project parameters can significantly enhance subcontractor performance. It also allows the main contractor to rectify issues early, ensuring project continuity and minimising disruption.

Therefore, controlling and follow-up of subcontractors' work by main contractors is crucial. It strengthens the trust between the parties and ensures better alignment with the project's objectives, thereby contributing to its overall success in the construction sector.

6. Conclusion and limitations of the study

The key findings of this study have significant implications for decision support in subcontracting. For instance, we identified project disruptions as a significant concern, primarily due to legal disputes, safety practices, delays in delivering detailed designs, and trust issues in payment and valuation practices. Regulatory and operational frameworks emerged as crucial in managing subcontractors, with government policy, structured payment procedures, and the presence of competent supervisory staff playing central roles.

Subcontractors play a critical role in the construction industry, an increasingly recognized fact. However, existing research primarily concentrates on subcontractor selection, performance evaluation and monitoring, and the relationship dynamics between contractors and subcontractors. Improvements in these areas do not necessarily guarantee successful subcontracting outcomes. Project completion within a predetermined timeframe, budget, and quality specifications significantly depends on subcontractor performance, highlighting the need for effective contractor management of subcontractor operations. This study aims to pinpoint the central challenges in subcontractor management and suggest a practical framework for main contractors. The study also stressed the importance of financial and leadership evaluations for subcontractor performance, ensuring a balance between price and quality, financial stability, and sound leadership capabilities. The need for effective control and follow-up of subcontractors by main contractors was also highlighted.

Despite these findings, the study has some limitations. The Bayesian analysis is based on past research focusing on subcontracting. Thus, the results may not capture the full complexity of subcontractor management. Also, the reliance on subcontractor performance as the main determinant of project success might overlook other potentially significant factors, such as market conditions, regulatory changes, and technological advancements. The proposed framework might be insufficiently flexible to adapt to different project contexts or unique subcontractor characteristics. Future research could address these limitations by adopting a more holistic and flexible approach to subcontractor management, considering broader external factors, and accommodating unique subcontractor characteristics.

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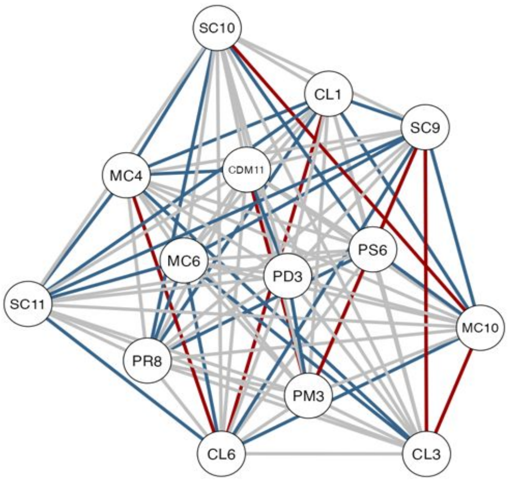
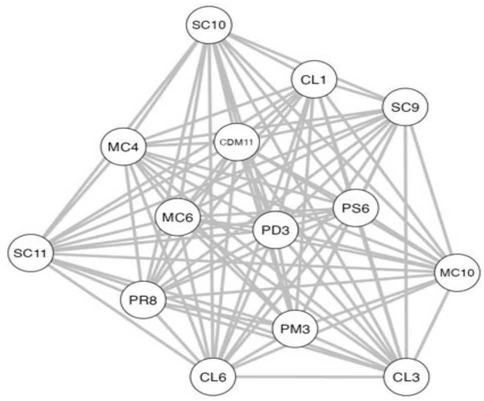
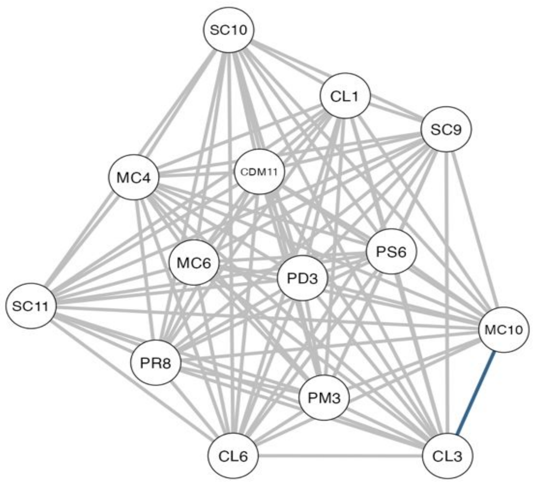
Figures



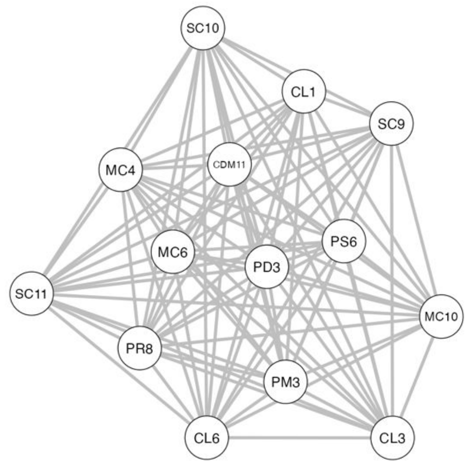
a) Commercial/office buildings



b) Government office building



c) *Hotel retail/shopping centre*



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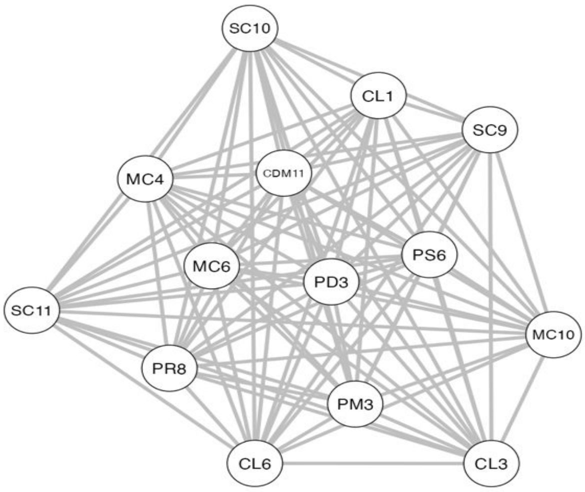
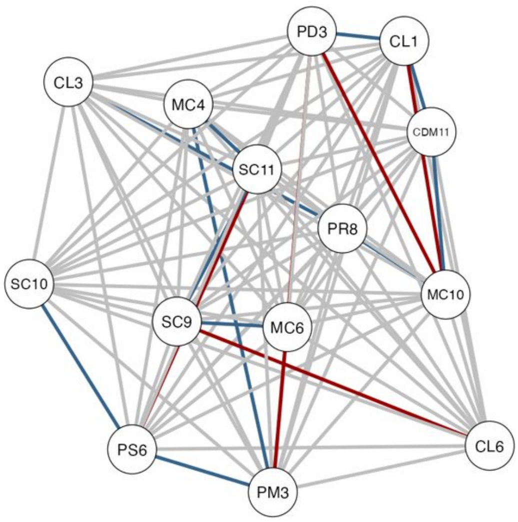
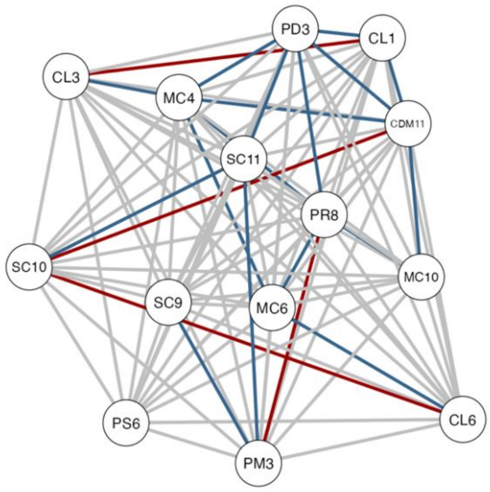


f) Hospital buildings

Figure 1(a)- (f). Edge evidence network plots for the type of subcontracting project



a) Consultancies



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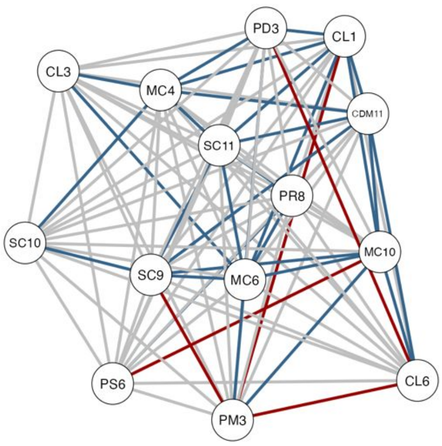
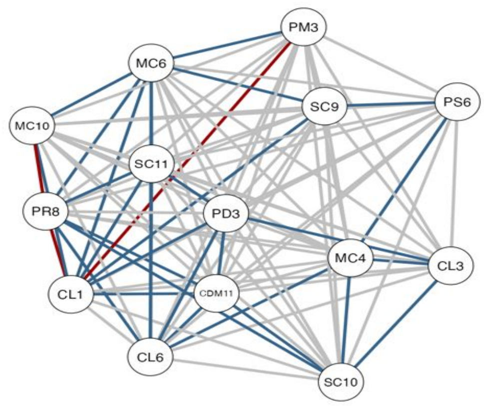
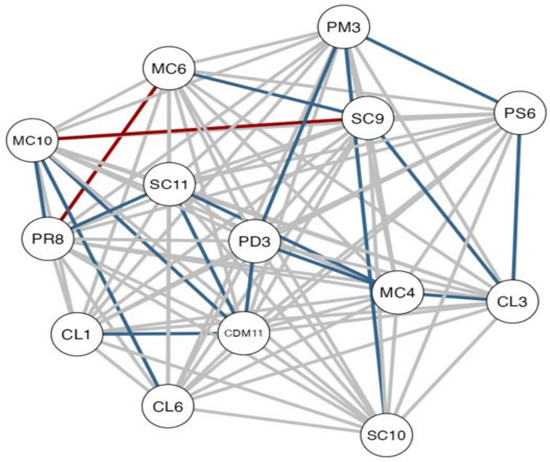


b) Subcontractor

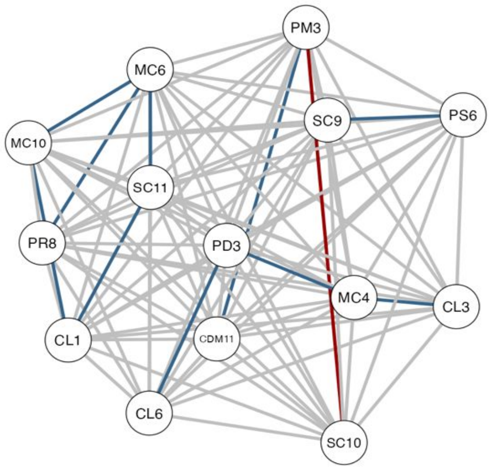
Figure 2 (a) –(c). Edge evidence network plots for the type of organisation



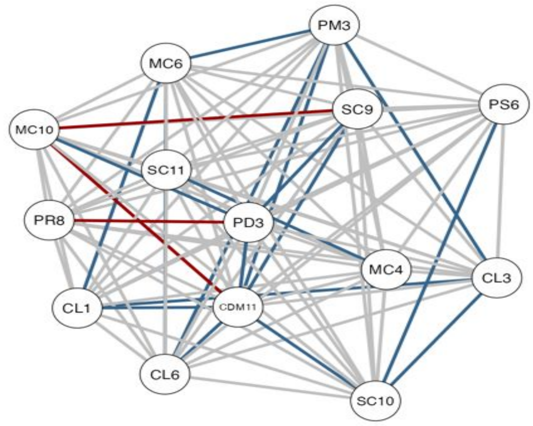
a) *Construction project manager.*



b) Architect



a) Quantity surveyor



d) Civil and structural engineer

Figure 3(a)-(d). Edge evidence network plots for professional affiliation of subcontractors

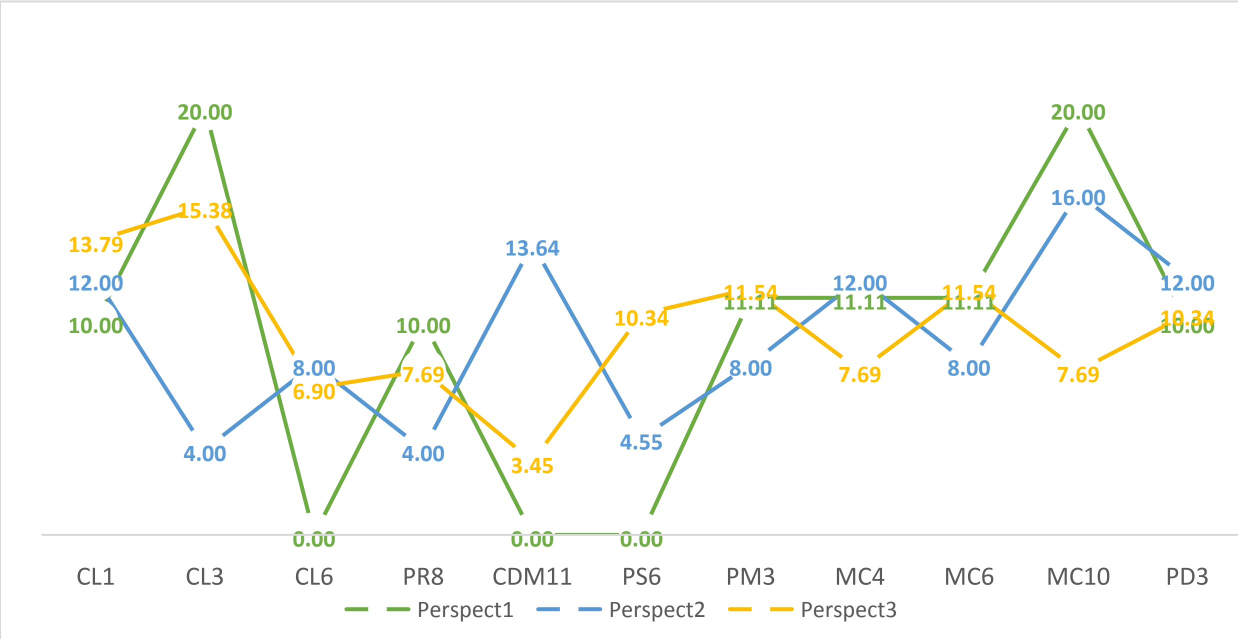


Figure 4. Chart showing the significant percentage distribution of the factors *[Note: The figures in this chart are percentages taken from Table 5]*

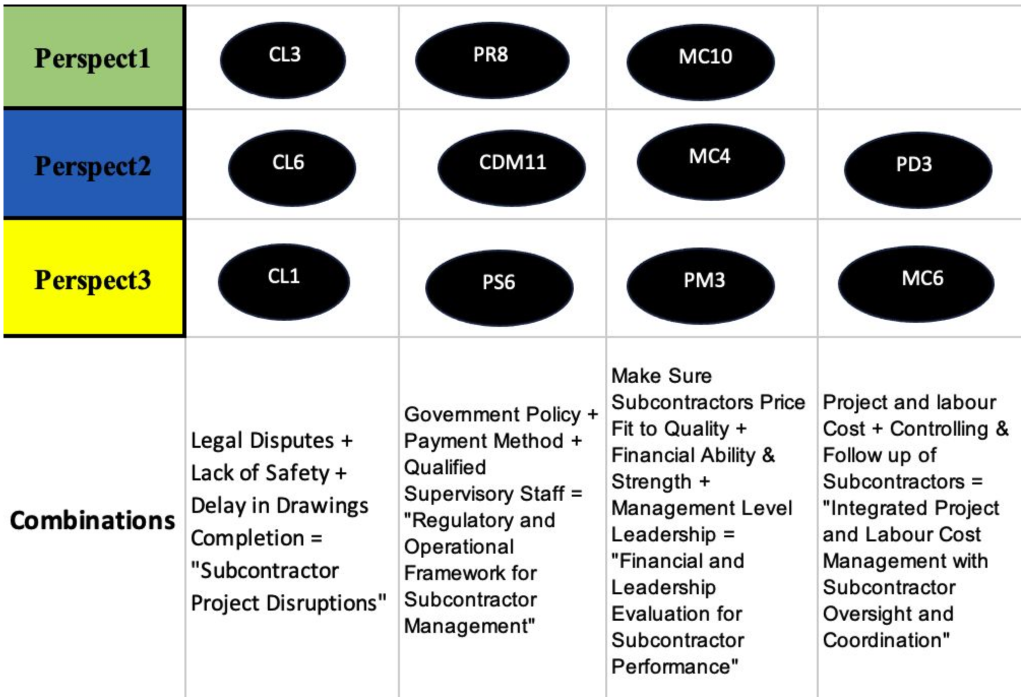


Figure 5. Derivation of factors influencing subcontractor decision in the construction

List of Tables

Table 1. Category of factors of subcontractor management challenges

	Category	Factor	Code
1	*Project Related (PR) Factors*	Densely Populated Place	PR1
		Large Project	PR2
		Additional Work Increase	PR3
		Remote Location	PR4
		No Contingency Budget	PR5
		Fundamental Changes Increase	PR6
		Many Execution Obstacles	PR7
		Government Policy	PR8
2	*Contract Documents and Management (CDM) Related Factors*	Lowest Bid Price Implement	CDM1
		Competitive Strategy Selection o Subcontractors	CDM2
		Assist Main Contractors in Pricing	CDM3
		Subcontractors ID Preferred	CDM4
		Clear Understanding	CDM5
		Clarity of Contract	CDM6
		Delays in Adoption of change	CDM7
		Compliance with Regulations	CDM8
		Adherence to Subcontract	CDM9
		Quality and Clarity of Design Drawing	CDM10
		Payment Method	CDM11
		Insurance Terms	CDM12
3	*Factors Pertaining to Project Staff (PS) In General*	Lack of Efficiency	PS1
		Morally Support	PS2
		Preparation of Training Courses	PS3
		Work On-site	PS4
		Number of Craftsmen and Labourers	PS5
		Qualified Supervisory Staff	PS6
4	*Factors Pertaining To Project Manager (PM)*	Manager Personality	PM1
		Salary of Managers	PM2
		Management Level Leadership	PM3
		Regular and Effective Communication	PM4
		Managers Recognition of Construction	PM5
5	*Factors Related To Main Contractors (MC)*	Previous Experience	MC1
		Practical & Technical Ability of Main Contractors	MC2
		Contractors Performance	MC3
		Financial Ability & Strength	MC4
		Ability in Dealing with Uncertainty	MC5
		Controlling & Follow up of Subcontractors	MC6
		Financial Facilitation to Subcontractors	MC7

		Main Contractor give Subcontractors Work Plan	MC8
		Provide Subcontractors Location Services	MC9
		Make Sure Subcontractors Price Fit to Quality	MC10
		Commitment of Main Contractors with Project Schedule	MC11
		Ability in Bearing risk	MC12
		Bearing Responsibility in Case of Accidents	MC13
		Relationship With Subcontractor	MC14
		Lack of Trust	MC15
6	*Factors Related To Subcontractors (SC)*	Size of Subcontractors Staff	SC1
		Previous Experience	SC2
		Practical & Technical Ability	SC3
		Financial Ability & Strength	SC4
		Performance of Relevant Previous Projects	SC5
		Subcontractor Familiarity with Work	SC6
		Extent of Subcontractors Commitment to Specifications	SC7
		Extent of Subcontractors Commitment to Schedule	SC8
		Close Control Over the Cost by Subcontractors	SC9
		Prompt Payment to Labourers	SC10
		Provide Adequate Information	SC11
7.	*Factors affecting cost and time legal performance of subcontractors (CL)*	Legal Disputes	CL1
		Shortage of Construction Material	CL2
		Delay in Drawings Completion	CL3
		Amendments	CL4
		Incomplete Work-drawings or Specifications	CL5
		Lack of Safety	CL6
		Site Coordination Challenges	CL7
		Lack of Proper Communication	CL8
		Non-Adherence to Schedule	CL9
		Non-Adherence to Schedule	CL10
8.	*Project development challenges facing subcontractors (PD)*	Profit rate of project	PD1
		Material and Equipment Cost.	PD2
		Project and labour Cost.	PD3
		Waste rate of materials.	PD4
		Cost of variation.	PD5
		Planned time errors.	PD6
		Time needed to implement variation.	PD7
		Time needed to rectify defects.	PD8

		Overhead percentage of project	PD9

Table 2. Participant profile showing frequency and percentage

Attribute	Level	Frequency	Percent	Cumulative Percent
Org	1	19	21.591	21.591
Org	2	26	29.545	51.136
Org	3	43	48.864	100.000
ProfB	1	29	32.955	33.333
ProfB	2	19	21.591	55.172
ProfB	3	19	21.591	77.011
ProfB	4	20	22.727	100.000
TypSP	1	39	44.318	90.698
TypSP	2	1	1.136	93.023
TypSP	3	1	1.136	95.349
TypSP	4	1	1.136	97.674
TypSP	5	1	1.136	100.000

[Org=Organisation{1=Consultant, 2=Main contractor, 3=Subcontractor}; ProfB=Profession{1=Construction project manager, 2=Architect, 3=Quantity surveyor, 4=Civil and structural engineer}; Exp=Years of experience{1=1-5, 2=6-10, 3=11=15, 4=16 and above}; Spec=Specialisation{1=Building, 2= Mechanical, 3=Plumbing, 4=Tiling, 5=Electrical, 6=Glazing, 7=Others}; TypSP=Type of subcontracting project{1=Commercial/office building, 2=Government office building, 3=Hotel retail/shopping centre, 4=Residential development, 5=Hospital, 6=School sports centre, 7=Market, 8=Library, 9=Others}]

Table 3. Frequentist item reliability statistics

S/N	Item	**Cronbach's α**	**Guttman's λ2**	**Guttman's λ6**
1	CL1	0.684	0.721	0.763
2	CL2	0.620	0.666	0.711
3	CL3	0.693	0.728	0.758
4	CL4	0.657	0.700	0.737
5	CL5	0.613	0.658	0.691
6	CL6	0.713	0.747	0.792
7	CL7	0.666	0.712	0.759
8	CL8	0.667	0.714	0.738
9	CL9	0.712	0.740	0.777
10	CL10	0.662	0.708	0.754
11	PR1	0.479	0.586	0.665
12	PR2	0.550	0.632	0.678
13	PR3	0.366	0.503	0.569
14	PR4	0.398	0.496	0.552
15	PR5	0.456	0.556	0.631
16	PR6	0.458	0.560	0.628
17	PR7	0.567	0.634	0.719
18	PR8	0.603	0.656	0.678
19	CDM1	0.325	0.440	0.633
20	CDM2	0.372	0.493	0.663
21	CDM3	0.371	0.506	0.679
22	CDM4	0.373	0.513	0.697
23	CDM5	0.436	0.551	0.702
24	CDM6	0.421	0.552	0.718
25	CDM7	0.393	0.532	0.734
26	CDM8	0.364	0.506	0.676
27	CDM9	0.474	0.508	0.695
28	CDM10	0.502	0.571	0.723
29	CDM11	0.502	0.593	0.729
30	CDM12	0.421	0.544	0.682
31	PS1	0.361	0.451	0.397
32	PS2	0.308	0.426	0.324
33	PS3	0.281	0.390	0.249
34	PS4	0.264	0.379	0.350

35	PS5	0.239	0.318	0.307
36	PS6	0.412	0.488	0.464
37	PM5	0.348	0.442	0.405
38	PM1	0.367	0.455	0.356
39	PM2	0.305	0.396	0.374
40	PM3	0.376	0.467	0.418
41	PM4	0.348	0.444	0.389
42	MC1	0.470	0.572	0.705
43	MC2	0.512	0.542	0.714
44	MC3	0.517	0.600	0.716
45	MC4	0.534	0.617	0.739
46	MC5	0.468	0.566	0.712
47	MC6	0.520	0.607	0.733
48	MC7	0.485	0.587	0.687
49	MC8	0.502	0.596	0.723
50	MC9	0.402	0.531	0.693
51	MC10	0.537	0.619	0.744
52	MC11	0.506	0.598	0.737
53	MC12	0.414	0.528	0.679
54	MC13	0.432	0.547	0.698
55	MC14	0.505	0.591	0.699
56	MC15	0.504	0.587	0.691
57	PD1	0.491	0.353	0.348
58	PD2	0.365	0.350	0.338
59	PD3	0.249	0.347	0.352
60	PD4	0.430	0.458	0.414
61	PD5	0.332	0.492	0.415
62	PD6	0.355	0.466	0.368
63	PD7	0.314	0.365	0.375
64	PD8	0.386	0.493	0.426
65	PD9	0.359	0.448	0.380

Table 4. Summary of edge evidence plot

Network	Number of nodes	Number of non-zero edges	Sparsity
Type of subcontracting project			
1	14	65/91	0.385
2	14	42 / 91	0.538
3	14	51 / 91	0.440
4	14	48 / 91	0.473
5	14	43 / 91	0.527
Organisations			
1	14	49 / 91	0.462
2	14	49 / 91	0.462
3	14	57 / 91	0.374
Profession			
1	14	62 / 91	0.319
2	14	65 / 91	0.385
3	14	53 / 91	0.418
4	14	69 / 91	0.242

Table 5. Presentation of factors within the varying perspectives

S/N	Codes	Perspective 1	Perspective 2	Perspective 3
1	CL1	1	3	4
2	CL3	2	1	4
3	CL6	0	2	2
4	PR8	1	1	2
5	CDM11	0	3	1
6	PS6	0	1	3
7	PM3	1	2	3
8	MC4	1	3	2
9	MC6	1	2	3
10	MC10	2	4	2
11	PD3	1	3	3
Total		10	25	29

[Note: perspective 1= Type of subcontracting project; Perspective 2= Type of organisation; Perspective 3= profession of the respondents]