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Effect of Implementing Sustainable Management Practices on Construction Claims Mitigation

By

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Dedication Page

I dedicate this thesis work to my husband, Rayan, who has been a constant source of support and encouragement during the challenges of the two years of my graduate studies.

I also dedicate this work to my parents and sisters who have never left my side and are very special.

To my lovely daughter, Mila, I would like to thank her for her tolerance and understanding.

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EFFECT OF IMPLEMENTING SUSTAINABLE MANAGEMENT PRACTICES ON CONSTRUCTION CLAIMS MITIGATION

Zeina Farid Thabet

Abstract

The fragmented management of traditional construction projects, which mainly lacks the integration of project processes, often results in schedule delays and cost overruns leading to client dissatisfaction, quality defects, and increase in work accidents and injuries. As a result, claims and disputes are most likely to arise between the contracting parties that can be extremely expensive and may severely impact the project performance. Numerous studies have investigated the influence of integrating sustainable management practices (SMPs) in construction projects on specific project performance objectives, such as cost, time, and quality; however, none has considered the effect of implementing SMPs on claims and dispute resolution. This gave the impetus for this research which aims at studying the impact of implementing an integration of SMPs clusters on construction claims mitigation. To achieve this goal, a comprehensive literature review was conducted and resulted in the identification of 25 critical SMPs and 10 frequent construction claims. Then, a survey was designed and a total of 144 construction engineering industry experts participated to assess the effect of implementing the identified SMPs on claims mitigation. The received data was checked for reliability and then analyzed using Mean Score technique and factor analysis to identify major clusters of SMPs. Then, an adaptive neuro-fuzzy inference system (ANFIS) model was developed via MATLAB software, to establish optimal approaches for integrating SMPs that promote the reduction of different claim types. The research findings highlighted 12 optimal SMPs integrated approaches in eliminating different types of claims. Particularly, the research revealed that high implementation of three clusters of SMPs, namely "experienced green building certified professionals", "sustainability requirements at early design phase", and "sustainability requirements at execution phase" have the potential to eliminate or at least reduce the majority of construction claims. This study assists construction project management experts in identifying an optimal combination of a minimum number of sustainable management practices that, if implemented together, can help in significantly reducing targeted types of claims.

Keywords: Sustainability, Triple bottom line (TBL), Construction Management, Claims, Neurofuzzy Inference System

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Chapter One

Introduction

One of the challenging issues in construction projects is the presence of claims and disputes which are considered one of the most unpleasant and disruptive events of a project. Claims and disputes are practically inevitable in any construction project, and managing them is consequently considered critical in order to ensure a successful project delivery (Kululanga et al., 2001; Kang et al., 2013; Kim et al., 2016; Olatunji, 2015; Seo and Kang, 2020). In fact, urbanization and expansion of the construction industry have led to the investment in larger and more complex projects (Seo and Kang, 2020). Each project is characterized by its own uniqueness, complexity, and uncertainty making it vulnerable to risks, disputes and severe fluctuations in budget and time constraints (Zaneldin, 2006). Considering the increasing number and size of projects, it is obvious that the number of claims continues to increase as well. In general, the fragmented management of traditional construction projects results in schedule delays and cost overruns which often lead to client dissatisfaction, quality defects, increase in risk factors (e.g., unforeseen site conditions, poorly drafted contracts, change orders, poor project management), and raise in safety-related accidents (Tommelein et al., 1993; Awwad et al., 2016; Shaikh et al., 2020) . As a result, claims and disputes are most likely to arise between the contracting parties (Shaikh et al., 2020). The average of claim and dispute occurrence in all construction projects is between 10 and 30% and the cost for resolving such claims and disputes varies from $4 to $12 billion or more per year (Gebken and Gibson, 2006). In 2011, the average cost of construction disputes in the United States was $10.5 million (Rajendran et al. 2013). According to Seo and Kang (2020), construction claims avoidance has been regarded as a main target for proper management of construction projects. Moreover, Bakhary et al. (2015) affirmed that the rising quantity of claims dictates the importance of implementing effective construction claim management plan. Once a claim has occurred, contractors should submit a breakdown for the activities causing extra costs and time and provide all sufficient documentation while project owners should track and manage the claims submitted by contractors (kululanga et al, 2001). As a result, the owner and contractor would reach an agreement concerning the claim or may get into a conflict and then a dispute (Abdul-Malak et al, 2002).

Becoming more aware of the high risks and costs associated with claims and litigations, several attempts were made in the literature to study claims and help in their reduction. Moreover, because construction claims' mitigation is a critical success component for enhancing project's performance, many researchers have investigated the causes of claims and disputes. Mitkus and Mitkus (2014) observed that poor communication between the project stakeholders is the reason behind 90% of the construction claims and disputes. Other significant causes of claims can be stated as follow: payments' delay, design error, insufficient drawings and design specifications, variation orders, site and weather conditions, deficient contractor experience, unforeseen risks and submission of low budget bids due to high competition in the construction market (Hassanein and Nemer, 2007; Shah, 2014; Hashem, 2018; Hayati et al., 2019). On the other hand, several studies went beyond identifying the most frequent claims to studying and devising different approaches to control the frequency and severity of their occurrence such as pre-contract negotiation, project delivery method, contract type, partnering and trust, detailed risk analysis shared and discussed with different project's stakeholders (Aibinu, 2009; Awwad et al, 2016; Hashem et al, 2018).

Despite the significant efforts of previous studies in identifying construction claims types, main causes, and recommendation for their resolution, no study has investigated the effect of implementing sustainable management practices on the mitigation of construction claims. In fact, different studies have emphasized that project management of the construction sector should evolve towards the sustainable track (Saad et al., 2019). Several researchers argued that integrating sustainability key factors (encompassing economic, environmental, and social dimensions) would contribute in delivering successful projects by improving quality of output, increase in productivity, profitability, decrease in life cost and enhance construction companies competitiveness abilities (Zainul-Abidin & Pasquire, 2007). Furthermore, according to Shen et al. (2010), the reasons that sustainability should be integrated in the project management plan is that sustainability contributes to the well-being of the construction business, has a positive impact on the environment and the society as well, and provides competitive advantages and financial gains for construction enterprises. Mainly, sustainable project management involves the management of all phases during the entire life-cycle of a project via planning, monitoring and controlling the total project's processes, in order to fulfill stakeholders' demands and content, and ensure that the triple bottom line concept (economic, social and environmental dimensions) of sustainability is well considered (Stanitsas et al., 2021). Consequently, it is becoming crucial to adjust the traditional construction management practices into more sustainable ones to minimize risks and improve the chances of delivering a project with minimum cost and time constraints (Robichaud and Anantatmula, 2011). Such adjustments may include advanced level of coordination and communication among the project's team in addition to proper project planning in the early phases of the project life cycle.

The success of a project therefore requires an integrated approach in which all stakeholders are involved in order to quickly detect and resolve deviations and problems encountered during execution and subsequently avoid costly and lengthy litigation (Gebken and Gibson, 2006). Yet the majority of engineering firms show a lack of interest in claims management. They do not have an integrated process for tracking and proactive management of claims. The management of these disputes is often considered a legal process that takes place in the final phase of the project. However, it is essential for each project management company to put in place an integrated process which makes it possible to manage the claims from the identification of the causes until the closing, and also to take actions in order to identify the claims at the appropriate time to reduce them or better avoid them. This aspect is part of the preventive management of claims, which consists of identifying claims during the execution of projects in order to analyze and resolve them before reaching the legal route, which is extremely expensive for the stakeholders. The difficulty lies in the early identification of claims. This changes from project to project, contract to contract and team to team. Effective management of claims is therefore essential, which requires a good understanding of the risks and responsibilities of each stakeholder, good control of the scope of the project and good communication between the different parties.

The main objective of this thesis is to propose an integrated claims management process based on the implementation of sustainable project management practices. To achieve this goal, an adaptive neurofuzzy inference system model has been developed in this study and sensitivity analysis was conducted to determine the optimal combinations of clusters of sustainable management strategies that may significantly reduce the number and frequency of targeted types of construction claims at the very early stages of a project. Considering the constraints and limitations on sustainable practices' implementation in projects, this model provides practitioners with essential knowledge for proper selection of the critical sustainable management practices that can significantly mitigate specific types of construction claims and thus improve the project performance in terms of cost, time, and quality.

The first step of this research consisted of conducting a comprehensive literature review of all publications discussing construction claims types, frequency and mitigation approaches along with sustainable construction aspects and practices. Based on identified sustainable management practices (SMP) and most frequent types of claims in the literature, a survey was designed and administered to construction professionals to collect their feedback about the impact of SMPs on potentially related claims' mitigation. Then, the data collected from the survey was tested for robustness using Cronbach's alpha test and mean score technique to check the rankings and significance of SMPs in claims mitigation. Then an adaptive neurofuzzy inference system model was developed to reveal the complex relationships between the analyzed SMPs in promoting construction claims mitigation. Finally, sensitivity analysis was adopted to analyze the results and recommendations about optimal strategies for SMPs implementation have been provided to construction professionals.

Chapter Two

Literature Review

The literature review of this thesis is divided into three sections. The first one discusses sustainable construction, its challenges, and the importance of integrating sustainable management practices into construction projects. The second section identifies the frequent claim types highlighted in literarture, their main causes, and effective mitigation strategies. Then, the third section discusses neurofuzzy systems' applications in the construction management literature.

2.1 Sustainable Construction Management

The triple bottom line (TBL) of sustainability integrates the concepts of economic prosperity, environmental quality, and social justice (Elkington, 1998). As explained by Sourani and Sohail (2010), the social dimension focuses on a number of issues, including adoption of health and safety plans, involvement of stakeholders, equality and diversity in the workplace, and generation of employment opportunities. The economic dimension involves the whole life costing, support of local economies, and financial affordability for intended beneficiaries (Sourani and Sohail, 2010). Regarding the environmental dimension, it includes the reduction of energy and water consumption by using renewable resources, which contributing to minimizing pollution (Sourani and Sohail, 2010; Du Plessis, 2007). Therefore, achieving the right balance between these three pillars (i.e., economic, social, and environmental) could maintain the true intent of sustainability (CIRIA, 2006).

In their capacity, engineering and contracting (E/C) firms can contribute to sustainable development by adopting measures that support sustainable management of human and natural resources and contribute to the welfare of society and the economy as a whole in order to ensure long term operation (Mitchell et al., 2007). That said, a number of E/C companies are shifting from a conventional economic perception of business to a more sustainable business version involving environmental, social, and economic concerns in their operations (Berns et al., 2009). Moreover, it is stated that (1) the growing market demand and public policy (Haapio and Niitaniemi, 2008) and (2) the binding legal obligations, as delineated in the guidelines and legal procedures (Goh and Rowlinson, 2013) have both driven the applicability of sustainable construction in the developed countries. Pearce et al. (2010) reported that the implementation of various sustainability initiatives are being fostered by the legal laws such as the "Occupational Safety and Health Acts" (OSHA) and "erosion and sediment control" (ESC).

Engaging the concepts of sustainability in project management has started gaining momentum in the last decade (Silvius and Tharp, 2013). Several authors argued that integrating sustainability in project management requires a perspective shift from managing time, budget and quality, to managing social, environmental and economic impacts (Ebbesen & Hope, 2013; Haugan, 2012; Silvius et al., 2012). In traditional project management, controlling time, quality, and budget is limited to short-term project processes and outcomes while the integration of sustainability entails a complete shift from such limited perspective of predictability and accountability to considering long-term overview of the project lifecycle characterized by flexibility to changes and complexity in economic, environmental, and social aspects (Carboni & Reeson, 2012). This shift in project management style should also affect the behavior and attitude of project managers towards the delivery of their projects (Crawford, 2013). In traditional projects, project managers tend to perform tasks and duties by keeping the project team focused around scope, deliverables, budget, risks and resources, as specified by the stakeholder's requirements. However, project managers can play a significant role in the integration of sustainability project management concepts which influence all the processes and practices at the economic, environmental, and social levels throughout the whole lifecycle of a project realizing the targeted development of the organization and the society as well. To this end, Silvius and Schipper (2014) suggested the following definition for sustainable project management: "Sustainable Project Management is the planning, monitoring and controlling of project delivery and support processes, with consideration of the environmental, economical and social aspects of the life-cycle of the project's resources, processes, deliverables and effects, aimed at realizing benefits for stakeholders, and performed in a transparent, fair and ethical way that includes proactive stakeholder participation".

In many countries mainly developing ones, the integration of sustainability into the basic project management practices is still lagging behind (Banihashemi et al., 2017). This could be attributed to the fact that in developing countries economic development is prioritized over sustainability requirements. Adding to that, managerial challenges are found to be one of the most influencing challenges in the delivery of sustainable projects (Othman and Ahmed, 2013). In fact, the implementation of sustainable aspects to project management practices require incentives from the government, change in clients' demands, as well as enforcement of existing environmental regulations (Banihashemi et al., 2017). Moreover, the identification and understanding of the critical success factors associated with sustainability is a prerequisite for integration of sustainability into project management practices in construction projects (Pade et al., 2008).

Several studies in the literature aimed at identifying sustainable management practices that are deemed effective in construction projects. Sappe (2007) stated that conventional construction projects are characterized by their fragmentation, improper coordination, and lack of communication among the different project stakeholders. Technical expert teams working on a project tend to perform their own construction methods without referring to the other entities involved in the project (Sappe, 2007). This prohibits the ability to track changes, eliminate risks, and manage cost and time variations on site (Reed and Gordon, 2000). As a remedy, different stakeholders and subcontractors should work together to improve communication and link different project phases and processes to share common outcomes and decisions. For instance, the establishment of a design charrette at the beginning of a project can also enhance communication, exchange of data, and detection of risks and conflicts at very early stages. Moreover, a design charrette can support critical project planning at the beginning of projects as well as proper management in terms of containing cost variation associated to green projects implementation (Lennertz, 2003). In general, the main adjustments entailed for traditional management practices to become sustainable include promoting cooperation among stakeholders, coordinated site selection, modifying construction techniques and building systems to adapt to sustainable development requirements (Robichaud and Anantatmula, 2011). Robichaud and Anantatmula (2011) suggested multiple approaches to adjust conventional management practices which include: (1) specifying sustainability goals and green building requirements for the project initially in the feasibility phase, (2) employing green building experts and technicians at early stages of feasibility, design, and execution, (3) maintaining good collaboration between project team members starting from the initial design concepts to final design plans, work specifications, cost estimation, and execution plans, (4) including incentives and bonuses to encourage the implementation of sustainable development, and (5) providing continuous training and spread education regarding sustainability concepts among on-site construction personnel. Another study established by Gunhan (2018) provides recommendations regarding sustainable practices that should be integrated into project processes. The study indicated that exquisite levels of communication and collaboration must be attained between stakeholders to share expertise in executing complex sustainable building projects. Adding to that, trust and chemistry are considered other vital factors that affect the successful delivery of sustainable projects (Nofera and Korkmaz, 2010). Korkmaz et al. (2010) also revealed that project delivery methods such as construction management at risk (CMR) and design-build (DB) can enhance early coordination among key project parties in the design phase as opposed to the traditional design-bid-build (DBB) method. It was highlighted in different studies that adoption of DB method can improve the achievement of sustainable development in construction projects where teams can interact effectively and decisions can be made faster (Miller at al., 2009; Tulacz, 2011b; Gultekin et al, 2013; Tulacz, 2017c). Moreover, introducing technology such as building information modeling (BIM) can effectively assist in managing different project processes (Gultekin et al, 2013). BIM encourages the early involvement of all key contractors and designers (civil, mechanical, electrical, plumbing, architects) as well as it improves documentation, monitoring and control of energy use throughout the useful life of the project (Tulacz, 2010b). Shurrab et al. (2018) emphasized the importance of implementing environmental management plan, adoption of offsite-prefabrication, and the use of updated machinery as critical sustainable factors that can significantly improve sustainability achievement. Nevertheless, it is vital to shift the traditional approach of project's feasibility study to a novel one which encompasses the TBL concepts of sustainability (Shen et al., 2009). It is found that considerable attention is given to identifying environmental goals, assigning green certification levels, and amount of capital investment on green resources (Ding, 2008). Other social aspects that are recommended to be included in the feasibility study include assessment of the project’s influence on the local social development and considerations of safety measures (Robichaud and Anantatmula, 2011). On the environmental level, noise assessment, waste assessment, construction site selection, and land consumption shall be taken into consideration when conducting feasibility study (Kumar and Gupta, 2014). Many other sustainability considerations were emphasized in the literature such as abiding by various government sustainability laws such as environmental regulations and social responsibility (Kibert, 2008). Nelms et al. (2007) shed light on enforcing green design and supporting adequate procurement and contracting strategies. Shen and Yao (2006) argued that ensuring collaboration among project teams as well as improving employee education and training enhance an organization's commitment to sustainable development. Moreover, increasing the company's technological and innovative capabilities, and implementing adequate documentation and reporting systems are deemed vital to promote sustainability in construction projects (Bakhtiar et al., 2008).

Previous research also concentrated on the classification of sustainable management indicators into the dimensions of the TBL (Economic, environmental, and social) (Stanitsas et al., 2021). It classified sustainability indicators into the three pillars of sustainability to allow construction managers distinguish between different indicators and concentrate on what benefit them best. Other studies emphasized the role of implementing sustainable management practices in optimizing the delivery of cost efficient green construction projects. Implementing sustainable management practices can considerably increase a sustainable construction project's ability to be completed within tolerable cost constraints (Robichaud and Anantatmula, 2011). A study conducted by Shurrab et al. (2018) demonstrated that the incorporation of sustainable management factors can considerably enhance the business performance of construction companies in the United Arab Emirates (UAE). The findings of this study clearly indicated that, despite the significant financial and resource commitment required to develop a green project, it is still worthwhile because sustainable development can offer the business financial and competitive advantages on the long term (Shurrab et al., 2018). This relationship between sustainability performance and business competitiveness was also examined by Tan et al. (2010) who found that on the long-term, sustainability performance can greatly contribute to business competitiveness. Nonetheless, there has been no research in the literature that studied the impact of applying sustainable construction management practices on construction claims' mitigation, which mainly constituted the incentive for this study.

2.2 Claims in construction projects

A claim can be defined as a declaration of the right to property, money, remedy, lost time, and relief, or a compensation for the damages made by any party to the contract (Semple et al. 1994). Examining the various types and causes of claims is an essential task that may help in resolving them (Ren et al. 2003). Several research studies have classified claims into different types. Moura and Teixeira (2007) identified eight types of claims as follows: termination of contracts, measurement and payments, acceleration, suspension of works, beginning and ending, force majeure, delays, and changes. Zaneldin (2006) ranked six different types of claims based on their frequency of occurrence from most occurring to least as follows: changes claims, extra work claims, delay claims, different site conditions claims, acceleration claims, and contract ambiguity claims. According to Shaikh et al. (2020), eight common claims are frequently occurring in construction sites, namely: delay claims, extra work claims, work acceleration claims, contract ambiguity claims, extension of time claims, suspension of works claims, work volume changes claims, and design error and change in scope claims. The identified types of claims extracted from the literature are summarized in Table 2.1. Furthermore, different studies have identified the different causes of claims, such as delays due to design errors, differing site conditions, variation orders, oral change orders by owner, contractor's poor organization, contractor financial problems, poor quality of contractor's work, among others (Diekmann and Nelson, 1985, Zaneldin, 2006). Shaikh et al (2020) argued that main causes of construction claims can be attributed to delay of payments, incomplete design, inadequate specifications and drawings, variation orders, weather conditions, decision making, delay in drawings & specifications, and site conditions. Aibinu (2009) also indicated that delay of payments is a major cause for conflicts between the contracting parties.

Another delay cause is design error and imprecise drawings and specifications (Diekmann and Nelson, 1985). Semple et al. (1994) also focused on variation orders and weather conditions as sources of claims that are due to changes ordered by the owner and to severe weather conditions that affect the progress of the project. Awwad et al. (2016) discussed the major causes for claims in the Middle East region which include but are not limited to imprecise information in the contract documents, variations ordered by the owner, inaccurate technical plans and specifications, poor administration of contracts, unbalanced bidding and inadequate contractor's experience, contractors or owners violation of contract's obligations.

Table 2.1 Types of Claims Mentioned in Previous Studies

Claim Types	Moura and Teixeira (2007)	Zaneldin (2006)	Shaikh et al. (2020)	Semple et al. (1994)	Diekmann and Nelson (1985)
Termination of Contract	x				
Measurements and Payments	x				
Work Acceleration	x	x	x	x	
Suspension of Works	x		x		x
Force Majeure	x				
Delay	x	x	x	x	
Change Orders	x	x		x	x
Extra Work		x	x	x	
Different Site Conditions		x			x
Contract Ambiguity Claims		x	x		
Extension of Time			x		
Work Volume Changes			x		
Design Error and Change in Scope			x		x
Scheduling				x	
Weather Conditions					x

As can be deduced from the conducted literature review, causes of claims and disputes are diverse where any source of ambiguity leads to conflicts between the related parties. Sources of ambiguity include ambiguities in contracts, poor contract draftsmanship, contract modifications, lack of local industry readiness, and missing information in contracts. To diminish the frequent occurrence of claims in construction projects, practitioners must be aware of the core reasons of such claims to be able to resolve them in the initial stages of drafting the contract documents and conditions. Different scholars have suggested strategies for claims' mitigation during construction, for instance, proper contract management, adequate planning and scheduling, appropriate documentation and record keeping (Hassanein and El-Nemr, 2008), pre-contract negotiation (Aibinu, 2009), stakeholders' involvement' at early project stages (Eom and Paek, 2009), partnering agreements between stakeholders, and proper value engineering processes (Eom and Paek, 2009; Soe and Kang, 2020). Zaneldin (2006) included several recommendations to reduce or prevent the occurrence of claims, to name some: sufficient time should be offered to design team to produce complete and adequate plans, enforce quality control techniques during the design process for the detection of errors, discrepancies, and missing data in documents, properly draft contract documents with no ambiguities, empower communication, cooperation, and trust among stakeholders, create risk management plan to deal with different construction processes and tight schedules, and maintain proper job records on timely manner. However, no study in the construction literature addressed the potential of shifting from the traditional fragmented project management approach to a more up-to-date modernized management style that takes into account the three pillars of sustainability on the mitigation of construction claims.

2.3 Neurofuzzy systems in construction management research

Construction engineering is susceptible to a wide range of uncertainties such as weather conditions, unknown site conditions, human judgments, lack of project controls, random market fluctuations, etc (Chan et al., 2009). The execution of construction operations requires adequate management of the projects' activities by integrating construction resources such as manpower, money, materials, and machinery/equipment (Cheng and Ko, 2003). In general, construction engineering and management problems are characterized by high level of complexity due to the uncertainty and changing nature of the environment in which the construction industry operates (Cheng and Ko, 2003; Georgy et al., 2005; Chan et al., 2009; Nourani et al, 2016). It is complicated to simply represent such complex construction and management problems in mathematical or statistical terms (Chan et al., 2009; Aydin and kisi, 2015). The probability-oriented multiple linear regression technique was found to be unable to identify all the factors necessary to reflect realistic situations for more accurate prediction purposes (Jin 2010a). Consequently, artificial intelligence (AI) techniques proved to be adequate in solving such complex and uncertain real-world problems (Atsalakis et al., 2019). A substantial amount of relevant research has been recently conducted in the field of AI applications for solving real-life construction and management problems (Kar et al., 2014; Siraj et al. 2016; Chen et al, 2018; Jaafari et al., 2019). Different examples of artificial intelligence systems include expert systems, fuzzy systems, artificial neural networks (ANN), Bayesian networks, evolutionary computation, and genetic programming (Chen et al, 2018; Atsalakis et al., 2019). In addition to that, hybrid approaches that combine two or more AI methods – such as neuro-fuzzy systems (NFS), neuro-genetic systems, genetic fuzzy systems, and genetic programming neural networks – are being widely used in solving practical real-world problems (Georgy et al., 2005; Cheng et al., 2008; Kar et al., 2014; Chen et al., 2018; Rajab and Sharma, 2018). Existing literature indicates that shifting from stand-alone AI techniques towards employing hybrid systems (e.g. NFS) is more effective. For instance, fuzzy systems are strong in reasoning and inference while lacking learning ability, which makes the system less suitable for prediction (Chan et al., 2009; Shihabudheen and Pillai, 2017; Atsalakis et al., 2019). Consequently, combining fuzzy systems with ANN - which have powerful learning ability – would allow the system to possess the capability in handling the uncertainty, nonlinearity, and complexity of most construction problems (Jang 1993; Jang and Sun 1995). NFS is characterized by its capability of knowledge representation (Shihabudheen and Pillai, 2017; Atsalakis et al., 2019), automated learning (Georgy et al., 2005; Shihabudheen and Pillai, 2017), and ability to use linguistic variables (Georgy et al., 2005) to model the input–output relationships of a given system making it a powerful technique to solve complex real-world problems. NFS has emerged as a dominant technique in modeling and solving complex real-world problems, and it has attracted the growing interest of researchers in various business, scientific, and engineering application areas because of its effective learning and reasoning capabilities (Cheng et al., 2008; Kar et al., 2014; Chen et al., 2018; Rajab and Sharma, 2018; Shihabudheen and Pillai, 2018). A review of past studies indicates extensive application of NFS techniques due to its robust, fast, and effective characteristics for solving complex problems in construction engineering and management. Jang (1993) introduced the adaptive neuro-fuzzy inference system (ANFIS) which is a fuzzy inference system implemented in the framework of adaptive networks. The proposed ANFIS is employed to model nonlinear functions, identify nonlinear components in a control system, and predict future values of a chaotic time series. Jin (2011) applied ANFIS for the purpose of forecasting efficient risk-allocation strategies for privately financed public infrastructure projects at a highly accurate level that multiple linear regression models and fuzzy inference systems could not achieve. Rashidi et al. (2011) used neuro-fuzzy genetic algorithm to identify the important criteria in selecting the most qualified project manager for a construction project. Likewise, Shahtaheri et al. (2015) developed an ANFIS-based model for estimating baseline rates for on-site work categories in the construction industry based on existing knowledge using 272 data points available from 14 projects. Yevu et al (2022) employed a neurofuzzy model and sensitivity analysis to predict and determine optimal strategies for promoting electronic procurement systems implementation. The abundance of published articles demonstrates the robustness of NFS as a powerful tool widely used in solving complex and non-linear problems in various research fields.

The aim of this research is to investigate the influence of optimal implementation of sustainable management practices on claims mitigation in construction sites. To this extent, there is a need to explore how these practices interact to facilitate the effective reduction of construction claims. In other words, the complex and uncertain interrelationship among the sustainable management practices should be identified to ensure optimal claims mitigation in resource-constrained sustainable construction projects. For this purpose, a neurofuzzy model will be developed and sensitivity analysis method will be used to determine optimal correlations between sustainable practices to achieve effective claims reduction. The neurofuzzy technique and sensitivity analysis are robust in exploring complex nonlinear patterns of problems (Tiruneh et al., 2020) and thus will be used in this study.

Chapter Three

Research Contribution

This study conducted a comprehensive literature review about sustainability development concepts and the need to incorporate sustainability management practices into traditional construction projects. It was perceived by researchers that implementing sustainability concepts is deemed extremely beneficial to achieve economic prosperity, environmental protection, and social well-being. Subsequently, it has been shown in the literature that construction claims and disputes are almost inevitable in all construction projects. Studies have therefore been developed to investigate frequent claim types, major sources and causes of conflicts and disputes, as well as recommendations for reducing or eliminating claims. Basically, it is essential for construction industry experts to thoroughly understand the core causes of claims and disputes to be able to identify remedies to deal with ambiguities and unforeseen risks that are often accompanied with construction projects. Although previous research has broadly identified major causes and solutions for claims reduction, there still exist some major gaps. There is not sufficient information to develop correlations between recent management practices implemented in sustainable projects and claims occurrence. Moreover, the body of knowledge lacks the presence of a comprehensive framework that can identify and quantify relationships between management practices based on their impact on claims mitigation. Existing solution strategies are mainly in the form of qualitative recommendations based on experience from past construction projects. Consequently to address this gap, a logical link between sustainable management practices and construction claims was developed via establishment of adaptive neurofuzzy inference system model. Neurofuzzy inference systems are being widely used in solving practical real-world problems in the construction engineering management sector as supported by several research studies. The developed neurofuzzy model provides owners and contractors with various approaches to ensure optimized implementation of sustainable management practices resulting in effective claims mitigation. Considering the constraints and limitations on sustainable practices' implementation in projects, this model provides practitioners with essential knowledge for the proper and minimal selection of critical sustainable management practices that can significantly mitigate construction claims and thus improve the project performance in terms of cost, time, and quality.

Chapter Four

Research Methodology

4.1 Overview

The aim of this research is to examine the effect of implementing sustainable management practices (SMP) on the mitigation of claims that arise in construction projects. To accomplish the study's objectives, this research methodology followed a mixed methods approach to identify correlations between SMPs and claims elimination. These methods include identification of critical SMPs and claims via a comprehensive literature review, data collection through a survey, and data analysis through reliability test, mean score technique, and factor analysis. Then, the analyzed data served as an input/output dataset to establish the neurofuzzy system model.

4.2 Identification of Critical SMPs and Claims

A thorough literature review was conducted to identify major sustainable management practices identified in previous construction management research studies, and explore relationships between the implementation of these practices and the mitigation of most frequent construction claims. The literature review was conducted in two folds. First, a journal search was performed to extract critical sustainable management practices. The relevant research studies were obtained from online databases and libraries, including Scopus, American Society of Civil Engineers (ASCE), Elsevier, and Science Direct. Many combinations of keywords such as "practices," "key factors," "indicators, "sustainable construction," "green construction," "sustainable project management," and "triple bottom line" were used in order to retrieve the related studies. The aforementioned databases were specifically selected because of their wide coverage of journals with topics related to sustainable development and construction engineering management (Falagas et al, 2008). As a result, 25 main sustainable management practices were extracted from previous studies and classified into three phases of the project's lifecycle (feasibility, design, and implementation) as shown in Table 4.1. Then, a thorough review of the existing literature related to claims and disputes in construction projects was conducted. Using the same online databases, ten main types of claims were extracted from the literature based on their frequency of occurrence in construction projects and which are shown in Table 4.2.

Table 4.1 Sustainable Management Practices

Project Phase	Code	Sustainable Construction Management Practice	References
Feasibility (F)	F1	Evaluate building purpose and properly target market needs in order to determine the required sustainable features of the final project's outcome.	Ding, 2008
	F2	Identify the environmental goal, assign green certification level as well as the amount of capital investment toward green initiatives	Robichaud and Anantatmula, 2011; Pissourios, 2013; Martens and Carvalho, 2017
	F3	Hire an experienced green building consultant/project manager who is familiar with the product type and market and has exposure to all phases of sustainable construction	Robichaud and Anantatmula, 2011
	F4	Finalize economic and ecological goals based on cost/benefit analysis. Consider site characteristics and weigh building needs against ecological issues. The preliminary budget must align resources with the project's goals in order to ensure that project's priorities are not mismatched to resources.	Matthiessen and Morris 2004
	F5	Establish a design charrette that includes representatives from internal stakeholders (structural engineer, architect, mechanical and electrical engineer, building contractor, environmental engineer, real estate consultant, etc.) as well as key external stakeholders, including surrounding property owners and other community representatives	Robichaud and Anantatmula, 2011; Labuschagne and Brent, 2005; Martens and Carvalho, 2017)
	F6	Select the appropriate site based on stakeholders involvement	Robichaud and Anantatmula, 2011;
	F7	Attain social responsibility towards competition, pricing policies, and comply with anticorruption practices.	Xing et al., 2009; Ukaga, 2014
Design (D)	D1	Initial budget and schedule should include input from the involved stakeholders (builder, project manager, architect, real estate consultant) in order to incorporate their needs and concerns during the execution of the project.	Buson, 2009; Martens and Carvalho, 2017
	D2	Select core design team early at the planning phase. Additional experts for technical systems (i.e. Air conditioning, heating, sanitary works, solar thermal systems, irrigation systems, etc) should also be selected at early design stages.	Kumar and Gupta, 2014; Robichaud and Anantatmula, 2011
	D3	Use digital technologies such as Building–Information Modeling (BIM) in the design phase that can create a full 3D model early in the project in addition to precise budgeting and scheduling. This improves coordination and communication with material suppliers, allows early clash detection, and design and planning improvements.	Gunhan, 2019; Hussin et al. 2013

	D4	Include team members who are green building certified professionals to estimate costs associated with specialized areas like green-building products. The budget should emphasize on life cycle costing through shifting focus from short term return on investment to long term profits from operational savings.	Robichaud and Anantatmula, 2011
	D5	Set environmental management plan to select environmentally friendly primary energy sources, minimize resource usage, primary selection of materials, wastewater and erosion control, waste recovery and disposal operations.	Fellows and Liu, 2008; Spangenberg, 1998; Martens and Carvalho, 2017; Gotschol et al., 2014)
	D6	Properly select the project delivery method (Design-build, Construction management agency at risk, Integrated project delivery), the procurement method (Open bid, prequalification, one-stage request for proposals, two-stage request for proposals), and the contract type (Lump sum, cost-plus, Guaranteed Maximum Price) that best suit sustainable projects	Mehany et al., 2018; Raouf et al, 2019;
	D7	Adopt “Open book” subcontracting process in bidding which allows the owner to have access to the estimates and pricing submitted by subcontractors.	Robichaud and Anantatmula, 2011; Reed and Gordon, 2000
	D8	Clarify allocation of roles and responsibilities, warranty specifications, as well as claims, litigations and dispute resolutions clearly in contracts	Guan et al., 2020
	D9	Include performance agreements, incentives, and bonuses for implementing sustainable practices and exceeding sustainability goals in contracts	Pennsylvania State University 2004
Implementation (IM)	IM1	Launch construction with kickoff meeting that includes a well-defined project execution plan and a sustainable education component for on-site construction personnel.	Robichaud and Anantatmula, 2011; Yates, 2014
	IM2	Empower communication and collaboration among project stakeholders at early stages of the construction phase. This could be performed via mobile project-management apps and cloud-based project control systems that integrate communication among teams on site and synchronize with sensors, wearable devices, and desktop machines to constantly track progress and updates.	Buson, 2009; Martens and Carvalho, 2017; Robichaud and Anantatmula, 2011
	IM3	Lay foundation for testing and commissioning activities by involving a quality control and assurance manager at early stages of the project. A commissioning manager may be appointed to give advice during design, construction planning and installation, and then to manage commissioning, testing, and handover.	Yates, 2014; Raouf and Al-Ghamdi, 2019
	IM4	Shift from traditional on-site construction to efficient off-site manufacturing and prefabrication which involves integrating automated production systems thus enabling the project to attain new levels of quality, variability and efficiency.	Marjaba and Chidiac, 2016
	IM5	Integrate technologies and innovations to different project processes (such as additive construction (3-D printing), autonomous navigation technology for construction machinery and robotics and drone technology) that would greatly affect energy consumption, project’s cost, time, and quality.	Martens and Carvalho, 2017; Liu et al., 2016; Pham et al., 2020

IM6	Maintain a long-lasting relationship and a stable collaboration between the contractor and the supplier. Such relationships derive supply chain improvements.	Martens and Carvalho, 2017; Li et al., 2011
IM7	Allocate expert team to execute the sustainable construction project having one or more members with professional expertise in the current practices or trends in sustainable construction technology and management	Opoku and Fortune, 2011; Kumar and Gupta, 2014; Akadiri, 2015
IM8	Provide continuous training and education workshops to assist employees in learning and adapting to sustainability concepts which can improve the project function and performance in all respects	Pitt et al., 2009; Tabassi et al., 2016
IM9	Implement an effective health and safety program on construction sites in order to enhance workers' comfort, health, and productivity in addition to minimizing absenteeism, turnover rate and liabilities.	Ali et al., 2008; Martens and Carvalho, 2017; Guan et al., 2020

Table 4.2 Types of Construction Claims

Construction Claim Type	References
Delay claims	Zaneldin, 2006; Ujene and Edike, 2016; Shaikh et al., 2020; Malki and Alam, 2021
Extra work claims	Zaneldin, 2006; Ujene and Edike, 2016; Shaikh et al., 2020; Malki and Alam, 2021
Contract ambiguity claims	Zaneldin, 2006; Shaikh et al., 2020; Malki and Alam, 2021
Extension of time claim	Shaikh et al., 2020
Suspension of work claims	Shaikh et al., 2020
Environmental disputes due to noise and vibration	Eom and Paek, 2009
Weather Condition Claims	Diekmann and Nelson, 1985
Safety and Health claims	Eom and Paek, 2009
Design error and change in scope claims	Diekmann and Nelson, 1985
Fluctuation in the price of construction materials claim	Malki and Alam, 2021

4.3 Survey Design and Data Collection

The data collected through the conducted literature review formed the foundation for the developed comprehensive questionnaire. The survey population consisted of developers, contractors, consultants, project managers, and architects engaged in the establishment of construction projects in the Middle East and North Africa (MENA) region. The web-based questionnaire consisted of two main sections. The first section consisted of an introduction that explained the background of the survey to the respondents and questions about their general demographics. The second section was concerned mainly with assessing the impact of each SMP on reducing a set of different claim types associated to it using a five point Likert-scale; namely: 1 = strongly ineffective, 2 = ineffective, 3 = neutral, 4 = effective and 5 = strongly effective. The survey was sent to 630 respondents and 167 responses were received back. The participants’ responses were then analyzed and checked for outliers. The response pattern was checked for all participants and the ones that indicated same option answer for many consecutive questions as well as incomplete responses were discarded. The final number of included survey responses in the study analysis was 144 respondents, resulting in a response rate of 23%. Figure 1 shows some demographic statistics of the survey respondents. The respondents’ population included 43% contractors, 20% developers, 20% project managers, 14% consultants, and 3% architects. Among all participants, around 78% have more than 10 years of experience in the construction industry and 90% of the respondents have experience in green building projects. Moreover, the professional experience of participants covers different types of construction: 46% residential, 31% infrastructure, and 23% commercial. Figure 1 also shows the distribution of participants over the MENA region. The majority of construction professionals who participated in the survey were located in Lebanon, Kingdom of Saudi Arabia (KSA), and United Arab Emirates (UAE) with the possibility of organizations being located in more than one country. Consequently, the demographic data of respondents reveal that they have adequate experience in green building construction and project management to provide satisfactory and reliable information towards the effect of SMPs in claims mitigation.

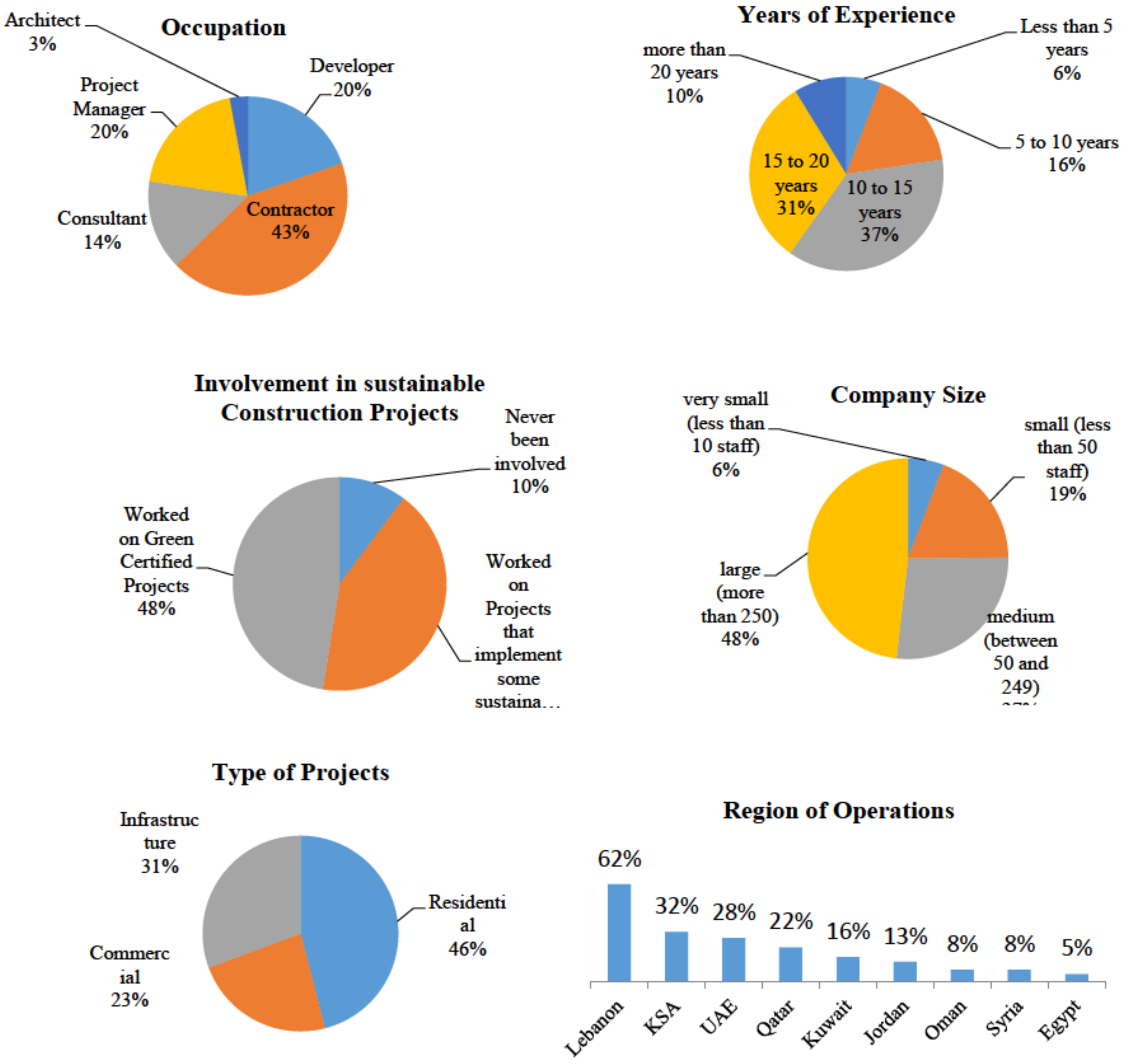


Figure 4.1 Demographic Statistics of the Survey

4.4 Survey Data Analysis

Data analysis tests were performed using the IBM Statistical Package for Social Sciences (SPSS) software. The Cronbach's alpha measure was employed in this study to check the reliability of the survey responses. The Cronbach's alpha is used to evaluate the internal consistency of questionnaire data by checking to what extent the data collected by the survey is coherent within the group of respondents (Field, 2013). The Cronbach's alpha can take any value between 0 and 1; however, a value greater than 0.7 is recommended for the consistency and reliability of collected survey data to be accepted (Field, 2013). Moreover, Shapiro-Wilk test was performed to verify whether the data is normally distributed or not. The null hypothesis of this statistical test is rejected when the p-value is less than 0.05 thus inferring that the data is not normally distributed (Royston, 1992).

Subsequently, the mean score technique was used to measure the rankings of the effect of SMPs on claims mitigation from the most effective one to the least as perceived by the respondents. The mean score technique has been widely considered in construction-related studies to measure the significance of analyzed factors (Razkenari et al., 2020; Olawumi et al., 2018). If two strategies have the same mean score, a higher rank is assigned to the strategy with lower standard deviation (Adabre et al., 2020). Critical practices are identified when their normalized mean score is greater than 0.5 indicating significant impact on claims mitigation.

Then, in order to determine the existence of significant differences between the rankings of two or more groups of independent variables, two non-parametric statistical tests were utilized: The Kendall's coefficient of concordance (Kendall's W) and the Kruskal-Wallis test. In this study there exist five independent groups: Developers, contractors, consultants, project managers, and architects. The Kendall's W is used to determine the agreement within the groups' rankings (Field, 2013). A value of 0 indicates total disagreement while 1 indicates total agreement (Field, 2013). To further check any differences between the rankings of different groups of participants, the Kruskal-Wallis test was conducted. The Kruskal-Wallis test does not assume normality in the data and is less effective to outliers (Montgomery, 2012). If the p-value of this statistical test is less than 0.05 then we can assume that there exist significant differences in the rankings of the different participants' groups (Montgomery, 2012).

The sustainable management practices were then grouped into clusters using the factor analysis technique to reduce the data set to a more manageable size by grouping the variables that are mostly correlated (Field, 2013). Factor analysis assumes that the analyzed factors are linearly related, there is no multi-collinearity, the analyzed variables are relevant to each other, and that the factors must highly correlate with each other (Field, 2013). Two tests shall be performed to check the applicability of factor analysis; the Kaiser-Meyer-Olkin (KMO) test which verifies the adequacy of the analyzed sample when having an acceptable value greater than 0.5, and the Bartlett's test of sphericity which compares a given correlation matrix to the identity matrix. The Bartlett’s test is performed to verify that the used data reduction technique (Factor analysis) will be meaningful in creating a smaller group of factors (Field, 2013). Factor analysis was conducted in this study using SPSS software. Principal component analysis (PCA) was used which is considered the most common type of factor analysis used by researchers and the selected rotation method was Varimax rotation method. The extraction of factors was determined based on the factor loadings and the Eigen values. Variables with factor loadings greater than 0.50 and components with eigenvalues equal to 1 were only considered due to their considerable involvement in the factor group and the identification of the corresponding cluster. Factor loadings indicate the variance explained by that variable on the factor and a value above 0.5 shows that the variance of the variable sufficiently explains the factor (Field, 2013). Eigen values indicate the variance explained by a given factor out of the total variance of the group. An Eigen value greater than 1 is satisfactory (Field, 2013).

4.5 Development of Adaptive Neuro-Fuzzy Inference System Model

4.5.1 Classification Methods of NFS

NFS classification offers a methodology for evaluating and making comparisons of neurofuzzy systems to help guide researchers in selecting a suitable NFS for modeling and solving a particular real-life problem. There exist several classification approaches for NFS in literature that can be summarized as (1) NFS architecture, (2) learning algorithm, (3) and fuzzy method (Sahin et al., 2012; Viharos and Kis, 2015; Shihabudheen and Pillai, 2018).

4.5.1.1 Classification based on NFS architecture

The techniques of combining fuzzy systems and ANNs result in three types of NFS architectures: cooperative NFS, concurrent NFS, and hybrid NFS (Vieira et al., 2004; Rajab and Sharma, 2018). Literature reveals that hybrid NFS is extensively being used in a wide range of applications in solving construction problems (Vieira et al., 2004; Viharos and Kis, 2015; Shihabudheen and Pillai, 2018). Moreover, hybrid NFS are classified based on their architecture, as ANFIS, FALCON, GARIC, NEFCON, SONFIN, and dmEfuNN (Vieira et al., 2004; Viharos and Kis, 2015). A study made on the comparison of NFS architectures revealed that ANFIS is the most accurate among the presented architectures since it uses a Takagi-Sugeno-Kang (TSK) inference mechanism (Viharos and Kis, 2015).

4.5.1.2 Classification based on learning algorithm

NFS can be grouped into five major categories based on their learning algorithm, as gradient-, hybrid learning-, population-, ELM-, and SVM-based NFS (Shihabudheen and Pillai, 2018). A study revealed that 43.10% of 116 selected articles used hybrid learning-based NFS for various construction and management applications. Hybrid learning-based NFS combines two or more learning techniques, such as BP, clustering, least square method (LSM), or Kalman filter (KF) to find the parameters, which is used to achieve stable and fast convergence (Tushar et al., 2015; Shihabudheen and Pillai, 2018). NFS that use hybrid learning help to avoid the difficulties commonly faced while using a single learning technique, such as BP, to train the parameters if the network structure and parameters become large. Hence, hybrid learning-based NFS improve accuracy and convergence (Tushar et al., 2015; Shihabudheen and Pillai, 2018).

4.5.2 Development of neurofuzzy model

The neurofuzzy model development consists of structure learning and parameter learning (Premkumar and Manikandan, 2015). The conducted literature review and the questionnaire surveys served as a basic step to initiate the learning process in the neurofuzzy model where domain knowledge about input and output variables and a set of input/output data can be obtained (Gerek, 2014). The learning process is implemented in two sequential learning modules, the structure learning module (SLM) and the parameter learning module (PLM). By generating fuzzy rules based on the numerical data obtained in the fieldwork, the neuro-fuzzy model will be able to realize the synthetic benefits associated with neural networks and fuzzy logic (Jin, 2011).

4.5.2.1 Structure learning module

Before a fuzzy system can be optimized in a training process, its structure must be defined, i.e. a fuzzy rule base must be created (Nauck, 2000). The SLM determines and generates fuzzy if-then rules of the input and output variables from the data set (Rashidi et al., 2011). Fuzzy rules are a collection of linguistic statements that describe how the fuzzy inference system should make a decision regarding classifying an input or controlling an output (Jin, 2011). A well-known inference method to generate fuzzy rules is the Sugeno or Takagi–Sugeno–Kang method (TSK). This method was introduced by Sugeno (1985). Generally, the fuzzy if-then rules are expressed as follows:

Rule 1: If x is $A1$ and y is $B1$ then $f1(x,y) = p1x+ q1y+ z1$,

Rule 2: If x is $A2$ and y is $B2$ then $f2(x,y) = p2x+ q2y+ z2$.

Where $f(x, y)$ is the Sugeno fuzzy first-order polynomial, x and y are numerical inputs, and f is the output, and A and B are numerical variables, and p, q and z are parameters determining relationships of inputs-outputs.

Then each fuzzy value is determined by a membership function (MF) (Rashidi et al., 2011). MFs assist when precise values of real world parameters cannot be measured because of sensitivity (Seresht and Fayek, 2020). A membership value between 0 and 1 is assigned to each fuzzy number in the input space. The most commonly used MFs are triangular, trapezoidal, and gaussian functions. In this study Gaussian function was adopted because it has good capabilities in achieving smoothness and in avoiding zero in the denominator in MFs (Jin, 2011). Moreover, A Gaussian MF is characterized by its robustness because it generates a system with lower degree of freedom (Hameed, 2011; Seresht and Fayek, 2020). The Gaussian function is defined as follows:

$\mu(x; \sigma, c)= e^{[-(x-c)^2]/(2\sigma^2)}$

where c is the curve mean and σ is the variance.

Each factor of the input variables is assigned three linguistic terms to demonstrate the level of implementation of each input variable (low (L), medium (M), high (H)). The fuzzy value of each linguistic term is determined by the MF. The potential values of the output variables are C(1, 2, 3, 4, 5), where {1, 2, 3, 4, 5} indicates the rating scale for the level of impact in a continuous range from 1 representing low level, through 3 representing medium level to 5 representing high level. The overall number of MFs for the output variables is the same number of fuzzy if-then rules created with the fuzzy sets since the first order Sugeno-type was initially used in the neurofuzzy model. The MFs of the output variables are expressed as $fi = p_i x_1 + q_i x_2 + r_i x_3 + s_i x_4 + t_i x_5 + z_i$, where ($p_i$, q_i, r_i, s_i, t_i, z_i) denotes the i^{th} fuzzy if-then rule of the subsequent parameter set and i represents fuzzy if-then rules. According to the output target value and the related data pair, the consequent parameters are initialized. Considering the initial values, parameter

(z_i) is designated with the output target value and the zero is designated to the remaining parameters. For example, if the targeted output has a value of 3 then the initial parameters of the data pair set are: {0, 0, 0, 0, 0, 3}.

4.5.2.2 Generating Fuzzy Rule Set

Rules form the basis for the fuzzy logic to obtain the fuzzy output. The rule-based form uses linguistic variables as its antecedents and consequents. The fuzzy rule-based system uses IF–THEN rules in the form of: IF antecedent, THEN consequent (Sivanandam et al, 2007). In order to ensure a fast, reliable, and highly intuitive learning process, concise and robust rules shall be identified to provide an initial structure of networks (Kim and Kasabov, 1999). Wang and Mendel (1992) proposed a method for generating fuzzy rules from a numerical input/output data consisting of the following three steps:

i. Determine the membership values of each input value of a given data set.
ii. Assign each input value with a fuzzy value that the input value has the maximum membership value of.
iii. Obtain one rule from each input/output data pair.

The aforementioned steps for generating fuzzy rules are explained in the example below. The membership functions and initial values of the five variables (SCs) in our study are shown in Table 4.3. First to determine the membership values, we take case 1 that participated in the survey, having the input/output data set as (5, 3.8, 5, 3, 1, 4) where the first five values represent the input variables and the sixth value is the output. The values of the membership functions are shown in Table 4.4. Then we assign a fuzzy value for each input variable according to the maximum membership value for it as shown also in Table 4.4. Finally, we obtain the rule for case 1 as follows: if SC1 is high and SC2 is medium and SC3 is high and SC4 is medium and SC5 is low then the output variable is

$$F1 = p_1 *5 + q_1*3.8 + r_1*5 + s_1*3 + t_1*1 + z_1=4$$

Table 4.3 Fuzzy Values and Membership Functions for Input Variables

Variable	**Value**	**Initial Membership Function**
SC1: Feasibility study for sustainable development	High (H)	e^[-(x-5)]^2]/[2(0.75)^2]
	Medium (M)	e^[-(x-3)]^2]/[2(0.75)^2]
	Low (L)	e^[-(x-1)]^2]/[2(0.75)^2]
SC2: Experienced green building certified professionals	High (H)	e^[-(x-5)]^2]/[2(0.83)^2]
	Medium (M)	e^[-(x-3)]^2]/[2(0.83)^2]

	Low (L)	e^[-(x-1)]^2]/[2(0.83)^2]
SC3: Sustainability requirements at early design phase	High (H)	e^[-(x-5)]^2]/[2(0.72)^2]
	Medium (M)	e^[-(x-3)]^2]/[2(0.72)^2]
	Low (L)	e^[-(x-1)]^2]/[2(0.72)^2]
SC4: Sustainability requirements at execution phase	High (H)	e^[-(x-5)]^2]/[2(0.81)^2]
	Medium (M)	e^[-(x-3)]^2]/[2(0.81)^2]
	Low (L)	e^[-(x-1)]^2]/[2(0.81)^2]
SC5: Social responsibilities to maintain sustainable development	High (H)	e^[-(x-5)]^2]/[2(0.79)^2]
	Medium (M)	e^[-(x-3)]^2]/[2(0.79)^2]
	Low (L)	e^[-(x-1)]^2]/[2(0.79)^2]

Table 4.4 Determining the If-Then Rules for a Given Input Data

Variable	Input Data	Membership Value	Fuzzy Value
SC1	5	**1 (High)** 0.03 (Medium) 0.00 (Low)	High
SC2	3.8	0.35 (High) **0.63 (Medium)** 0.13(Low)	Mediem
SC3	5	**1 (High)** 0.02 (Medium) 0.00 (Low)	High
SC4	3	0.05 (High) **1 (Medium)** 0.04 (Low)	Mediem
SC5	1	0.00 (High) 0.04 (Medium) **1 (Low)**	Low

Fuzzy inference system consists of a fuzzification interface, a rule base, a database, a decision-making unit, and finally a defuzzification interface (Sivanandam et al., 2007). A FIS with five functional block described in Fig.4.2. The function of each block is as follows:

- a rule base containing a number of fuzzy IF–THEN rules;
- a database which defines the membership functions of the fuzzy sets used in the fuzzy rules;
- a decision-making unit which performs the inference operations on the rules;
- a fuzzification interface which transforms the crisp inputs into degrees of match with linguistic values;

- a defuzzification interface which transforms the fuzzy results of the inference into a crisp output.

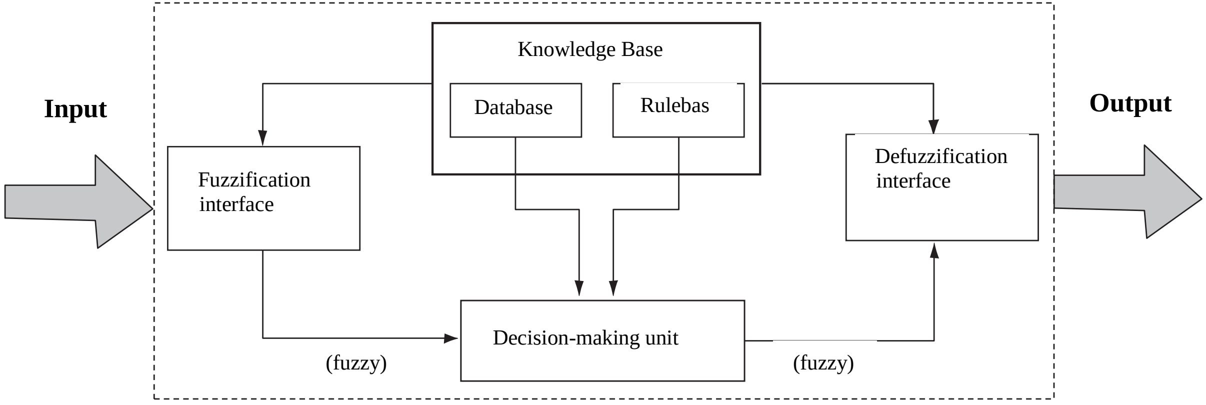


Fig.4.2. Fuzzy inference system (Sivanandam et al., 2007)

4.5.2.3 Parameter learning module

The structure of the PLM can be established based on the input and output variables that have been determined and the fuzzy rules that have been obtained. The parameter learning tunes the MFs to maximize performance or reduce output error through modifying the parameters (Rashidi et al., 2011; Gerek, 2014). The ANFIS can be used for the parameter learning. The architecture of the ANFIS integrates the fuzzy reasoning of a Sugeno FIS and facilitates learning from the input/output data set. The learning algorithm of ANFIS is performed via gradient-descent optimization and least square estimation methods (Jang, 1993).

4.5.2.4 Architecture of ANFIS

The ANFIS architecture has five hidden layers, without counting the input and output layers. The functions of the hidden layer nodes are based on fuzzy rules and MFs, which make them have an advantage over conventional neural networks that are difficult to interpret (Tavana et al., 2016).

Input layer: The input layer defines the crisp values of inputs connected to nodes in layer 1. The nodes in this layer only transmit input values to the corresponding nodes in Layer 1.

Layer 1: Nodes in Layer 1 act as membership functions that define the fuzzy values of the input variables. The outputs of this layer are thus the membership values of the crisp input values. The Gaussian function is taken as MFs with σ and c as the parameter set. Therefore, the output of a node in Layer 1 is defined by

$$O_j^{(1),k} = e^{\left[-\left(x_k - c_j^k\right)^2\right]/(2\sigma_j^{k^2})}$$

where σ_j^k and c_j^k = parameters of the membership function that represent the lth fuzzy value of the kth input variable; (1) denotes Layer 1; k denotes the number of input variables; and j denotes the number of the assigned fuzzy values (i.e., low, medium, high)

Layer 2: This layer consists of nodes (п) denoting the if-part of fuzzy rules. Each node multiplies the incoming signals and the product is the output representing the firing strength (w_i).

$$O_i^{(2)} = w_i = \prod O_j^{(1)}$$

where (2) represents layer 2; *i* denotes the index of fuzzy rules; and $i \in \{1, 2, \ldots, n\}$, in which *n* is the number of fuzzy rules generated in the structure learning.

Layer 3: In this layer, every node is adaptive and computes the ratio of *i*th rule's firing strength to the sum of all rules firing strength.

$$O_i^{(3)} = \overline{w}_i = \frac{w_i}{w_1 + w_2 + \cdots + w_n}$$

where w_n represents the last firing strength. A node's output represents the normalized firing strength.

Layer 4: In this layer, each node *i* is adaptive and endowed with a node function *fi*. The node output is given by:

$$O_i^{(4)} = \overline{w}_i f_i = \overline{w}_i(p_i x_1 + q_i x_2 + r_i x_3 + s_i x_4 + t_i x_5 + z_i)$$

where $\overline{w}_i$ is the output of layer 3 and p_i, q_i, r_i, s_i, t_i *and* z_i are adjusted consequent parameters.

Layer 5: This layer computes the overall output of ANFIS from layer 4.

$$O_i^{(5)} = \sum \overline{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i}$$

where $\overline{w}_i$ is normalized firing strength.

Output layer: This layer receives the final node from layer 5 to present the final output of the ANFIS system.

The aforementioned five-layer structure of the ANFIS model is illustrated in Figure 4.3.

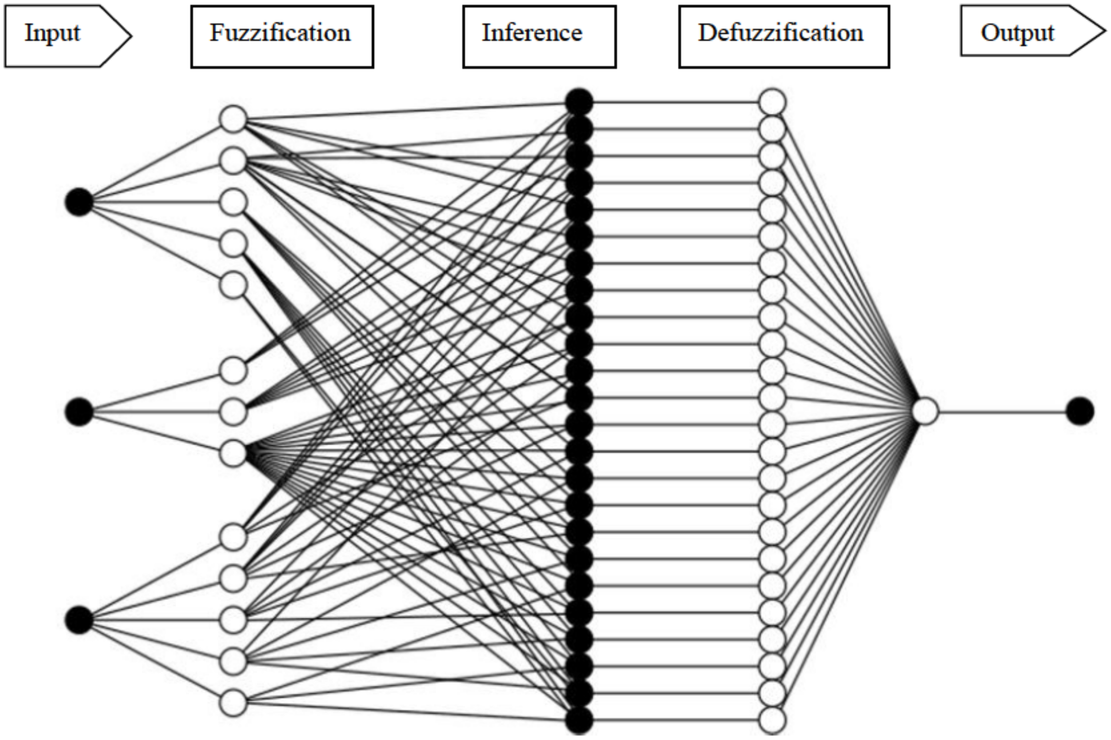


Figure 4.3: Structure of the formed Neuro-Fuzzy Network

4.5.2.5 Parameter Learning Algorithms

ANFIS is used to tune the antecedent and consequent parameters through the adaptations of learning weights and nonlinear membership functions using suitable algorithms. ANFIS applies a hybrid learning algorithm which integrates the gradient descent-based back propagation algorithms with least squares estimator for premise and consequent parameter optimization (Jang, 1993). The transmission of forward pass and backward pass enables the hybrid algorithms to learn from the dataset (Jin, 2011).

The ANFIS model was generated with the aid of ANFIS toolbox in MATLAB software. In this study, 10 ANFIS models were developed to assess the impact of implementing sustainable management practices on the mitigation of 10 different construction claims.

4.5.3 Neurofuzzy model training

The database obtained from the survey is used to train and validate the neurofuzzy model. Then the database is divided into two subsets: the training dataset and the evaluation dataset. Dividing the dataset facilitates the examination of models to guard against over fitting when checked with the evaluation dataset for generalization (Haykin, 2007). The early-stopping method was adopted to tackle over fitting and to ensure that while learning new things the learning model preserves knowledge and remains adaptive (Amari et al., 1996). The training dataset can be partitioned using the multi-fold cross-validation technique. This technique uses separate data from the total dataset to estimate a model's prediction of outputs from an untrained dataset (Wong, 2015). The root-mean square error (RMSE) is then employed to estimate and validate the models for the selection of best performing model as used in previous studies (Statkic et al., 2020).

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{t_i - y_i}{n}}$$

where n = number of datasets; t_i = impact level observed in the i^{th} case; and y_i = predicted impact level in the i^{th} case by the model.

4.5.4 Neurofuzzy model evaluation and sensitivity analysis

The performance of the neurofuzzy model is evaluated using data from the evaluation dataset. In addition to RMSE, performance indices including mean percentage error (MPE) and mean absolute percentage error (MAPE) are used to evaluate the developed model. The MPE indicates the model's tendencies to over-or-under forecast while MAPE estimates the magnitude of errors that may be contained in the forecast (Jin, 2011). These performance indexes have been widely used to evaluate model performance (Gerek, 2014; Statkic et al., 2020).

$$\text{MPE} = \left(\sum_{i=1}^{n} \frac{y_{ti} - y_{oi}}{y_{ti}} \times 100\%\right)/n$$

$$\text{MAPE} = \left|\sum_{i=1}^{n} \frac{y_{ti} - y_{oi}}{y_{ti}} \times 100\%\right|/\text{n}$$

where n is the number of evaluation models; y_{ti} *and* y_{oi} represent the observed and model output of the i^{th} data case.

Then sensitivity analysis is conducted to assess the impact levels on claims mitigation through the integration of various clustered strategies of sustainable practices. By varying the influence values of specific inputs while keeping the remaining inputs at ideal values (El-Gohary et al., 2017), sensitivity analysis provides an approach for identifying ways that optimize the strategies for selecting critical sustainable practices to reduce construction claims. The sensitivity analysis is conducted by varying the input values of the strategies from high to medium level starting from one input variation to three inputs variations successively in order to compare the interrelationships between strategies (Yevu et al., 2022). This study will help contractors and owners in carefully selecting effective hybrid approaches that optimize sustainable management practices implementation and result in minimal number of claims in construction projects.

Chapter Five

Research Results

5.1 Research data Analysis

Based on the conducted literature review, 25 critical sustainable management practices and 10 different construction claim types were identified in this study. Subsequently, the data collected from the questionnaire formed a basis for the development of ANFIS models which were employed in the assessment of the significant impact of the implementation of sustainable management practices in construction sites on the mitigation of different claim types. Cronbach's Alpha test was adopted to check the reliability and consistency of the obtained survey data set. Table 5.1 shows the different α values for the data sets of the 10 claim types. An "α value" greater than 0.7 indicates that the internal consistency and reliability of the data collected is high and acceptable.

Table 5.1 Cronbach's Alpha Values for Different Survey Data Sets

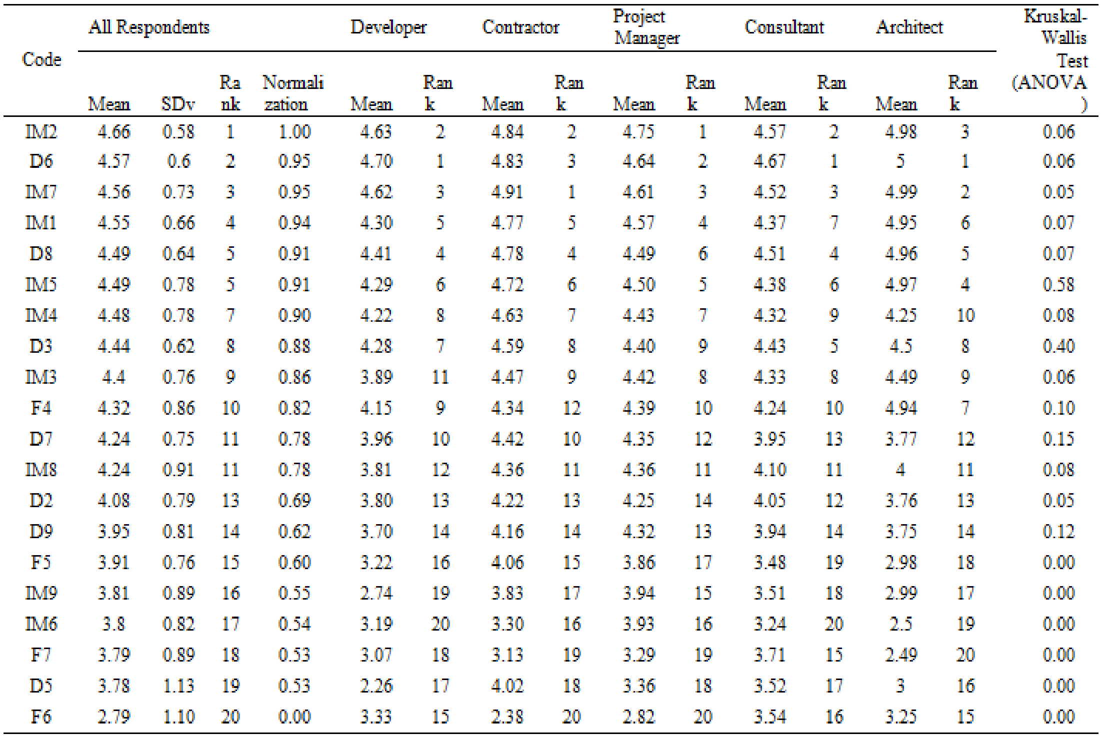
Claim Type	Cronbach's α value
Delay Claims	0.73
Suspension of Work Claims	0.76
Extra work claims	0.71
Contract ambiguity claims	0.7
Extension of time claim	0.76
Environmental disputes due to noise and vibration	0.7
Weather Condition Claims	0.68
Safety and Health claims	0.75
Design error and change in scope claims	0.77
Fluctuation in the price of construction materials claim	0.73

Then the data normality check was carried out using the Shapiro-Wilk test. The p-values of the Shapiro-Wilk test for all 10 claim types in this study were less than 0.05 (<0.001), therefore the data collected regarding all the claim types were not normally distributed.

Afterward, the mean score technique was used to evaluate the relative importance of the different sustainable practices in claims' mitigation. If two strategies have the same mean score, a higher rank is assigned to the strategy with lower standard deviation.

Normalization analysis was conducted to determine strategies that are critical, i.e. strategies with normalized values ≥ 0.50. For the sake of brevity, only the results for delay claims mitigation will be represented henceforward. The mean scores results for the significance of the different sustainable management practices in delay claims mitigation are summarized in Table 5.2 and the values range from 2.79 to 4.66. Normalization computations were conducted and the strategies with normalized scores greater than 0.50 were identified as critical sustainable practices in the reduction of claims in projects. Out of 20 practices identified, 19 practices had normalized values above 0.50 and were therefore deemed as critical strategies in the promotion of delay claims mitigation in building projects. The first ranked practice with the highest mean value of 4.66 was "IM2: Empower communication and collaboration among project stakeholders at early stages of the construction phase". This practice was also supported by previous studies that suggested early involvement and communication between construction parties for solving problems and complaints reduction (Zaneldin, 2006; Eom and Paek, 2009; Shaikh et al., 2020). The practice "D6: Proper selection of the project delivery method, the procurement method, and the contract type that best suits sustainable projects" was ranked second with a mean value of 4.57. Mehany et al (2018) argued that the selection of adequate project delivery method, procurement method, and contract type can play a vital role in project's overall success in terms of stakeholders' satisfaction, quality of contractor's work, and trust among different parties. The third rank was "IM7: Allocate expert team at the construction phase having professional expertise in the current practices or trends in sustainable construction technology and management" with mean score of 4.56. The fourth critical practice was "IM1. Launch construction with kickoff meeting that includes a well-defined project execution plan and a sustainable education component for on-site construction personnel" with mean score 4.55 and the fifth critical practice was "Use digital technologies such as Building–Information Modeling (BIM) in the design phase that can create a full 3D model early in the project in addition to precise budgeting and scheduling" with mean score 4.49. The integration of BIM early in the design phase was also recommended by several studies (Gunhan, 2019; Hussin et al, 2013; Santos et al, 2019). This gives a summary of the first five critical sustainable practices that can significantly affect delay claims reduction in construction sites.

Table 5.2 Mean Analysis for SMPs in Delay Claims’ Mitigation



Code	All Respondents				Developer		Contractor		Project Manager		Consultant		Architect		Kruskal-Wallis Test (ANOVA)
	Mean	SDv	Rank	Normalization	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	
IM2	4.66	0.58	1	1.00	4.63	2	4.84	2	4.75	1	4.57	2	4.98	3	0.06
D6	4.57	0.6	2	0.95	4.70	1	4.83	3	4.64	2	4.67	1	5	1	0.06
IM7	4.56	0.73	3	0.95	4.62	3	4.91	1	4.61	3	4.52	3	4.99	2	0.05
IM1	4.55	0.66	4	0.94	4.30	5	4.77	5	4.57	4	4.37	7	4.95	6	0.07
D8	4.49	0.64	5	0.91	4.41	4	4.78	4	4.49	6	4.51	4	4.96	5	0.07
IM5	4.49	0.78	5	0.91	4.29	6	4.72	6	4.50	5	4.38	6	4.97	4	0.58
IM4	4.48	0.78	7	0.90	4.22	8	4.63	7	4.43	7	4.32	9	4.25	10	0.08
D3	4.44	0.62	8	0.88	4.28	7	4.59	8	4.40	9	4.43	5	4.5	8	0.40
IM3	4.4	0.76	9	0.86	3.89	11	4.47	9	4.42	8	4.33	8	4.49	9	0.06
F4	4.32	0.86	10	0.82	4.15	9	4.34	12	4.39	10	4.24	10	4.94	7	0.10
D7	4.24	0.75	11	0.78	3.96	10	4.42	10	4.35	12	3.95	13	3.77	12	0.15
IM8	4.24	0.91	11	0.78	3.81	12	4.36	11	4.36	11	4.10	11	4	11	0.08
D2	4.08	0.79	13	0.69	3.80	13	4.22	13	4.25	14	4.05	12	3.76	13	0.05
D9	3.95	0.81	14	0.62	3.70	14	4.16	14	4.32	13	3.94	14	3.75	14	0.12
F5	3.91	0.76	15	0.60	3.22	16	4.06	15	3.86	17	3.48	19	2.98	18	0.00
IM9	3.81	0.89	16	0.55	2.74	19	3.83	17	3.94	15	3.51	18	2.99	17	0.00
IM6	3.8	0.82	17	0.54	3.19	20	3.30	16	3.93	16	3.24	20	2.5	19	0.00
F7	3.79	0.89	18	0.53	3.07	18	3.13	19	3.29	19	3.71	15	2.49	20	0.00
D5	3.78	1.13	19	0.53	2.26	17	4.02	18	3.36	18	3.52	17	3	16	0.00
F6	2.79	1.10	20	0.00	3.33	15	2.38	20	2.82	20	3.54	16	3.25	15	0.00

The Kendall’s W value and significance level for the ranked 20 practices were 0.289 and 0.000 respectively, indicating substantial level of agreement on the ranking of the practices from the respondent groups. The Kruskal-Wallis ANOVA test shows that most of the strategies had no significant statistical difference (significance > 0.05) between the five respondent groups except for six sustainable practices (IM8, IM9, IM6, F7, D5, and F6). In general, the rankings for contractors and project managers are very close but they differ from the rankings of the other respondent groups (developers, consultants, and architects). Contractors and project managers give higher ranking to sustainable practices at the implementation level in contrast to developers, consultants, and architects who emphasize more on the importance of practices at the feasibility and design phase in delay claims mitigation. This can be due to the fact that contractors and project managers call more attention to processes at the execution phase; however, developers, consultants, and architects are more aware of management practices at the feasibility and design phases.

5.2 Clustering of critical practices using factor analysis

The 20 sustainable practices identified previously significant in delay claims mitigation were grouped into clusters using the factor analysis (FA) technique to reduce the data set to a more manageable size by grouping the variables that are most related or correlated. For appropriateness of the data, the KMO value of 0.71 obtained in this study is acceptable since it satisfies the minimum threshold of 0.50 (Hair et al., 2009). The Bartlett's test value was 764.243 with associated significance level of 0.000, indicates that the population correlation is not an identity matrix (Pallant, 2011). Both the KMO and Bartlett's tests demonstrated the suitability of the data for FA. Hence, the principal component analysis was used for factor extraction based on varimax rotation. Variables with factor loadings ≥0.50 and components with eigenvalues ≥1 were retained due to their significant contribution in the factor group and determining underlying clusters. Five components were extracted which accounted for 65.20% of variance, satisfying the >50% acceptable threshold. The results of FA are tabulated in Table 5.3. The clusters were labeled as: Feasibility study for sustainable development (SC1), experienced green building certified professionals (SC2), sustainability requirements at early design phase (SC3), sustainability requirements at execution phase (SC4), and social responsibilities to maintain sustainable development (SC5). These five strategies clusters serve as input parameters for the neurofuzzy model to evaluate the influence of the sustainable practices in reducing claims in building projects.

Table 5.3 Clustering of sustainable practices

Clustering of Practices promoting claim mitigation						
Code	Practices promoting claim mitigation	Practices Clusters				
		1	2	3	4	5
SC1	**Feasibility study for sustainable development**					
F1	Evaluation of building purpose and targeting market needs to determine sustainable features of the final project's outcome	0.784	-	-	-	-
F2	Identification of environmental goal, green certification level, and amount of capital	0.832	-	-	-	-

	investment toward green initiatives					
F5	Selection of appropriate site based on stakeholders’ involvement	0.751	-	-	-	-
F7	Setting economic and ecological goals based on cost/benefit analysis. Preliminary budget must align resources with the project’s sustainable goals	0.796	-	-	-	-
SC2	**Sustainability requirements at early design phase**					
F3	Hire an experienced green building consultant/project manager who is familiar with the project’s outcome and market	-	0.643	-	-	-
F4	Establish a design charrette that includes representatives from internal stakeholders as well as key external stakeholders	-	0.718	-	-	-
D1	Select core design team early at the planning phase and additional technical experts at early design stages	-	0.592	-	-	-
D4	Include green building certified professionals to estimate costs associated with specialized green-building products	-	0.652	-	-	-
IM2	Empower communication and collaboration among project stakeholders at early stages of the construction phase	-	0.645	-	-	-
IM7	Allocate expert team having professional expertise in sustainable construction technology and management for execution	-	0.72	-	-	-
SC3	**Sustainability requirements at execution phase**					
D2	Initial budget and schedule should include input from involved stakeholders to incorporate their needs and concerns in the execution phase	-	-	0.772	-	-
D3	Use digital technologies such as Building–Information Modeling (BIM) in the early stages of the design phase	-	-	0.857	-	-
D5	Set environmental management plan	-	-	0.799	-	-

D6	Properly select the project delivery method, the procurement method, and the contract type that best suits sustainable projects	-	-	0.728	-	-
D7	Adopt “Open book” subcontracting process in bidding	-	-	0.818	-	-
SC4	**Sustainability requirements at execution phase**					
IM1	Launch construction with kickoff meeting that includes a well-defined project execution plan and a sustainable education component for on-site construction personnel.	-	-	-	0.788	-
IM3	Lay foundation for testing and commissioning activities at early stages of the project	-	-	-	0.756	-
IM4	Shift from traditional on-site construction to efficient off-site manufacturing and prefabrication	-	-	-	0.654	-
IM5	Integrate technologies and innovations to different project processes in the construction phase	-	-	-	0.652	-
IM8	Provide continuous training and education workshops to assist employees in learning and adapting to sustainability concepts	-	-	-	0.622	-
IM9	Implement an effective health and safety program on construction sites	-	-	-	0.66	-
SC5	**Social responsibilities to maintain sustainable development**					
F6	Attain social responsibility towards competition, pricing policies, and comply with anticorruption practices	-	-	-	-	0.733
D8	Clarify allocation of roles and responsibilities of the project parties, warranty specifications, as well as claims, litigations and dispute resolutions clearly in contracts	-	-	-	-	0.747
D9	Include performance agreements, incentives, and bonuses for implementing sustainable practices in contracts	-	-	-	-	0.695

IM6	Maintain a long-lasting relationship and a stable collaboration between the contractor and the supplier	-	-	-	-	0.645

5.3 Neurofuzzy model development

Fuzzy Inference System (FIS) is a decision-making methodology, which takes input values and creates output fuzzy values based on some logic rules. One disadvantage of traditional Fuzzy Inference System (FIS) is that it often requires users to design the rules, which is sometimes impractical because in some decision-making problems, the relationship between inputs and outputs are not clear and there are no insightful methods to design the rules. However, the Adaptive Neuro-Fuzzy Inference System (ANFIS) is a model that can learn characteristics and rules out of large amount of data. ANFIS works by adjusting the coefficients in the networks with the aim of reducing the error of output. The structure learning of this model determines and generates fuzzy rules of the input and output variables from the data set. The structure resolves fuzzy if-then rules and membership function approximations for inputs and outputs. The ANFIS model was designed and modeled using MATLAB ANFIS Toolbox program. The study generated 10 different ANFIS models each assessing the effect of implementing SMPs on the reduction of a specific claim type.

For delay claims, the five input variables (IVs) as derived from the principal component analysis for the neurofuzzy model are: Feasibility study for sustainable development (IV1), experienced green building certified professionals (IV2), sustainability requirements at early design phase (IV3), sustainability requirements at execution phase (IV4), and social responsibilities to maintain sustainable development (IV5).

The prioritized mean weight (PMW) was employed to compute the input values of the neurofuzzy model. The PMW computes the corresponding weight of a factor within a group based on factor loadings as shown on Table 5.3 and expert ratings that resulted from the survey. PMW technique permits the representation of the weight of each practice to be shown in the group. The PMW expresses the importance of VI using Eq. (1):

$$PMW_k=\sum_{i=1}^{h} V_{ki}, \quad \text{with } V_{ki}=W_c d \qquad \text{Eq. (1)}$$

where PMW_k is score of k^{th} group of IV_k ($k = 1, 2, \ldots, 5$), and V_{ki} is the i^{th} strategy score of the k^{th} IV group, Wc is the coefficient weight of a factor's loading divided by the sum of factor loadings in that group, d is the expert's strategy rating, and h is the number of practices within the IV.

The output variable (OV) indicates the impact level of SMPs in mitigating claims. The OV possible values are {1, 2, 3, 4, 5}, where {1, 2, 3, 4, 5} indicates the rating scale for the level of impact in a continuous range from 1 representing low level, through 3 representing medium level to 5 representing high level.

Table 5.4 indicates a sample of the input and output data based on the responses of the questionnaire's participants.

Table 5.4 Input and Output Sample Data Set for ANFIS (10 out of 144 participants)

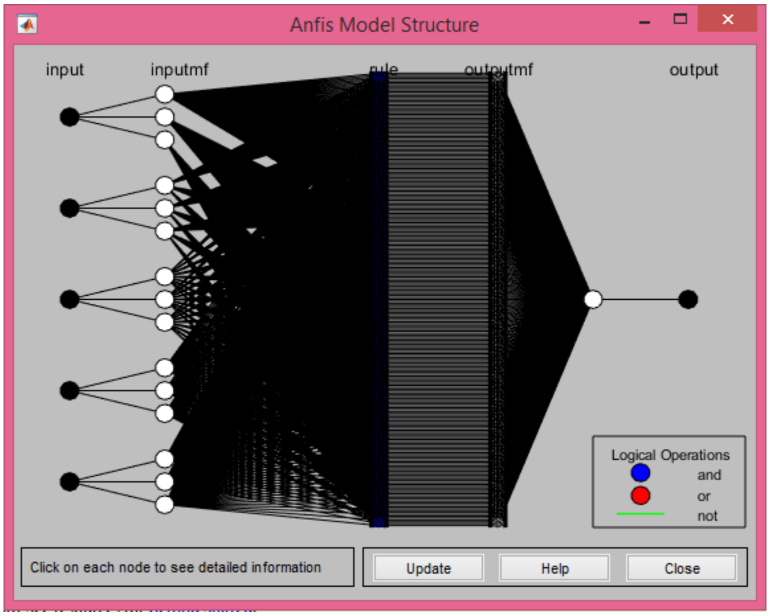
VI1	VI2	VI3	VI4	VI5	OV
3.485	3.966	4.583	4.467	3.480	4
3.485	5.000	4.605	5.000	4.234	5
4.485	4.310	3.592	3.578	3.771	4
3.515	3.964	4.415	3.840	3.494	4
3.000	4.690	4.593	4.341	4.023	4
4.000	5.000	4.616	4.682	4.543	5
4.515	4.690	3.188	3.405	3.790	4
4.000	3.999	3.572	3.030	3.239	3
3.000	4.310	3.378	3.506	3.503	3

The data set, containing 5 input parameters and 1 output parameter, was divided into 70% representing the training set and 30% representing the testing/validating set. The validating data plays a vital role in evaluating the models' performance and robustness. Furthermore, for the training set, a 10-fold cross-validation was performed. K-fold cross-validation is carried out to minimize sampling bias and over-fitting issues. For each of the 10 iterations of this validation process, the training data set was divided into 10 subgroups: nine of these were used for training each model, and the 10th was used to validating the accuracy of each model. Moreover, adequate fuzzy inference system parameters, hybrid training techniques, Gaussian membership function, and an optimal model of 100 epochs were selected for training the ANFIS model. The best-calibrated model is the one that yields lower error statistics, such as root-mean squared error (RMSE). Table 5.5 provides a summary of the 10 models trained in the ANFIS network architecture. The RMSE was used to estimate and validate the models for the selection of best performing model. As shown in Table 5.5, model 1 had the minimum value of RMSE, indicating that it is the best performing model. Hence, model 1 is selected for model evaluation.

Table 5.5 RMSE Values for the 10 Trained Models

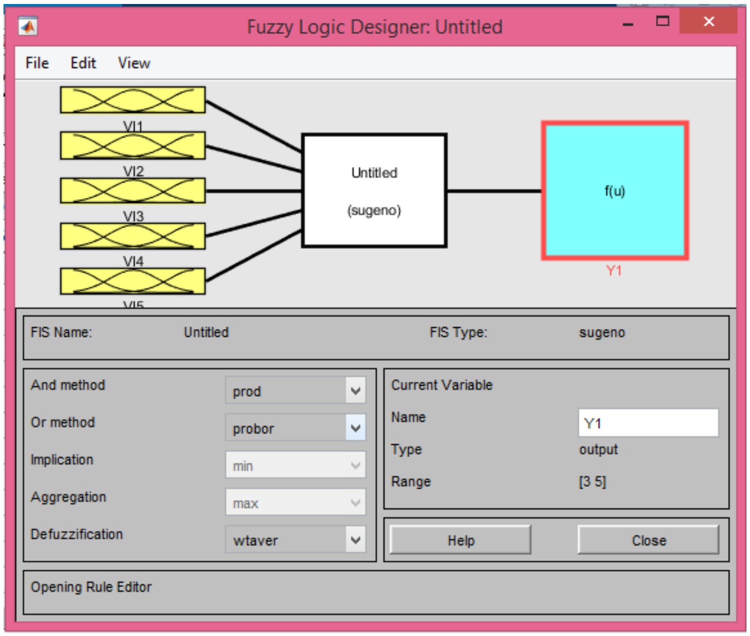
ANFIS model	**RMSE**	**ANFIS model**	**RMSE**
Training data (ANFIS 1)	**0.0005**	Training data (ANFIS 6)	0.00094
Validating data (ANFIS 1)	**1.44972**	Validating data (ANFIS 6)	1.63415
Training data (ANFIS 2)	0.00843	Training data (ANFIS 7)	0.0008
Validating data (ANFIS 2)	1.98818	Validating data (ANFIS 7)	2.13558
Training data (ANFIS 3)	0.00106	Training data (ANFIS 8)	0.00076
Validating data (ANFIS 3)	2.13779	Validating data (ANFIS 8)	1.63664
Training data (ANFIS 4)	0.00115	Training data (ANFIS 9)	0.00734
Validating data (ANFIS 4)	1.84343	Validating data (ANFIS 9)	1.61936
Training data (ANFIS 5)	0.00112	Training data (ANFIS 10)	0.00107
Validating data (ANFIS 5)	1.44136	Validating data (ANFIS 10)	1.9256

Figures 5.1 and 5.2 represent respectively the whole structure of the developed ANFIS model and the fuzzy logic designer page for the inputs to predict the desired outputs.



Click on each node to see detailed information

Figure 5.1 Structure of ANFIS Model



FIS Name: Untitled

FIS Type: sugeno

And method: prod

Or method: probor

Implication: min

Aggregation: max

Defuzzification: wtaver

Current Variable

Name: Y1

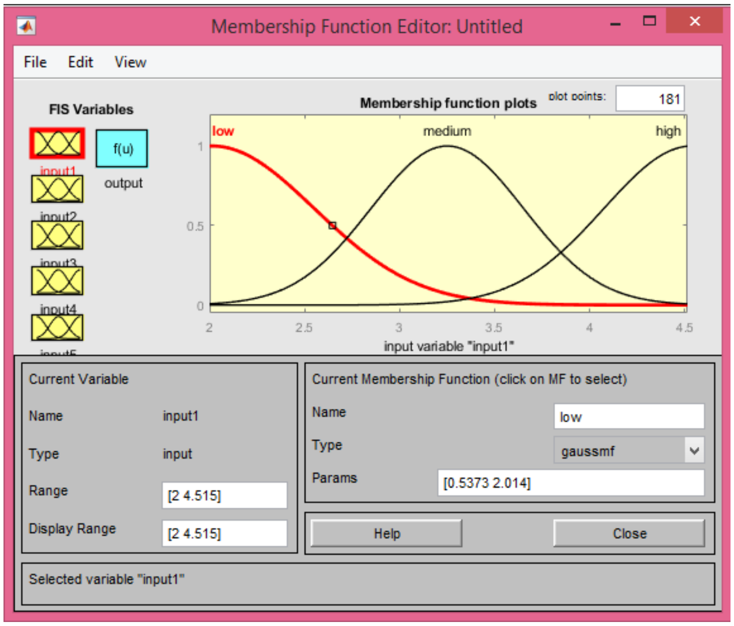
Type: output

Range: [3 5]

Opening Rule Editor

Figure 5.2 Inputs and Outputs in ANFIS

Furthermore, Figure 5.3 demonstrates the fuzzy ratings and the membership functions for inputs (i.e., gaussian membership functions).



plot points: 181

Current Variable

Name input1

Type input

Range [2 4.515]

Display Range [2 4.515]

Current Membership Function (click on MF to select)

Name low

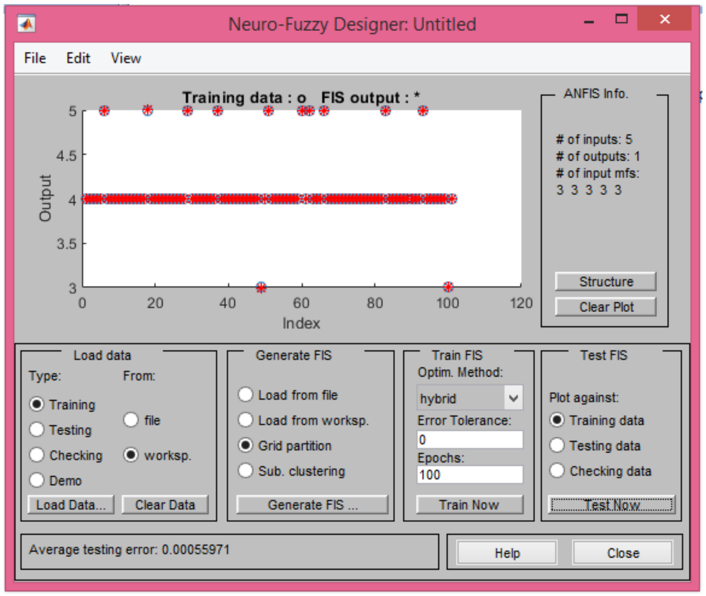
Type gaussmf

Params [0.5373 2.014]

Selected variable "input1"

Figure 5.3 Gaussian membership functions with membership values between 0–1

As inferred from Figure 5.4, the trained and tested output of ANFIS, which illustrates the predicted claim mitigation magnitude (FIS output) for both training and testing data, are in good harmony with the actual data.



\# of inputs: 5
\# of outputs: 1
\# of input mfs:
3 3 3 3 3

Type: ● Training ○ Testing ○ Checking ○ Demo

From: ○ file ● worksp.

○ Load from file
○ Load from worksp.
● Grid partition
○ Sub. clustering

Optim. Method: hybrid

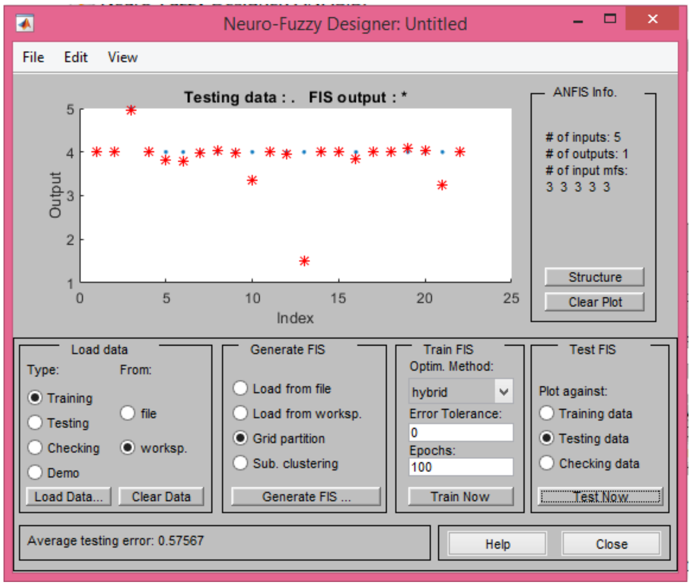
Error Tolerance: 0

Epochs: 100

Plot against: ● Training data ○ Testing data ○ Checking data

Average testing error: 0.00055971

(a) Training data against FIS output



# of inputs: 5
# of outputs: 1
# of input mfs:
3 3 3 3 3

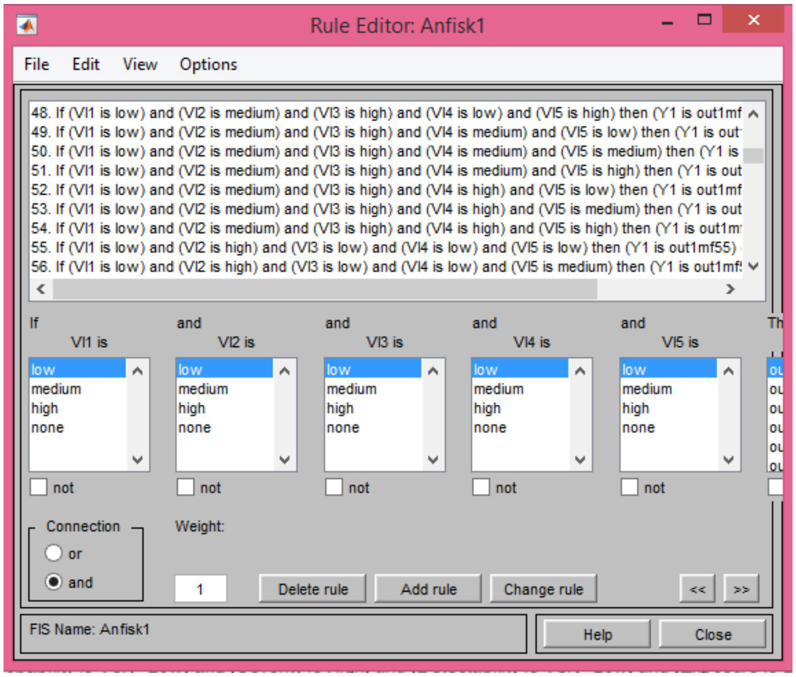
Type: ● Training
From: ● worksp.
● Grid partition
Optim. Method: hybrid
Error Tolerance: 0
Epochs: 100
Plot against: ● Testing data

Average testing error: 0.57567

(b) Testing data against FIS output

Figure 5.4 Performance of ANFIS model on (**a**) training, and (**b**) test data

Once the 144 training and testing data sets have been fed to the developed ANFIS Sugeno model, the rules were then automatically created as can be seen in Figure 5.5.



48. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is low) and (VI5 is high) then (Y1 is out1mf
49. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is medium) and (VI5 is low) then (Y1 is out
50. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is medium) and (VI5 is medium) then (Y1 is
51. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is medium) and (VI5 is high) then (Y1 is out
52. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is high) and (VI5 is low) then (Y1 is out1mf
53. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is high) and (VI5 is medium) then (Y1 is out
54. If (VI1 is low) and (VI2 is medium) and (VI3 is high) and (VI4 is high) and (VI5 is high) then (Y1 is out1m
55. If (VI1 is low) and (VI2 is high) and (VI3 is low) and (VI4 is low) and (VI5 is low) then (Y1 is out1mf55)
56. If (VI1 is low) and (VI2 is high) and (VI3 is low) and (VI4 is low) and (VI5 is medium) then (Y1 is out1mf

Connection: ● and
Weight: 1

FIS Name: Anfisk1

Figure 5.5 The constructed if-then Sugeno type rules by ANFIS

Chapter Six

Discussion of Results

6.1 Sensitivity Analysis

In this study, sensitivity analysis was performed to evaluate the significance of the different clusters of sustainable management practices (SMPs) in claims mitigation. Considering the fact that owners and project managers tend to deliver a green project within acceptable cost constraints and limited resources, sensitivity analysis can help in identifying approaches that optimize the implementation of critical sustainable management practices leading to claims resolution. In other words, by varying the influence level of specific inputs (strategies clusters) to medium implementation level (M) and maintaining the remaining inputs at high implementation level (H), sensitivity analysis can reveal which sustainable management practices can induce significant effect on reducing a specific type of construction claim. The medium implementation level indicates that the project has limitations in the enforcement of sustainable management practices on sites. The values of the input clusters are then entered into the trained ANFIS model mentioned previously in this study and the output possible values obtained from the model belong to the set interval [1, 5] which indicates the rating scale for the level of impact in a continuous range from 1 representing low (L) level, through 3 representing medium (M) level to 5 representing high (H) level. The tables below show the results of the sensitivity analysis for the different claim types starting with the variation of one input cluster up to the variation of three input clusters successively. Different numbers of project cases (PC) were illustrated in the tables based on the combinations of the strategies clusters between medium and high.

6.1.1 Delay Claims

Figure 6.1 shows the five clustered groups of SMPs that were deemed effective in delay claims mitigation.

SC1

- launch project's feasibility study based on cost/benefit analysis
- set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment
- properly select construction site based on stakeholders' concerns

SC2

- design charrette at feasibility phase
- green building certified professionals and technicians at early design phase
- green building consultant to estimate costs associated with green building products
- empower communication and collaboration among project stakeholders
- expert team in sustainable construction technology at early construction phase

SC3

- integrate digital technologies such as Building–Information Modeling (BIM) in the design phase
- incorporate involved stakeholders' concerns in initial budget and schedule
- select project delivery method, procurement method, and contract type
- adopt “Open book” subcontracting process in bidding
- set environmental management plan

SC4

- set a well-defined project execution plan
- integrate technologies to project processes at construction phase
- shift to efficient off-site manufacturing
- initiate testing and commissioning at early execution phase
- provide continuous training to familiarize employees with sustainability concepts
- implement effective health and safety program on construction sites

SC5

- be socially responsible towards competition, pricing policies, and anticorruption practices
- include incentives and bonuses for implementing sustainable practices in contracts
- specify claims, litigations and dispute resolutions clearly in contracts
- maintain long-lasting relationship between the contractor and the supplier

Figure 6.1 SCs for SMPs in Delay Claims Mitigation

Table 6.1 shows the impact of the combined five clusters of SMPs having one cluster varied to medium implementation level successively (PC1 to PC5). The five strategies clusters (SC1 to SC5) along with the different SMPs that they represent are demonstrated in Figure 6.1. The results show that only when varying the cluster SC2 “experienced green building certified professionals” to medium level, the reduction level of delay claims became medium; however, the level of delay claims mitigation remained high when the other clusters were varied to medium individually. This pinpoints that

SC2 can be considered as a key strategy in delay claims mitigation. One possible reason behind this result could be that early intervention of stakeholders and effective communication among them ensure that the parties have clear and common perceptions regarding the project requirements for contract, design, and execution. Hence when delay claims occur, the assessment and quantification of such claims would be based on technical information rather than personal opinions of stakeholders. Besides, the increase in trust between concerned parties enhances transparency in evaluation of delay claims making their resolution much easier and manageable. Moreover, previous studies have highlighted the importance of empowering communication among stakeholders in reducing the probability of claims and disputes (Hashem et al., 2018). Nevertheless, Ibrahim et al. (2020) emphasized that communication and early involvement of key stakeholders can significantly help in managing disputes and in successfully delivering projects on time and within budget.

Furthermore, Table 6.1 illustrates different impact levels for situations in which two clusters were varied to medium levels (PC6 to PC15). The project cases (PC7, PC8, PC9, PC14, and PC15) provide an approach to achieve high levels of delay claims mitigation in construction projects where sustainable development could be subjected to cost and resources constraints so the partial implementation of sustainable management practices can be satisfactory. For PC8, PC9 and PC15, high implementation of SC2 “experienced green building certified professionals” and SC3 “sustainability requirements at early design phase” combined with either SC1 “feasibility study for sustainable development” or SC4 “sustainability requirements at execution phase” or SC5 “Social responsibilities to maintain sustainable development” have great capabilities in promoting delay claims elimination in building projects. This reveals that hiring experienced green building professionals in the feasibility, design, and construction phases and empowering communication among all project’s stakeholders can be associated with technological support, well-defined project execution plan (including a health and safety program and training workshops for employees), proper selection of project delivery method, clear contract documents, and proper project feasibility assessment as a key strategy in the elimination of delay claims. Alternatively, the approach of SC2 and SC4 combined with SC1 or SC5 as depicted in PC7 and PC14 can also facilitate claims mitigation in construction projects. Zaneldin (2006) suggested that allowing reasonable time for the design team to produce initial budget and contract documents as well as having a clearly written contract with no ambiguities can minimize risks of claim occurrence. Hashem et al. (2018) indicated that the project delivery method selection can play a major role in construction overall success in terms of stakeholder satisfaction, contractor performance, and the competency and relational trust between the stakeholders.

Clearly, preceding research papers have shed light on the significant role of project schedule, design, and bidding (i.e. SC3) as well as communication and early involvement of stakeholders (i.e. SC2) in reducing claims, but high implementation of these practices alone may not sufficiently promote delay claims mitigation in construction projects. The existence of complementary correlations between the different clusters of practices, as shown in this study, emphasizes the need to engage three or more clusters at high levels for an effective attempt of delay claims resolution. This finding affirms the complex nonlinear relationships between sustainable management practices that are considered effective in reducing delay claims in our study. The implementation of certain clusters of sustainable practices at high levels can actively promote delay claims mitigation even though one or more clusters of practices may not have a high performance level. On the contrary, Table 6.1 also shows that approaches having three medium leveled clusters result in only one medium impact level on claim reduction (PC18), and hence needs to be critically examined and improved for optimum results. The remaining project cases (i.e. PC16, 17, 19, 20, and 21) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on delay claims mitigation. Figure 6.2 reveals five optimal approaches for delay claims mitigation by enforcing the implementation of three critical SCs only out of the five SCs.

Table 6.1 Sensitivity Analysis for Delay Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)						Project Case (PC)	Strategies Clusters (SC)					
	SC1	SC2	SC3	SC4	SC5	Output		SC1	SC2	SC3	SC4	SC5	Output
PC1	M	H	H	H	H	4.41 (H)	PC11	H	M	H	M	H	1.92 (L)
PC2	H	M	H	H	H	3.39 (M)	PC12	H	M	H	H	M	2.27 (L)
PC3	H	H	M	H	H	4.33 (H)	PC13	H	H	M	M	H	3.29 (M)
PC4	H	H	H	M	H	4.48 (H)	**PC14**	**H**	**H**	**M**	**H**	**M**	**4.06 (H)**
PC5	H	H	H	H	M	4.68 (H)	**PC15**	**H**	**H**	**H**	**M**	**M**	**4.17 (H)**
PC6	M	M	H	H	H	1.34 (L)	PC16	M	M	M	H	H	1.68 (L)
PC7	**M**	**H**	**M**	**H**	**H**	**4.45 (H)**	PC17	M	H	M	M	H	2.94 (L)
PC8	**M**	**H**	**H**	**M**	**H**	**4.27 (H)**	PC18	M	H	H	M	M	3.61 (M)
PC9	**M**	**H**	**H**	**H**	**M**	**4.59 (H)**	PC19	H	M	M	M	H	1.53 (L)
PC10	H	M	M	H	H	2.06 (L)	PC20	H	M	H	M	M	1.79 (L)
							PC21	H	H	M	M	M	2.43 (L)

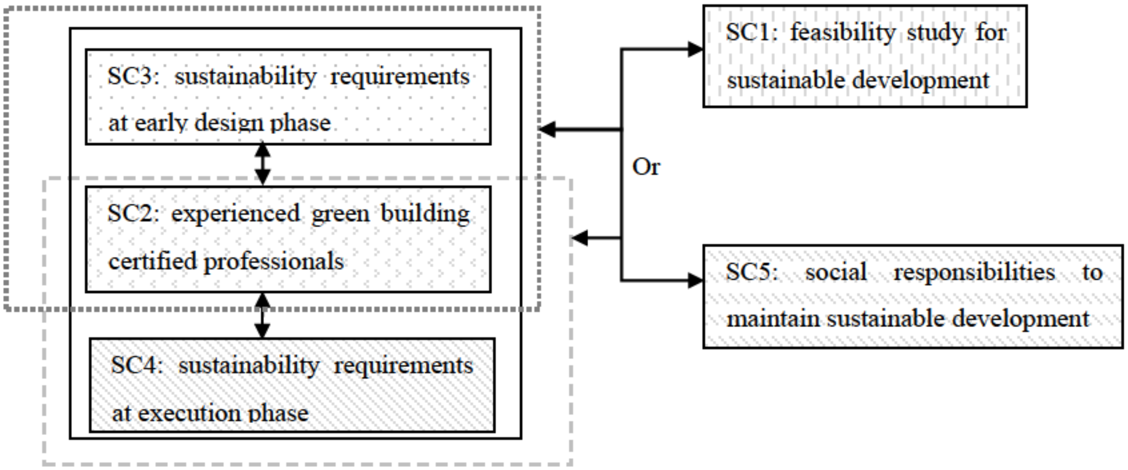


Figure 6.2 Optimal Approaches for Delay Claims Resolution

6.1.2 Suspension of Works Claims

Figure 6.3 shows the five clustered groups of SMPs that were deemed effective in suspension of works claims mitigation.

SC1

- launch project's feasibility study based on cost/benefit analysis
- set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment
- properly select construction site based on stakeholders' concerns

SC2

- design charrette at feasibility phase
- green building certified professionals and technicians at early design phase
- green building consultant to estimate costs associated with green building products
- empower communication and collaboration among project stakeholders
- expert team in sustainable construction technology at early construction phase

SC3

- integrate digital technologies such as Building–Information Modeling (BIM) in the design phase
- incorporate involved stakeholders' concerns in initial budget and schedule
- select project delivery method, procurement method, and contract type
- adopt "Open book" subcontracting process in bidding
- set environmental management plan

SC4

- set a well-defined project execution plan
- integrate technologies to project processes at construction phase
- shift to efficient off-site manufacturing
- implement effective health and safety program on construction sites

SC5

- be socially responsible towards competition, pricing policies, and anticorruption practices
- include incentives and bonuses for implementing sustainable practices in contracts
- specify claims, litigations and dispute resolutions clearly in contracts
- maintain long-lasting relationship between the contractor and the supplier

Figure 6.3 SCs for SMPs in Suspension of Works Claims Mitigation

In Table 6.2, the sensitivity analysis of suspension of works claims reveals that by varying cluster SC2 or SC3 to medium implementation level (PC2 and PC3), the level of claim mitigation was reduced to medium; however, high levels of claim reduction were attained when varying the other three clusters (SC1, SC4, SC5) individually (PC1, PC4, and PC5). Suspension of works claims could severely impact projects when the owner orders the contractor to cease construction works partially of completely. This result in delays to the work progress along with the compensating damages associated to it (Shaikh et al., 2020). Some causes to suspension of works claims can be: financial indiscipline, inadequate contractor experience, ineffective project management and scheduling, corruption tendencies, among others (Muhwezi et al., 2014). The five strategies clusters (SC1 to SC5) along with the different SMPs that they represent are demonstrated in Figure 6.3. The findings of Table 6.2 designate the significant effect of cluster SC2 "experienced green building certified professionals" and SC3 "sustainability requirements at early design phase" in the reduction of suspension of works claims. This conforms to the recommendations of previous studies that emphasized on the vital role of maintaining coordinating activities and communication throughout the project in addition to employing adequate cost, schedule, and quality control procedures in claims mitigation (Semple et al., 1994; Aibinu, 2009; Ujene and Edike, 2016). Also, pre-contract negotiation, adequate documentation, and record keeping can reduce bias problems thus ensuring transparent assessment and minimal subjectivity in the resolution of suspension of works claims (Ujene and Edike, 2016). Nevertheless, Table 6.2 further shows different impact levels for situations in which two clusters were varied at the same time (PC6 to PC15). The project cases (PC8, PC9, and PC15) provide an approach to achieve high levels of suspension of works claims mitigation in cases having limited implementation of SMPs in construction project environments. The results show that it is essential to maintain both clusters SC2 and SC3 at high implementation levels combined with one of the remaining 3 clusters SC1 "feasibility study for sustainable development" or SC4 "sustainability requirements at execution phase" or SC5 "social responsibilities to maintain sustainable development" to attain high level of suspension of works claims reduction. On the contrary, Table 6.2 shows that approaches having three medium leveled clusters result in two medium impact level on claim reduction (PC18 and PC21), and hence needs to be critically examined and improved for optimum results. The remaining project cases (i.e. PC16, 17, 19, and 20) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on suspension of works claims mitigation. This study emphasizes the need to incorporate at least three clusters at high levels for an effective attempt of suspension of works claims resolution. Figure 6.4

reveals three optimal approaches for suspension of works claims mitigation by enforcing the implementation of three critical SCs only out of the five SCs.

Table 6.2 Sensitivity Analysis for Suspension of Works Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)						Project Case (PC)	Strategies Clusters (SC)					
	SC1	SC2	SC3	SC4	SC5	Output		SC1	SC2	SC3	SC4	SC5	Output
PC1	M	H	H	H	H	4.57 (H)	PC12	H	M	H	H	M	3.81 (M)
PC2	H	M	H	H	H	3.78 (M)	PC13	H	H	M	M	H	3.37 (M)
PC3	H	H	M	H	H	3.63 (M)	PC14	H	H	M	H	M	3.12 (M)
PC4	H	H	H	M	H	4.19 (H)	**PC15**	**H**	**H**	**H**	**M**	**M**	**4.65 (H)**
PC5	H	H	H	H	M	4.65 (H)	PC16	M	M	M	H	H	2.01 (L)
PC6	M	M	H	H	H	3.69 (M)	PC17	M	H	M	M	H	2.15 (L)
PC7	M	H	M	H	H	2.61 (L)	PC18	M	H	H	M	M	3.67 (M)
PC8	**M**	**H**	**H**	**M**	**H**	**4.43 (H)**	PC19	H	M	M	M	H	1.87 (L)
PC9	**M**	**H**	**H**	**H**	**M**	**4.78 (H)**	PC20	H	M	H	M	M	2.49 (L)
PC10	H	M	M	H	H	2.46 (L)	PC21	H	H	M	M	M	3.64 (M)
PC11	H	M	H	M	H	3.58 (M)							

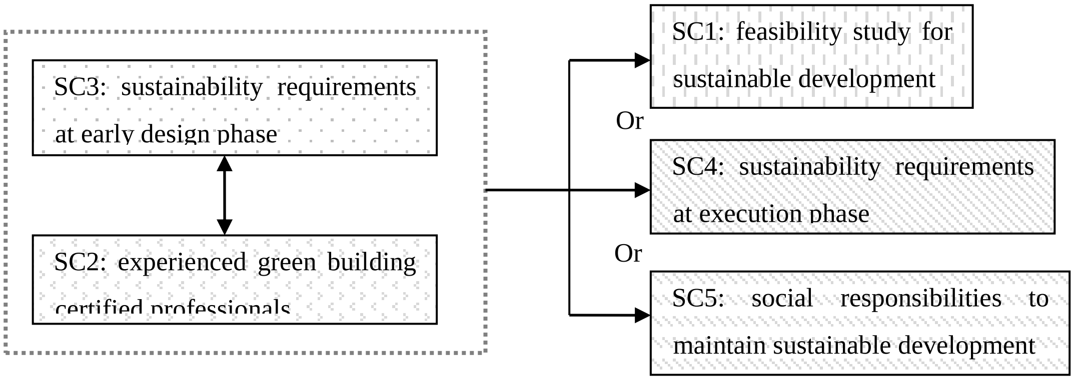


Figure 6.4 Optimal Approaches for Suspension of Works Claims Resolution

6.1.3 Contract Ambiguity Claims

Figure 6.5 shows the four clustered groups of SMPs that were deemed effective in contract ambiguity claims mitigation.

SC1

- launch project's feasibility study based on cost/benefit analysis
- set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment
- properly select construction site based on stakeholders’ concerns

SC2

- design charrette at feasibility phase
- green building certified professionals and technicians at early design phase
- green building consultant to estimate costs associated with green building products

SC3

- integrate digital technologies such as Building–Information Modeling (BIM) in the design phase
- incorporate involved stakeholders' concerns in initial budget and schedule
- select project delivery method, procurement method, and contract type
- adopt “Open book” subcontracting process in bidding

SC5

- be socially responsible towards competition, pricing policies, and anticorruption practices
- specify claims, litigations and dispute resolutions clearly in contracts

Figure 6.5 SCs for SMPs in Contract Ambiguity Claims Mitigation

Table 6.3 shows that high impact level of contract ambiguity claims reduction can be achieved having only one strategy cluster varied to medium implementation level successively (PC1 to PC4). This demonstrates that contract ambiguity claims resolution can be attained although some sustainable management practices are not sufficiently implemented during project’s processes. A construction contract is an agreement document signed between project parties that sets the scope and terms of work. Any ambiguity or missing information in drafting the contract can lead to conflicts between parties resulting in claims occurrence (Chan et al., 2021). Sources of ambiguities in construction contracts are mainly: poor contract draftsmanship, vagueness in contract terms, contract modifications, and missing data (Chan et al., 2021). The four strategies clusters (SC1, SC2, SC3, and SC5) along with the different SMPs that they represent are demonstrated in Figure 6.5. SC4 was not included in this analysis because it was perceived by the surveyor participants that the SMPs included in this cluster may not significantly alter in the reduction of contract ambiguity claims. On the other hand, different impact levels on claims mitigation were observed when varying two clusters to medium level at the same time (PC5 to PC10). The project cases (PC7, PC9, and PC10) provide an approach to achieve high levels of contract ambiguity claims mitigation in construction project environments subjected to restrictions in the achievement of sustainable development. From Table 6.3, it can be realized that Cluster SC5 “Social responsibilities to maintain sustainable development” has the least effect on contract ambiguity claims mitigation. On the contrary, each of the other clusters SC1 “feasibility study for sustainable development”, SC2 “experienced green building certified professionals” and SC3 “sustainability requirements at early design phase” can be deemed as a key strategy in the promotion of contract ambiguity claims elimination. High implementation of SC1 combined with either SC2 or SC3 have great capabilities of promoting contract ambiguity claims elimination in building projects. Alternatively, high implementation of SC2 and SC3 can also have a significant impact on contract ambiguity claims mitigation. This study identified optimal strategies for the selection of sustainable management practices to ensure the reduction of contract ambiguity claims in construction sites. The results highlight the essential role of (1) launching project's feasibility study based on cost/benefit analysis to set economic and ecological goals, market needs, building's sustainable features, green certification level, capital investment toward green initiatives, and proper site selection together with (2) establishing a design charrette at the feasibility phase, and selection of core design team, technical experts, and green building certified professionals to estimate costs associated with specialized green-building products at early design stages and (3) integration of digital technologies such as Building–Information Modeling (BIM) in the early design stages, incorporation of involved stakeholders' concerns in initial budget and schedule, proper selection of the project delivery method, the procurement method, the contract type, and adoption of “Open book” subcontracting process in bidding. Mehany et al. (2018) concluded that it is not sufficient to specify a suitable project delivery method or procurement method or contract type to promote contract ambiguity claims resolution; however, it is also essential to enforce the integration of stakeholders’ concerns, trust and long-lasting relationships between owners, contractors and suppliers as well as managerial skills and experience of contractors. This reconciles with the findings of Table 6.3 where the results reveal that it is essential to engage at least two sets of SCs (from SC1, SC2, and SC3) to achieve high levels of contract ambiguity claims mitigation. However, it is worth mentioning that approaches having three medium implementation leveled clusters (i.e. PC11 to PC 14) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on contract ambiguity claims mitigation. In brief, Figure 6.6 reveals three optimal approaches for contract ambiguity claims mitigation by enforcing the implementation of a minimal of two critical SCs out of the four identified SCs.

Table 6.3 Sensitivity Analysis for Contract Ambiguity Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)					Project Case (PC)	Strategies Clusters (SC)				
	SC1	SC2	SC3	SC5	Output		SC1	SC2	SC3	SC5	Output
PC1	M	H	H	H	4.13 (H)	PC8	H	M	M	H	3.12 (M)
PC2	H	M	H	H	4.57 (H)	**PC9**	**H**	**M**	**H**	**M**	**4.18 (H)**
PC3	H	H	M	H	4.61 (H)	**PC10**	**H**	**H**	**M**	**M**	**4.36 (H)**
PC4	H	H	H	M	4.84 (H)	PC11	H	M	M	M	2.14 (L)
PC5	M	M	H	H	3.23 (M)	PC12	M	H	M	M	2.61 (L)
PC6	M	H	M	H	3.47 (M)	PC13	M	M	H	M	2.34 (L)
PC7	**M**	**H**	**H**	**M**	**4.36 (H)**	PC14	M	M	M	H	1.94 (L)

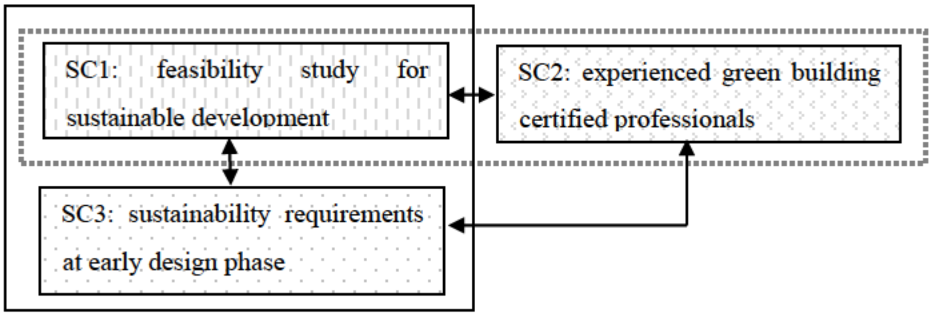


Figure 6.6. Optimal Approaches for Contract Ambiguity Claims Resolution

6.1.4 Work Volume Change Claims

Figure 6.7 shows the four clustered groups of SMPs that were deemed effective in work volume change claims mitigation.

SC1

- launch project's feasibility study based on cost/benefit analysis
- set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment
- properly select construction site based on stakeholders' concerns
- be socially responsible towards competition, pricing policies, and anticorruption practices

SC2

- design charrette at feasibility phase
- green building certified professionals and technicians at early design phase
- green building consultant to estimate costs associated with green building products
- empower communication and collaboration among project stakeholders
- expert team in sustainable construction technology at early construction phase

SC3

- integrate digital technologies such as Building–Information Modeling (BIM) in the design phase
- select project delivery method, procurement method, and contract type
- adopt "Open book" subcontracting process in bidding
- set environmental management plan

SC4

- set a well-defined project execution plan
- integrate technologies to project processes at construction phase
- shift to efficient off-site manufacturing
- initiate testing and commissioning at early execution phase
- provide continuous training to familiarize employees with sustainability concepts

Figure 6.7. SCs for SMPs in Work Volume Change Claims Mitigation

Table 6.4 signifies that the reduction of work volume change claims can be attained with high levels although one of the four clusters was varied to medium implementation level (PC1 to PC4). On the other hand, different impact levels on claims mitigation were observed when varying 2 clusters to medium level at the same time (PC5 to PC10). Work volume change claims occur when change orders and extra work are requested beyond contract agreement. Some sources of work volume change claims are: incomplete design, missing specifications and plans, owner changes, and updated information (Semple et al., 1994). The project cases (PC6, PC7, and PC10) provide an approach to achieve high levels of work volume change claims mitigation in typical resource constrained construction project environments. From Table 6.4, it can be realized that Cluster SC2 “experienced green building certified professionals” can be considered as a key strategy in the promotion of work volume change mitigation. The results show that when cluster SC2 is combined with any of the other three clusters, the level of influence on claims reduction is maintained high. The other clusters include: SC1 “feasibility study for sustainable development”, SC3 “sustainability requirements at early design phase”, and SC4 “sustainability requirements at the execution phase”. This can be due to the fact that main reasons behind work volume change claims occurrence can be attributed to incomplete and inaccurate design plans, incomplete tender information, poor communication among parties, inaccurate site assessment, among others (Zaneldine, 2006). For this reason it is vital to enhance collaboration among stakeholders and engage expert teams at early feasibility, design, and execution phases and allow concerned parties to make proper decisions regarding site selection (Shaikh et al., 2020). Table 6.4 also shows that approaches having three medium leveled clusters (i.e. PC11 to PC 14) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on contract ambiguity claims mitigation. Figure 6.8 reveals three optimal approaches for contract ambiguity claims mitigation by enforcing the implementation of a minimal of two critical SCs out of the four identified SCs.

Table 6.4. Sensitivity Analysis for Work Volume Change Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)					Project Case (PC)	Strategies Clusters (SC)				
	SC1	SC2	SC3	SC4	Output		SC1	SC2	SC3	SC4	Output
PC1	M	H	H	H	4.71 (H)	PC8	H	M	M	H	3.68 (M)
PC2	H	M	H	H	4.32 (H)	PC9	H	M	H	M	3.47 (M)
PC3	H	H	M	H	4.44 (H)	**PC10**	**H**	**H**	**M**	**M**	**4.32 (H)**
PC4	H	H	H	M	4.38 (H)	PC11	H	M	M	M	2.51 (L)
PC5	M	M	H	H	3.51 (M)	PC12	M	H	M	M	2.47 (L)
PC6	**M**	**H**	**M**	**H**	**4.17 (H)**	PC13	M	M	H	M	2.18 (L)
PC7	**M**	**H**	**H**	**M**	**4.26 (H)**	PC14	M	M	M	H	2.09 (L)

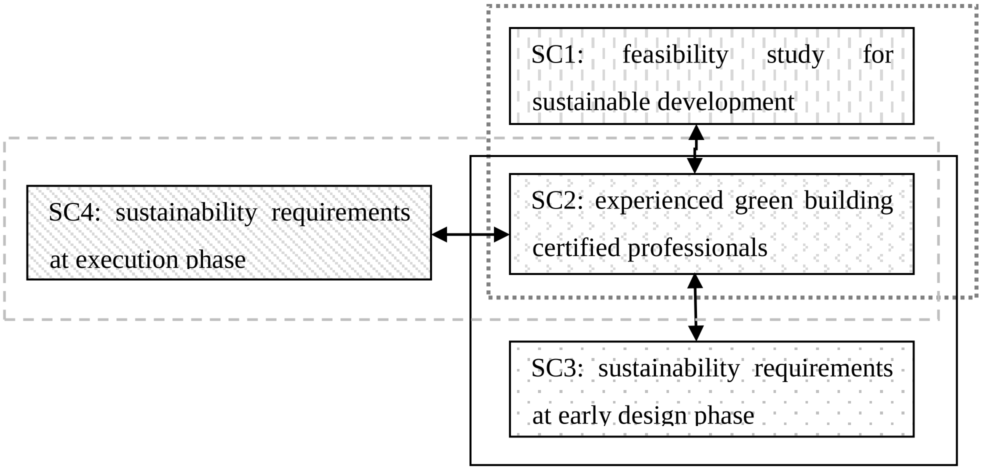


Figure 6.8. Optimal Approaches for Work Volume Change Claims Resolution

6.1.5 Design Error and Change in Scope Claims

Figure 6.9 shows the four clustered groups of SMPs that were deemed effective in design error and change in scope claims mitigation.

SC1

- launch project's feasibility study based on cost/benefit analysis
- set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment
- properly select construction site based on stakeholders' concerns

SC2

- design charrette at feasibility phase
- green building certified professionals and technicians at early design phase
- green building consultant to estimate costs associated with green building products
- empower communication and collaboration among project stakeholders
- expert team in sustainable construction technology at early construction phase

SC3

- integrate digital technologies such as Building–Information Modeling (BIM) in the design phase
- select project delivery method, procurement method, and contract type
- incorporate involved stakeholders' concerns in initial budget and schedule
- include incentives and bonuses for implementing sustainable practices in contracts

SC4

- set a well-defined project execution plan
- shift to efficient off-site manufacturing
- initiate testing and commissioning at early execution phase
- provide continuous training to familiarize employees with sustainability concepts

Figure 6.9 SCs for SMPs in Design Error and Change in Scope Claims Mitigation

Table 6.5 reveals that the reduction of design error and change in scope claims can be attained with high levels even when individually varying clusters SC1, SC3, or SC4 to medium implementation level (PC1, PC3, and PC4). However, when only varying cluster SC2 to medium while keeping the rest of the clusters at high levels (PC2), the influence level of claim reduction is also reduced to medium. This implies that cluster SC2 “experienced building certified professionals” is deemed as an essential strategy in the mitigation of design error and change in scope claims. Semple et al. (1994) recommended allowing reasonable time for the design team to generate clear and complete design plans and specifications. Adding to that, developing cooperative and problem solving mindsets among construction parties, employing expert teams for designing and executing the project, as well as maintaining job records on a timely manner can promote design error claims mitigation (Zaneldin, 2006). On the other hand, different impact levels on claims mitigation were observed when varying two clusters to medium level at the same time (PC5 to PC10). The project cases (PC6, PC7, and PC10) provide an approach to achieve high levels of design error and change in scope claims mitigation in construction projects having limited resources to SMPs implementation. The results show that when cluster SC2 is combined with any of the other three clusters, the level of influence on claims reduction is maintained high. The other clusters include: SC1 “feasibility study for sustainable development”, SC3 “sustainability requirements at early design phase” and SC4 “sustainability requirements at execution phase”. On the contrary, Table 6.5 also shows that approaches having three medium leveled clusters (i.e. PC11 to PC 14) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on design error and change in scope claims mitigation. Figure 6.10 reveals three optimal approaches for contract ambiguity claims mitigation by enforcing the implementation of a minimal of two critical SCs out of the four identified SCs.

Table 6.5 Sensitivity Analysis for Design Error and Change in Scope Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)					Project Case (PC)	Strategies Clusters (SC)				
	SC1	SC2	SC3	SC4	Output		SC1	SC2	SC3	SC4	Output
PC1	M	H	H	H	4.67 (H)	PC8	H	M	M	H	2.51 (L)
PC2	H	M	H	H	3.71 (M)	PC9	H	M	H	M	3.82 (M)
PC3	H	H	M	H	4.43 (H)	**PC10**	**H**	**H**	**M**	**M**	**4.39 (H)**
PC4	H	H	H	M	4.52 (H)	PC11	H	M	M	M	1.87 (L)
PC5	M	M	H	H	3.26 (M)	PC12	M	H	M	M	2.36 (L)
PC6	**M**	**H**	**M**	**H**	**4.19 (H)**	PC13	M	M	H	M	2.08 (L)
PC7	**M**	**H**	**H**	**M**	**4.25 (H)**	PC14	M	M	M	H	1.98 (L)

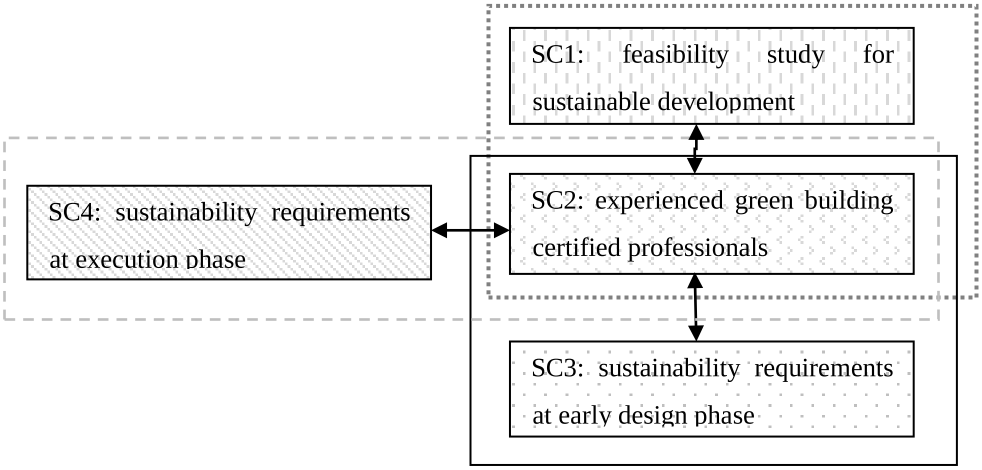


Figure 6.10 Optimal Approaches for Design Error and Change in Scope Claims Resolution

6.1.6 Extension of Time Claims

Figure 6.11 shows the four clustered groups of SMPs that were deemed effective in extension of time claims mitigation.

SC2

- design charrette at feasibility phase
- green building consultant to estimate costs associated with green building products
- empower communication and collaboration among project stakeholders
- expert team in sustainable construction technology at early construction phase

SC3

- integrate digital technologies such as Building–Information Modeling (BIM) in the design phase
- select project delivery method, procurement method, and contract type
- incorporate involved stakeholders' concerns in initial budget and schedule
- set environmental management plan

SC4

- set a well-defined project execution plan
- integrate technologies to project processes at construction phase
- shift to efficient off-site manufacturing
- initiate testing and commissioning at early execution phase
- provide continuous training to familiarize employees with sustainability concepts
- implement effective health and safety program on construction sites

SC5

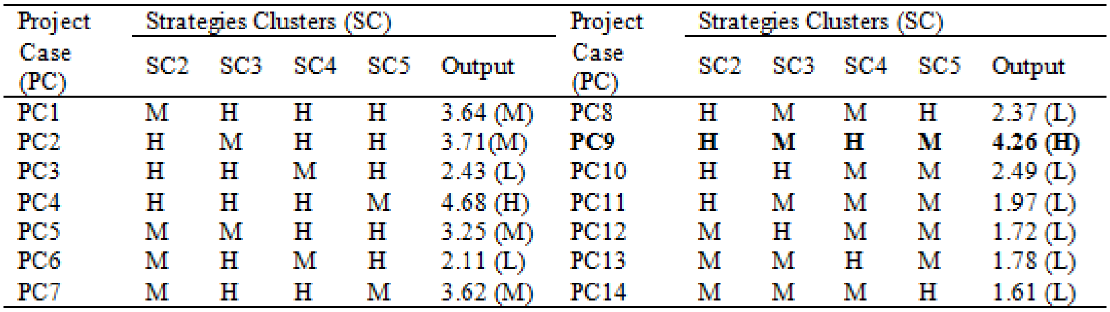
- specify claims, litigations and dispute resolutions clearly in contracts
- set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment
- include incentives and bonuses for implementing sustainable practices in contracts
- maintain long-lasting relationship between the contractor and the supplier

Figure 6.11. SCs for SMPs in Extension of Time Claims Mitigation

The sensitivity analysis of extension of time claims results, as shown in Table 6.6, reveal that varying any of the clusters to medium implementation level can lead to low (when SC4 was medium) or medium level (when SC2 or SC3 was medium) of claim reduction except for cluster SC5 where high level of claim reduction was attained. This designates the significant influence of cluster SC4 “sustainability requirements at the execution phase” on extension of time claims mitigation. The results also show that cluster SC2 “experienced green building certified professionals” and cluster SC3 “sustainability requirements at early design phase” represent vital strategies for the reduction of extension of time claims. Contrarily, cluster SC5 “social responsibilities to maintain sustainable development” can be deemed as the least effective cluster on extension of time claims elimination. On the other hand, low and medium impact levels on claims mitigation were observed when varying 2 clusters to medium level at the same time (PC5 to PC10). Only the project case PC9 provides an approach to achieve high levels of work volume change claims mitigation in typical resource constrained construction project environments. Extension of time claims are issued when the project is delayed; some of the delays are due to contractor errors and some are beyond his responsibility (Al-Azad, 2021). According to Alade et al. (2016), major causes for extension of time claims are: poor site management and supervision, contractor’s poor experience, and owner’s financial difficulties. The results show that when high influence level of cluster

SC2 is combined with high level of cluster SC4, the level of influence on claims reduction is maintained high. Extension of time claims could be due to contractor/sub-contractor low quality of work, owner's delay for payments and decisions, or due to design errors (Sweis et al., 2014). That said the findings in this study are in harmony with the aforementioned causes. The results emphasize on the importance of communication among stakeholders to avoid delays and ambiguities in work. It also stresses on implementing adequate execution plan and empower the use of technologies to accelerate work while maintaining its high quality. On the contrary, Table 6.6 also shows that approaches having three medium leveled clusters (i.e. PC11 to PC 14) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on extension of time claims mitigation. Figure 6.12 reveals only one optimal approach for extension of time claims mitigation by maintaining SC2 and SC4 at high implementation levels.

Table 6.6. Sensitivity Analysis for Extension of Time Claims Mitigation



Project Case (PC)	Strategies Clusters (SC)					Project Case (PC)	Strategies Clusters (SC)				
	SC2	SC3	SC4	SC5	Output		SC2	SC3	SC4	SC5	Output
PC1	M	H	H	H	3.64 (M)	PC8	H	M	M	H	2.37 (L)
PC2	H	M	H	H	3.71(M)	**PC9**	**H**	**M**	**H**	**M**	**4.26 (H)**
PC3	H	H	M	H	2.43 (L)	PC10	H	H	M	M	2.49 (L)
PC4	H	H	H	M	4.68 (H)	PC11	H	M	M	M	1.97 (L)
PC5	M	M	H	H	3.25 (M)	PC12	M	H	M	M	1.72 (L)
PC6	M	H	M	H	2.11 (L)	PC13	M	M	H	M	1.78 (L)
PC7	M	H	H	M	3.62 (M)	PC14	M	M	M	H	1.61 (L)

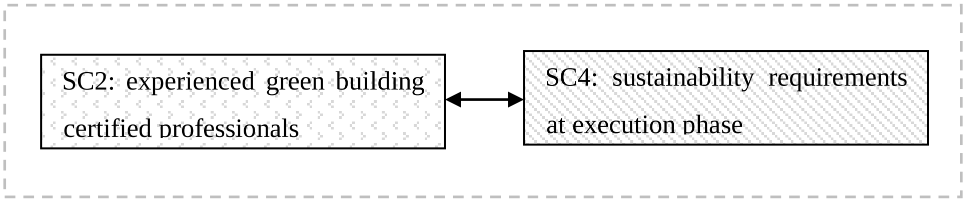


Figure 6.12. Optimal Approach for Extension of Time Claims Resolution

6.1.7 Environmental Disputes due to Noise and Vibration

Figure 6.13 shows the three clustered groups of SMPs that were deemed effective in environmental disputes due to noise and vibration mitigation.

SC1	SC2	SC4
• launch project's feasibility study based on cost/benefit analysis • set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment • properly select construction site based on stakeholders' concerns	• design charrette at feasibility phase • green building certified professionals and technicians at early design phase • green building consultant to estimate costs associated with green building products • empower communication and collaboration among project stakeholders • expert team in sustainable construction technology at early construction phase	• set a well-defined project execution plan • shift to efficient off-site manufacturing • initiate testing and commissioning at early execution phase • integrate technologies to project processes at construction phase • provide continuous training to familiarize employees with sustainability concepts • set environmental management plan

Figure 6.13. SCs for SMPs in Environmental Disputes due to Noise and Vibration Mitigation

The sensitivity analysis in Table 6.7 shows that clusters SC1 "feasibility study for sustainable development" as well as SC4 "sustainability requirements at execution phase" are deemed key strategies in the mitigation of environmental disputes. However, SC2 "experienced green building certified professionals" is considered insufficiently effective on reducing environmental disputes. It is noteworthy to mention that studies related to reducing environmental disputes on construction sites are minimal (Eom and Paek, 2009). Eom and Paek (2009) highlighted main risk factors that contribute to environmental conflicts in construction sites such as: review of environmental regulations, adequate investigation of site characteristics, development of appropriate environmental management plan, setting of proper construction plans and schedule, employing antipollution equipments and avoiding the use of old machinery, in addition to maintaining workers' carefulness and enthusiasm towards work. Hence, all of the aforementioned risks are consistent with the SMPs in SC1 and SC4 which were deemed critical in eliminating environmental disputes. On the other hand, Table 6.7 shows that the approaches having two medium leveled clusters (i.e. PC4 to PC6) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they all resulted in low impact levels on environmental disputes mitigation. Figure 6.13 enlists the different SMPs that constitute each SC (SC1, SC2, and SC4) and Figure 6.14 shows the optimal approach of integrating SC1 and SC4 together at high implementation levels to ensure adequate elimination of environmental disputes on construction sites.

Table 6.7. Sensitivity Analysis for Environmental Disputes due to Noise and Vibration Mitigation

Project Case (PC)	Strategies Clusters (SC)			
	SC1	SC2	SC4	Output
PC1	M	H	H	3.76 (M)
PC2	**H**	**M**	**H**	**4.27 (H)**
PC3	H	H	M	3.81 (M)
PC4	M	M	H	2.73 (L)
PC5	M	H	M	2.56 (L)
PC6	H	M	M	2.94 (L)

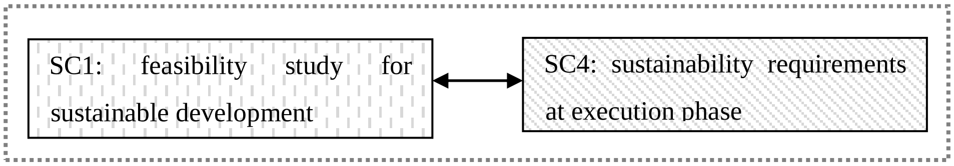


Figure 6.14. Optimal Approach for Environmental Disputes due to Noise and Vibration Resolution

6.1.8 Fluctuation in the Price of Construction Materials Claims

Figure 6.15 shows the three clustered groups of SMPs that were deemed effective in fluctuation in the price of construction materials claims mitigation.

SC1	SC2	SC3
• launch project's feasibility study based on cost/benefit analysis • set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment • properly select construction site based on stakeholders' concerns • maintain long-lasting relationship between the contractor and the supplier	• design charrette at feasibility phase • green building certified professionals and technicians at early design phase • green building consultant to estimate costs associated with green building products • empower communication and collaboration among project stakeholders • expert team in sustainable construction technology at early construction phase	• integrate digital technologies such as Building–Information Modeling (BIM) in the design phase • select project delivery method, procurement method, and contract type • incorporate involved stakeholders' concerns in initial budget and schedule • adopt "Open book" subcontracting process in bidding • set environmental management plan

Figure 6.15 SCs for SMPs in Fluctuation in the Price of Construction Materials Claims Mitigation

The sensitivity analysis in Table 6.8 shows that the three clusters are considered essential for the promotion of the reduction of the fluctuation in the price of construction materials claims. The three clusters SC1 "feasibility study for sustainable development", SC2 "experienced green building certified professionals", and SC3 "sustainability requirements at early design phase" should be implemented at high levels to ensure significant reduction of fluctuation in the price of construction materials claims. Fluctuation in the prices of construction materials can have severe impact on properly planning and managing construction projects. Therefore, several perceptional measures shall be taken at the very start beginning of a project. Allocation of risks and responsibilities in contract agreements as well as other proactive measures shall be implemented on site to avoid fluctuation impacts (Lamptey and Emmanuel, 2018). For instance, proper evaluation of the project's feasibility study can be useful in determining costs and availability of materials (Long et al., 2008). Also, maintaining a long-lasting relationship between suppliers and contractors play a vital role in controlling fluctuation of prices. Moreover, communication among stakeholders is considered a starting point for reducing fluctuation impacts (Shaikh et al., 2020). It is crucial that concerned parties communicate early about price impacts and availability of materials so that claims could be narrowed or eliminated on time. Adding to that, proper and clear design plans and specifications especially when using BIM software can also assist in managing fluctuation of prices by generating precise knowledge about material types and quantities especially special types of materials that are particularly high risk (e.g. steel, lumber, or copper) (Hussin et al., 2013). Figure 6.15 enlists the different SMPs that constitute each SC (SC1, SC2, and SC3) and Figure 6.16 shows the optimal approach of integrating SC1, SC2, and SC3 together at high implementation levels to ensure adequate elimination of fluctuation in the price of construction materials claims.

Table 6.8 Sensitivity Analysis for Fluctuation in the Price of Construction Materials Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)			
	SC1	SC2	SC3	Output
PC1	**H**	**H**	**H**	**4.68 (H)**
PC2	M	H	H	2.46 (L)
PC3	H	M	H	3.87 (M)
PC4	H	H	M	2.95 (L)
PC5	M	M	H	2.61 (L)
PC6	M	H	M	2.58 (L)
PC7	H	M	M	2.77 (L)

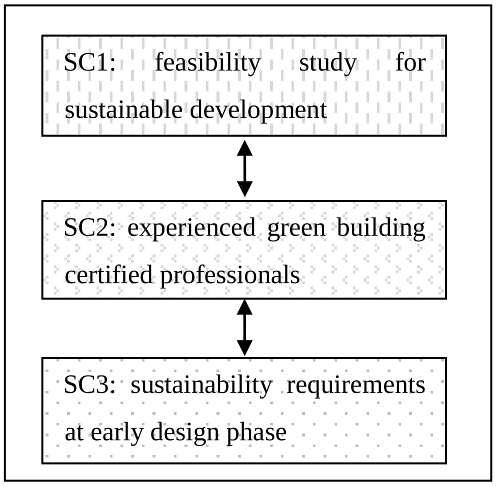


Figure 6.16 Optimal Approach for Fluctuation in the Price of Construction Materials Claims Resolution

6.1.9 Weather Condition Claims

Figure 6.17 shows the three clustered groups of SMPs that were deemed effective in weather condition claims mitigation.

SC2	SC3	SC4
• design charrette at feasibility phase • empower communication and collaboration among project stakeholders	• incorporate involved stakeholders' concerns in initial budget and schedule • set environmental management plan • properly select construction site based on stakeholders' concerns	• set a well-defined project execution plan • shift to efficient off-site manufacturing

Figure 6.17 SCs for SMPs in Weather Condition Claims Mitigation

Table 6.9 illustrates that the reduction of weather condition claims can be attained with high levels when individually varying cluster SC2 only to medium implementation level (PC1). This indicates that SC2 "experienced green building certified professionals" represents the least effective cluster in the promotion of mitigating weather conditions claims. However, SC3 "sustainability requirements at early design phase" and SC4 "sustainability requirements at execution phase" play a vital role in the reduction of weather conditions claims. Research on the impact of weather conditions on project productivity is limited and practitioners lack the knowledge on methods to mediate when weather condition conflicts occur on construction sites (Ballesteros-Pérez et al. 2017). However, findings of this study can be found rational in mitigating weather conditions claims. Setting a well-defined project execution plan shall take into consideration severe weather conditions and shall be negotiated in the schedule (Sweis et al., 2014). Moreover, shifting towards off-site manufacturing can avoid delays as well as enhance the duration and quality of productivity. Nevertheless, proper selection of construction site based on stakeholders' concerns and implementing effective environmental management plan can assist in managing productivity decrease in severe weathers, loss of resources, project delays, and financial losses to different construction parties (Ballesteros- Pérez et al., 2010). The results also show that the approaches having two medium leveled clusters (i.e. PC4 to PC6) are considered unsuitable approaches for the optimization of sustainable practices in reducing claims because they resulted in low and medium impact levels on weather conditions claims mitigation. Figure 6.18 shows the optimal approach of integrating SC3 and SC4 together at high implementation levels to ensure weather condition claims mitigation on construction sites.

Table 6.9 Sensitivity Analysis for Weather Condition Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)			
	SC2	SC3	SC4	Output
PC1	**M**	**H**	**H**	**4.33 (H)**
PC2	H	M	H	3.28 (M)
PC3	H	H	M	3.67 (M)
PC4	M	M	H	2.58 (L)
PC5	M	H	M	3.41(M)
PC6	H	M	M	2.97 (L)

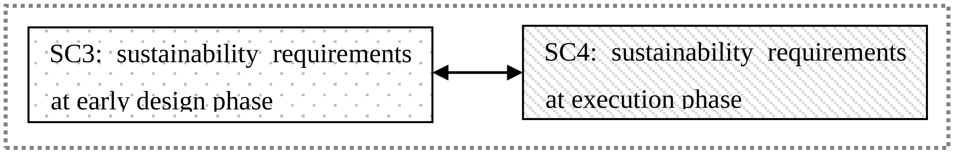
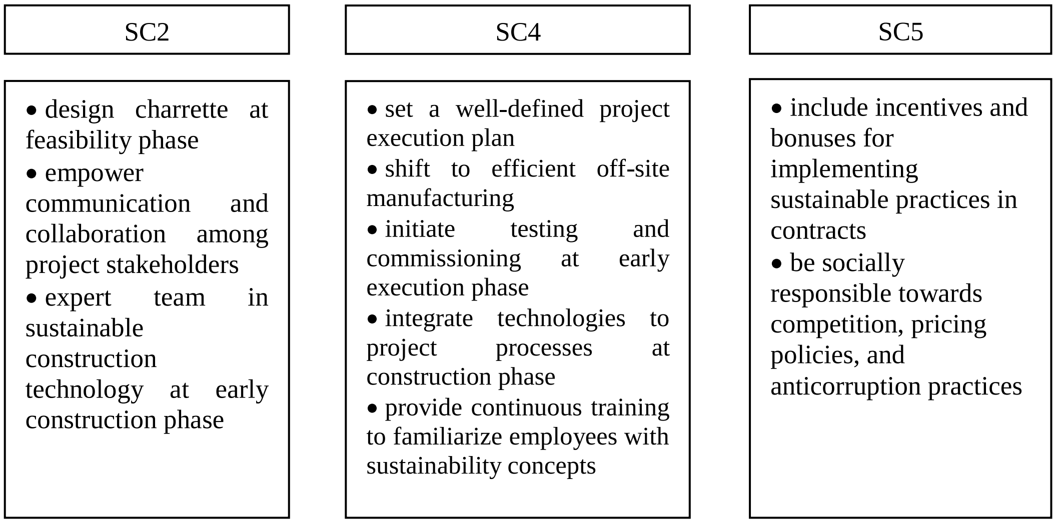


Figure 6.18 Optimal Approach for Weather Conditions Claims Resolution

6.1.10 Safety and Health Claims

Figure 6.19 shows the three clustered groups of SMPs that were deemed effective in safety and health claims mitigation.



SC2

- design charrette at feasibility phase
- empower communication and collaboration among project stakeholders
- expert team in sustainable construction technology at early construction phase

SC4

- set a well-defined project execution plan
- shift to efficient off-site manufacturing
- initiate testing and commissioning at early execution phase
- integrate technologies to project processes at construction phase
- provide continuous training to familiarize employees with sustainability concepts

SC5

- include incentives and bonuses for implementing sustainable practices in contracts
- be socially responsible towards competition, pricing policies, and anticorruption practices

Figure 6.19 SCs for SMPs in Safety and Health Claims Mitigation

The sensitivity analysis of safety and health claims results in Table 6.10 reveal that by varying cluster SC2 or SC5 to medium implementation level (PC1 and PC3), the level of claim mitigation remained high; however, low level of claim reduction was attained when varying the cluster SC4 individually (PC2). The three strategies clusters (SC2, SC4, and SC5) along with the different SMPs that they signify are presented in Figure 6.19. The results designate the significant effect of cluster SC4, mainly the following SMPs: well-defined project execution plan including shifting to off-site prefabrication, integrating technologies to construction processes, continuous training to employees, and effective safety and health plan on site in the mitigation of safety and health claims. The results also illustrate that maintaining cluster SC4 only at high implementation level while varying clusters SC2 and SC5 to medium levels provide an approach to achieve high levels of safety and health claims mitigation in construction project environments subjected to limited implementation of SMPs due to cost and resources constraints as shown in Figure 6.20. According to (Rivera et al., 2021), it was found that factors related to construction site were the most significant factors affecting construction safety. These factors include: site constraints, work scheduling, housekeeping, work environment, site workspace, and workers experience (Chan et al., 2020; Mohammadi et al., 2018). This conforms to the findings of this study that taking adequate safety measures at the execution phase is effectively critical in eliminating safety and health claims. The construction industry is considered the most hazardous industry regarding safety and health accidents. Implementing an effective health and safety plan as well as other safety precautions regarding machinery and continuous training to employees can lead to avoidable additional expenses, increase productivity time, and more importantly avoid long-term health accidents and death which in some cases may result in the suspension of construction works (Rivera et al., 2021).

Table 6.10 Sensitivity Analysis for Safety and Health Claims Mitigation

Project Case (PC)	Strategies Clusters (SC)			
	SC2	SC4	SC5	Output
PC1	M	H	H	4.28 (H)
PC2	H	M	H	2.63 (L)
PC3	H	H	M	4.46 (H)
PC4	M	M	H	2.91 (L)
PC5	**M**	**H**	**M**	**4.11 (H)**
PC6	H	M	M	2.74 (L)

SC4: sustainability requirements at execution phase

Figure 6.20 Optimal Approach for Safety and Health Claims Resolution

6.2 Summary of Results

This research has a significant contribution to the body of knowledge by recommending to the construction industry practitioners, mainly owners and contractors, a set of critical sustainable management practices that can effectively influence the resolution of construction claims. This research serves owners and contractors in choosing specific number of sustainable management practices tailored at the mitigation of specific types of claims that owners and contractors are mainly aware of in a certain project. This also can help reduce the cost of implementing sustainable practices specially that most developers refrain from going green due to the initial high costs associated to it. Considering the main barrier for the adoption of sustainable development which is initial high project cost, the findings of this study advocates specific amendments to the traditional management practices to ensure the delivery of a successful sustainable project within acceptable cost constraints and controllable number of claims. Construction practitioners can choose adequate approaches for implementing a critical set of sustainable management practices to eliminate targeted construction claims based on practitioners' preferences. Furthermore, the results of this study emphasize the significance of integrating a particular number of strategies clusters of different sustainable management practices depending on the type of construction claim to be mitigated. A detailed description of the different SCs is listed in Table 6.11.

Nevertheless, it can be concluded from the findings that implementing one strategy cluster of sustainable management practices would not be sufficient to ensure effective reduction of claims in projects. Two or more SCs are essentially required to maintain efficient claims mitigation. Practitioners and decision makers can choose different approaches for the resolution of each claim type as indicated in Table 6.12.

Table 6.12 summarizes the different optimal approaches for the engagement of clusters of SMPs in the mitigation of different types of construction claims. It can be concluded that high implementation of SMPs included in SC2, SC3, and SC4 (which encompass approaches 3, 9, 10, 11, and12) can contribute in the mitigation of 8 out of the 10 construction claims. However, the implementation of high levels of SMPs entailed in SC1, SC2, and SC3 (which include approaches 1, 6, 7, and 9) can promote the mitigation of 6 out of the 10 types of claims. Another major finding can be highlighted from Table 6.12 is the minimal effect of SC5 on claims mitigation perceived by construction management experts. One possible reason could be that construction practitioners allocate minor importance to the social pillar in sustainable development such as being socially responsible towards competition, pricing policies, and anticorruption practices, including incentives and bonuses for implementing sustainable practices in contracts, or maintaining long-lasting relationship between the contractor and the supplier. Notwithstanding the fact that one of the characteristics that serves as a basic intention for sustainable management development is that sustainable management should contribute to the sustainability of the organization and society (esp. ethics) (Stanitsas et al., 2021).

On the other hand, a study conducted by Al-Qershi and Kishore (2017) reveals that the most important claims based on their frequency of occurrence in construction sites are (1) work volume change claims, (2) delay claims, (3) design error and change in scope claims, (4) fluctuation in the price of construction materials claims, (5) contract ambiguity claims, (6) suspension of works claims, and (7) extension of time claims. Nonetheless, Zaneldin (2006) ranked construction claims based on their frequency of occurrence as such: (1) design error and change in scope claims, (2) work volume change claims, (3) delay claims, (4) extension of time claims, (5) contract ambiguity claims. In view of the aforementioned rankings, it can be deemed that the major claims that should be tackled by construction practitioners are: design error and change in scope claims, delay claims, work volume change claims, contract ambiguity claims, extension of time claims, suspension of works claims, and fluctuation in the price of construction materials claims. Considering the constraints and limitations on sustainable practices' implementation in projects, Tables 6.12 and 6.13 provides practitioners with essential knowledge for proper selection of the critical sustainable management practices to ensure effective reduction of major construction claims.

Summary of Results

Table 6.11 Strategies Clusters of the different critical SMPs

SC1: Feasibility study for sustainable development	SC2: Experienced green building certified professionals	SC3: Sustainability requirements at early design phase	SC4: Sustainability requirements at execution phase	SC5: Social responsibilities to maintain sustainable development
• launch project's feasibility study based on cost/benefit analysis • set economic and ecological goals, market needs, building's sustainable features, green certification level, amount of capital investment • properly select construction site based on stakeholders' concerns	• design charrette at feasibility phase • green building certified professionals and technicians at early design phase • green building consultant to estimate costs associated with green building products • empower communication and collaboration among project stakeholders • expert team in sustainable construction technology at early construction phase	• integrate digital technologies such as Building–Information Modeling (BIM) in the design phase • incorporate involved stakeholders' concerns in initial budget and schedule • select project delivery method, procurement method, and contract type • adopt "Open book" subcontracting process in bidding • set environmental management plan	• set a well-defined project execution plan • integrate technologies to project processes at construction phase • shift to efficient off-site manufacturing • initiate testing and commissioning at early execution phase • provide continuous training to familiarize employees with sustainability concepts • implement effective health and safety program on construction sites	• be socially responsible towards competition, pricing policies, and anticorruption practices • include incentives and bonuses for implementing sustainable practices in contracts • clarify allocation of roles and responsibilities of different parties and specify claims, litigations and dispute resolutions clearly in contracts • maintain long-lasting relationship between the contractor and the supplier

Table 6.12 Optimal Approaches in the selection of SMPs to mitigate specific types of construction claims

	Delay Claims	Contract Ambiguity Claims	suspension of Works Claims	Work Volume Change Claims	Design Error and Change in Scope Claims	Extension of Time Claims	Environmental Disputes due to Noise and Vibration	Fluctuation in the Price of Construction Materials Claims	Weather Condition Claims	Safety and Health Claims
Approach 1 (SC1, SC2, SC3)	√		√					√		
Approach 2 (SC1, SC2, SC4)	√									
Approach 3 (SC2, SC3, SC4)	√		√							
Approach 4 (SC2, SC3, SC 5)	√		√							
Approach 5 (SC2, SC4, SC5)	√									
Approach 6 (SC1, SC2)		√		√	√					
Approach 7 (SC1, SC3)		√								
Approach 8 (SC1, SC4)							√			
Approach 9 (SC2, SC3)		√		√	√					
Approach 10 (SC2, SC4)				√	√	√				
Approach 11 (SC3, SC4)									√	
Approach 12 (SC4)										√

Table 6.13 Optimal Approaches in the selection of SMPs to mitigate specific types of construction claims

	SC1: Feasibility study for sustainable development	**SC2: Experienced green building certified professionals**	**SC3: Sustainability requirements at early design phase**	**SC4: Sustainability requirements at execution phase**	**SC5: Social responsibilities to maintain sustainable development**
Delay Claims	√	√	√		
	√	√		√	
		√	√	√	
		√	√		√
		√		√	√
Contract Ambiguity Claims	√	√			
	√		√		
		√	√		
Suspension of Works Claims	√	√	√		
		√	√	√	
		√	√		√
Work Volume Change Claims	√	√			
		√	√		
		√		√	
Design Error and Change in Scope Claims	√	√			
		√	√		
		√		√	
Extension of Time Claims		√		√	
Environmental Disputes due to Noise and Vibration	√			√	
Fluctuation in the Price of Construction Materials Claims	√	√	√		
Weather Condition Claims			√	√	
Safety and Health Claims				√	

Chapter Seven

Conclusion

Construction claims and disputes are considered one of the most inevitable conflicts that arise in the construction sector. To address the frequent occurrence of claims in construction projects, this research developed an adaptive neurofuzzy inference system model to analyze the effect of implementing sustainable management practices on construction claims mitigation. The ANFIS model was established to assess the performance of integrating critical SMPs on the reduction of different types of claims. The initial phase of the research relied on a comprehensive literature review resulting in the identification of 25 critical SMPs and 10 frequent construction claims. Subsequently, a survey questionnaire was conducted and resulted in 144 responses from construction engineering experts including developers, contractors, project managers, consultants, and architects. The obtained data was then checked for normality, reliability, criticality, and consistency of rankings between different participants' occupation categories. Furthermore, the critical SMPs were grouped into five main strategies clusters using factor analysis, namely SC1: feasibility study for sustainable development, SC2: experienced green building certified professionals, SC3: sustainability requirements at early design phase, SC4: sustainability requirements at execution phase, and SC5: social responsibilities to maintain sustainable development. The aforementioned SCs served as inputs to the different ANFIS models that were developed to assess the complex and non-linear relationships between the SMPs in the promotion of mitigating different claim types. Finally, sensitivity analysis assisted in the identification of optimal approaches for combining SMPs which lead to the reduction of construction claims.

The findings of this research resulted in the identification of optimal approaches for the implementation of SMPs in order to avoid the occurrence of 10 frequent claim types. Moreover, the study shed light on critical SMPs that were deemed significantly effective in mitigating several types of construction claims, in particular (1) hiring of a design charrette at the feasibility phase, (2) employing green building certified professionals, consultants, and technicians at early design phase, (3) empowering communication and collaboration among project stakeholders, (4) integration of digital technologies such as

Building–Information Modeling (BIM) in the design phase, and (5) selection of appropriate project delivery method, procurement method, and contract type. This research study contributes to the body of knowledge by emphasizing the need to incorporate sustainable management practices into traditional construction projects in order to improve project's delivery within acceptable cost constraints and minimal claims occurrence. This study also enabled the development of complex and nonlinear relationships between SMPs to quantitatively assess the performance of their implementation on claims mitigation using ANFIS models. Nevertheless, this study provides construction management practitioners with essential knowledge for proper selection of the critical sustainable management practices to ensure effective reduction of major construction claims based on their preferences.

One main limitation of this study is the relatively small sample size of the survey where a larger sample size could have resulted in a wider coverage of expert's opinions. Another limitation is the inability to implement the developed models in a real-life construction project for further practical verifications due to time limits of the research study. Hence, future work may extend the implementation of the developed models to different construction projects in order to empirically measure its performance on claims mitigation. Another recommendation is to develop a model that can estimate the amount of saved costs and expenses due to elimination of claims through the implementation of SMPs.

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