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A Study of Design Change Management for Infrastructure Development Projects in New Zealand

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Abstract: Design changes seem to be an inevitable part of engineering, procurement and construction EPC projects. Such changes create a need for a proactive approach to adjusting project scope, cost and time (the triple constraints) for efficiency and effectiveness in overall delivery. This study investigates the causes and implications of design changes in order to improve design change management practices. Data for the study were obtained through online interviews with New Zealand industry practitioners. Thematic analysis was used to collate the results into meaningful data. The study found that design changes were predominantly caused by clients' inadequate strategic planning, insufficient attention to design, EPC contractors' inadequate design ability, and on-site variations. There were three categories of such design changes: direct impact on the project, the reciprocal and complementary effect on stakeholders, and the far-reaching impact on the community. The study concludes by suggesting improvements, such as strengthening the integration of project teams to enhance design quality, strategic alignment of stakeholders at the planning stage, early contractor involvement (ECI) between the planning and design phases, and improving collaboration between design and construction teams. Further, a combination of high technical skills (e.g., design ability) and soft skills (can-do attitude, interpersonal skills, problem-solving skills, documentation skills, etc.) are needed to generate the desired improvement in design change management.

Keywords: engineering procurement and construction project (EPC); project management; design changes; infrastructure development projects; construction management; New Zealand

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1. Introduction

The New Zealand Government has raised capital investment to its highest level in more than 20 years and has announced plans to increase infrastructure investment by NZD 12 billion over the next five years [1]. This scale of investment is expected to increase the economy's size and increase the number infrastructure projects. Infrastructure projects are often 'mega projects' that cost billions of dollars, take many years to develop and complete, and involve multiple public and private stakeholders [2]. They are large in scale, long in schedule and high in complexity [3], and the success of an infrastructure project requires the multidisciplinary contribution of many stakeholders [4]. Infrastructure projects are designed to change the structure of society and have a transformational impact on people's daily lives. Examples include roading, bridges, water treatment projects, irrigation, oil drilling and gas transmission projects.

When clients develop projects, they must determine a project delivery method. This defines the roles and responsibilities of the parties involved [5]. The project delivery method effectively influences project performance [6], and an appropriate project delivery method is a key performance indicator for measuring project success [7]. There is no single best project delivery model—a client selects the delivery model that is most suitable and favourable for the project. Considering the levels of infrastructure project complexity, more and more clients prefer a model that allows them to have centralised control with less contact. To develop the project, clients usually prefer to delegate contractual responsibility to a more professional team. This approach to project implementation is also recognised as a 'turnkey solution' [8]. The Engineering, Procurement and Construction (EPC) model fits such requirements best because it transfers more responsibility to the contractor. A client would rather bear high contract costs and gain vital protection in contract transactions.

Along with the trend of increased infrastructure construction in New Zealand [9], it is predicted that the EPC model will play an increasingly important role in NZ's infrastructure construction. Irrespective of the project delivery model, EPC projects are always prone to risks. Project changes are often perceived as risks. All changes are presented as adjusting the 'iron triangle' in project management [8]. When change occurs, the iron triangle will reshape to meet new requirements. Change can have a positive or negative impact on project success [10]: When a change is intended to maximise clients' interest by reducing costs and delivery time, or by a quality improvement, it impacts the project positively; however, if a change increases costs, reduces project profitability, delays the project schedule, or reduces project quality, it negatively impacts the project. Change is negatively correlated to deliverables [11]. The greater the change, the more deliverables and costs are degraded and the higher the risks that projects seem to face [12].

From a risk management perspective, the key to managing projects is to prevent and minimise change as much as possible. Rebalancing the iron triangle is risky, especially under a lump sum contract. Lump sum arrangements significantly protect the client from paying additional fees beyond the total contract price; thus, clients choose lump sum contracts for the same reason they choose an EPC model—to avoid risk. Under lump sum contracts, changes cause delays, increase costs and lower profits. This could create irreconcilable conflict between contractors and clients, and projects are likely to stall and require arbitration.

Design quality plays a decisive role in project implementation [13]. If there are missing items, faulty items or variable bias in the design works, it will lead to incorrect budgets and construction difficulties. Ultimately designs will have to be changed. Design change is the modification of an existing design due to changes in conditions, assumptions or requirements [14]. Design changes can occur at any time after designs are completed. In general, the client and the professional advisors together with the contractors are considered to be the top key players in a typical construction project. Design changes arise, impacting the cost overruns due to intentional or unintentional actions by the top key players, or their negligence [15]. A study conducted by Shoar and Chileshe [16] found that the main causes of design changes include unfamiliarity with new construction methods, design errors, value engineering, scope uncertainty, changed orders and constructability ignored in the design phase. Design change risk is similar to other construction risks in that it has the same characteristics and effects as described above. Understanding the causes and outcomes of design changes is the key to effectively preventing and managing EPC project design changes and their negative consequences.

This study aims to identify the causes and impact of design changes in EPC projects and to offer suggestions that could improve the effectiveness and efficiency of design change management. Thus, the study addresses the following pertinent questions within a New Zealand context:

1. What factors drive design changes in EPC projects?
2. To what extent do design changes impact an EPC project and associated stakeholders and communities?
3. How can design changes be managed effectively and efficiently?

2. Literature Review

2.1. EPC Project Delivery Model

An EPC project delivery model defines a contractor's responsibilities for engineering, procurement and construction aspects [17]. As shown in Figure 1, EPC projects allow the client to have a single contact point and fewer responsibilities and enable contractors to execute projects with greater control and flexibility [18].

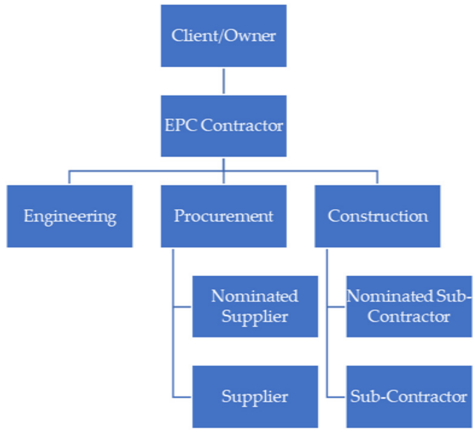

Figure 1. EPC project organization chart.

EPC models have become favoured for infrastructure project clients in the international market [19] and are commonly used in Australia, China, India, Europe, the Middle East and Latin America [20]. These countries and regions quickly developed significant infrastructure during the past three decades [21]. Infrastructure projects involve complex transactions and uncertainties; thus, clients select contractors who can provide a turnkey solution [22]. A turnkey solution is a complete arrangement where one organisation accepts total responsibility for completing a project [23]. However, there is no best delivery model—the EPC model has its characteristics and effects on client and contractor (see Table 1), and these impacts go both ways.

In the EPC model, the client is not risk free; infrastructure projects that adopt the EPC approach can still experience cost and schedule overruns [25]. A lump sum contract is commonly used in EPC projects with the expectation of a turnkey solution. Under a lump sum contract, there is a greater degree of certainty about the final project price and the construction time, which protects clients' interests and lowers risks to the greatest extent [26]. The commercial and technical requirements are clearly defined at the tender stage in an EPC project; thus, the contractor can accurately price the project [27]. The client does not need to pay additional claims, and the contractor has little flexibility in obtaining the client's change order and agreement on extra costs. The contractor carries more risks, which is why an EPC project has a high contract value. The purpose and premise of using EPC models and lump sum contracts are that there will be no significant post-contract changes. However, a high contract value does not ensure high profitability. Changes mean uncertainties, which can lead to risks. The more changes made under a lump sum contract, the more delayed the project will be, the more the cost will increase and the lower will be the project profit. This may create irreconcilable conflict between the contractor and the client. When an EPC contractor cannot afford rising costs, there will be an inevitable dispute between client and contractor, and the project will be delayed significantly. Therefore, a common risk that can lead to delays and disputes in the construction industry is design change.

2.2. Design Change Issues in an EPC Model

Design changes are variations made to improve, correct or adjust designs, so that the design is complete and accurate [28]. Design changes mainly affect two variables: design drawings and design documents. Changes in design will impact the project's iron triangle [29]. In the project iron triangle model, as shown in Figure 2, project scope, time, and cost are represented on each corner. They are connected and constrained by each other. If one of the variables changes, the other variables will change. For example, to produce the same project results (scope) in a shorter time (time), the project cost will need to increase (cost).

Table 1. EPC project model impact for client and contractor.

	Client	Contractor
Bidder requirements	• High commercial and technical requirements. • Few qualified contractors in the market.	• There are not many competitors, but the competition is intense.
Single contact point	• Less communication engagement for overall management [24]. • Less control over the project after the contract is signed, as more responsibilities are transferred to the contractor.	• Greater control of the project after the contract is signed but faces more risks than the client, as they carry most project responsibilities [21]. • Less control over planning, which poses significant risks if there is insufficient planning and weak design. • Has legal constraints from project clients and sub-contractors.
Turnkey solution	• Shifts more risks and responsibilities to the contractor [20]. • Fewer design changes and a shorter construction period.	• Can improve work efficiency and reduce the coordination workload. • More responsibilities bring more risks. To reduce risk and gain more profits, an EPC contractor may reduce the cost by adjusting the design or sub-contracts, thus affecting project quality in the long term.
Lump-sum	• Fixed contract value. • Unfixed profitability. • Not risk-free.	• High contract value. • Unfixed profitability. • Unpredictable risks.

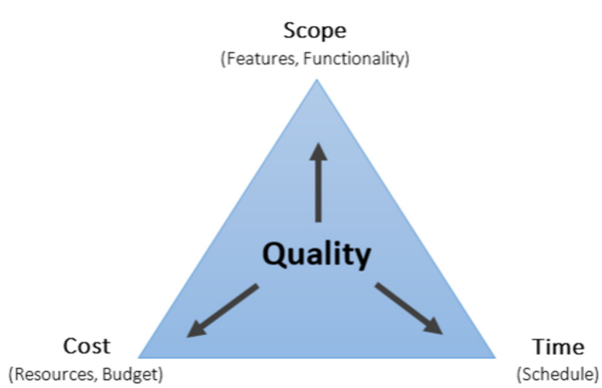

Figure 2. Project iron triangle model.

In Friedman's test [30], 'quality management' is rated as having the most significant impact on project success, more so than 'schedule management' and 'budget management'. This conclusion is consistent with the iron triangle model, in which quality is the project's central objective. If the design scope changes in the design process, it will affect the project cost, schedule, and quality. High design quality refers to high design accuracy and completeness. Design is the foundation of a project; project success is highly dependent on the quality of the design. From statistics accrued from building projects, it has been shown that design change often negatively impacts project outcomes. The number of claims for engineering changes accounted for about 26% of incremental claims and about 28% of the total compensation paid. In many engineering claims, the claim amount is as high as 10% to 20% of the contract price [31]. Therefore, it is important to understand the reasons for the design changes and the impacts of the changes.

2.3. Design Change Stages in Project Phases

Design is iterative, and the results of the changes can pass through different engineering disciplines, which makes the impact of any changes difficult to predict. When trying to understand and analyse the causes and effects of design changes, it is necessary to look at all design stages because design changes can occur at any stage of the project life cycle. Design can be divided into three stages: schematic design, preliminary design and construction drawing design [32]. When looking at the project stage and the responsible parties, these three design stages can be divided into two project phases: the conceptual planning phase and the design phase. The client drives the planning phase, and the design phase is the EPC contractor's responsibility.

During the conceptual planning phase, schematic design occurs when the client and architect define the project scope [33]. When developing a new project, the first thing is to visit the site to look at the land. After studying the characteristics of the plot, the client and architect can begin to consider the first problem of schematic design: how to plan the building that suits the landscape by entirely using of its strengths and circumventing its weaknesses. The client or consultant company needs to define the project purpose and scope and is responsible for the conceptual plan and feasibility study [34]. Then, the contractor designs the whole project and assumes full responsibility. Thus, the design development is partially dependent upon the client's preliminary work. In the concept planning phase, the client needs to determine the overall direction and preliminary functional assumptions, which are the key factors impacting preliminary design implementation [35]. It is necessary to evaluate the conceptual plan for its feasibility. This feasibility study is also one of the client's responsibilities; thus, the client (or its consulting company) is highly involved in the conceptual planning phase.

Preliminary design and construction drawing design are the EPC contractor's responsibility. The preliminary drawing outlines technical requirements and involves sketches through measured perspective drawings used for draft tendering documents. The design depth is the main difference between the preliminary and construction drawings. The construction drawing, used to develop construction, is more specific and operable than the preliminary drawing. Preliminary design is the basis of construction drawing design. Construction drawing design documentation is more detailed and should meet the construction equipment and material procurement needs.

3. Research Design

This exploratory study adopts a qualitative research method and aims to provide a better understanding of design change issues on construction projects. This qualitative research used in-depth information to answer the three research questions [36]. A major criterion for the participants was for them to have a holistic understanding and perspective of the potential causes and impacts of design changes and the methods for managing them. Qualitative research methods are based on specific theories and experiences [37] and focus on the depth of factors rather than comprehensive statistical data. Thus, the nature of the current research follows social constructivism, as it recognises the way that the participants interpret and make meaning of their experiences associated with construction design changes [34]. The qualitative approach deductively captures the characteristics of the main aspects of the problem [38], and moves from general to more specific conclusions. Participants' experiences and their perspectives help to inform recommendations for better managing design changes on projects. The reliability and validity of the research is dependent on the diversity of information and in-depth elaboration of the issue. Similar qualitative research methods were used in studies that focused on only one company or project [30].

Secondary data were collected from ready-to-use information from published materials, computerised databases and websites. Reviews of the secondary data assisted with the formulation of interview questions that were used for collecting primary data. Primary data are first-hand data sources collected through surveys, interviews or experiments [37]. Research participants were identified and selected using criterion sampling strategies. Participants were all experienced (between 10 and 42 years) in construction and infrastructure projects had experience with, or were affected by design changes, and had previously executed projects under an EPC model. These criteria ensured the reliability and validity of the collected data [39]. Data saturation was reached after 13 interviews because of the high level of information being repeated from previous interviews. The 13 interviewees (see Table 2), who had worked in infrastructure development projects for 10 years or more, provided a diversity of opinions from all design stages, thus ensuring the reliability and validity of data collection [40]. The study engaged a diverse sample with opinions and comments from clients and professional advisors (e.g., a client, a design manager, architects, a structural engineer, a quantity surveyors and local council members) and contractors (e.g., project managers) to ensure that the research findings reflected the diversity [41] of the typical construction projects. Follow-up interviews were conducted with some participants to seek further insights on the research findings.

Table 2. Participant profile.

Participants	Position	Project Experiences
1	Project Manager, contractor side	Roading project
2	Project Manager, contractor side	Wind farm project
3	Project Manager, client side	Water treatment project, hydraulic energy project, transportation project
4	Structure Engineer	Commercial buildings
5	Architect	Multi-storey buildings, residential houses
6	Architect	Multi-storey buildings, residential houses
7	Client	Residential houses
8	Architect	Multi-storey buildings, residential houses
9	Quantity Surveyor	Commercial construction
10	Project Manager, contractor side	Infrastructure, commercial construction, residential projects
11	Council, Development Engineer	Infrastructure and construction project
12	Client Design Manager	Commercial construction
13	Architect	Commercial construction, residential construction

The interview used eight indicative, open-ended questions, which guided the direction of the interviews and allowed participants to express their opinions in alignment with their experiences [42]. This study received full ethics approval before collecting primary data. The researcher sent interview questions to participants in an introductory email before the interviews. Each interview took about one hour. The researcher asked more in-depth questions depending on project type, participants' positions, and issues' complexity. Participants were encouraged to provide more detailed answers and information freely around the questions. In-depth questions yielded more insightful information and ensured the reliability and validity of data [42].

The interviews were transcribed to aid in the analysis of the data collected. Thematic analysis was used to identify the salient themes and pattern of themes within the interview data. Thematic analysis is useful in assigning labels or codes to words and phrases to translate the phrasing into different themes [43]. The approach undertaken followed a suggested framework involving six logical phases [44]. To identify the themes better, the analysis focused on the coherence of the participants' responses and relevance between phrases rather than the number of questions and coding. The study ensured that the content of the interviews was consistent with the overall research questions, and the thematic pattern that was summarised fitted the overall research objectives. This way, the study could ensure the validity and reliability of the thematic data. The key findings of the qualitative data analysis are provided in Tables 3 and 4.

Table 3. Direct factors result in design change.

Driving Factors	Impact on Project	Impact on Design
Client Aspects		
Client lacks visionary planning and experience	Design does not fit or mismatch project purpose or meet requirement Underbudgeting Poor control of schedule Change on requirements Missing resource or building consent Lack of project preparation: access to water supply, electricity and roads as well as land levelling Insufficient resources (human and physical) and supporting facility Focus on budget rather than quality (as quality is intangible and hard to measure at early phase)	Conceptual design failures and direction deficiency Change in design scope Devalue engineering A fear of getting contractor involved
Engineers Aspects		
Inadequate design ability	Mistakes on drawings and bill of quantity list	Slow design speed Low design quality
Limitations on Design resource	Lack of dedicated architect/designer/engineer allocated to project	
Lack of knowledge of New Zealand's procedures, standards regulations and guidelines	Duplication in process Inadequate site investigation weak Geo report Poor feasibility study	Lack of comprehensive consideration to implement adequate and quality design
Contractor Aspects		
Lack of experience	Continuous defects increase contractor's cost and possibility for rework Slow down and even delay the schedule for rework Cost increase or overrun Contract suspension or arbitration Creates trust issues and ruins relationship	Continuous disputes and argumentative situation for design change through the whole of the contract
Philosophy of win the project in lower price and recover profit through construction by site variations	Makes unnecessary variations slows or delays project schedule Cost increase or overrun Contract suspension or arbitration Creates trust issues and ruin relationship	Push for design change on purpose Continuous disputes and argumentative situation for design change through the whole of the contract

Table 4. Indirect factors affect design change outcomes.

Driving Factors	Impact on Projects, Stakeholders and Community	Impact on Design
Council Aspects		
Bureaucratic and lack of industrial or market drive Person–job fit issue • Employees lack industrial skill set to deal with complex variations/amendment Person—organisation fit issue • Lack of motivation for innovative solutions/alternatives	• Restraining the growth of regional economy • Restricting the speed of urban development • Negative impacts on innovation of cityscape • Ongoing constraints to industrial developments	• Objection attitudes towards innovative design and their amendments • Slow approval
Industrial sector/commissions		
Competitive tendering of Design and Build project	• Contractor lowers their prices as much as they can to win the contract and applies site variations to increase profit during construction • Contractor is not obligated to inspect site before bidding, bidding is based on client's study and inspection performed by design company. Contract discovers variations after accessing the site • The purchase list in the tender prompts the contractor to lock in a price or even sign a supply contract with a material or equipment supplier before visiting the site. Any design change discovered at a later stage will put the contractor in a dilemma and face claims from the equipment/material manufacturer, which will increase the project cost and communication time.	Ongoing constraints between clients and contractor, and open risks for argumentative discussion along the project lifecycle • Contractor misses the critical phase to review preliminary design before bid for a contract • Contractor under budgeting on purpose and push design change on purpose Ability to influence cost over time effectiveness
Landowner		
Landowner's perception towards local development Iwi Māori cultural respect of land	Lack of communication or consultation with landowners before developing project. Objection on use of land will suspend the project and slow down regional development	Results in change design

4. Key Findings

This section covers interview findings on reasons for design change, impacts, and management recommendations from client and EPC contractor perspectives.

4.1. Driving Factors for Design Change

Interviewees' key points are summarised according to their positions and the stages of their participation in a project—these were divided into planning, design, and execution stages (see Figure 3). The opinions of the participants were similar and are summarised as themes below.

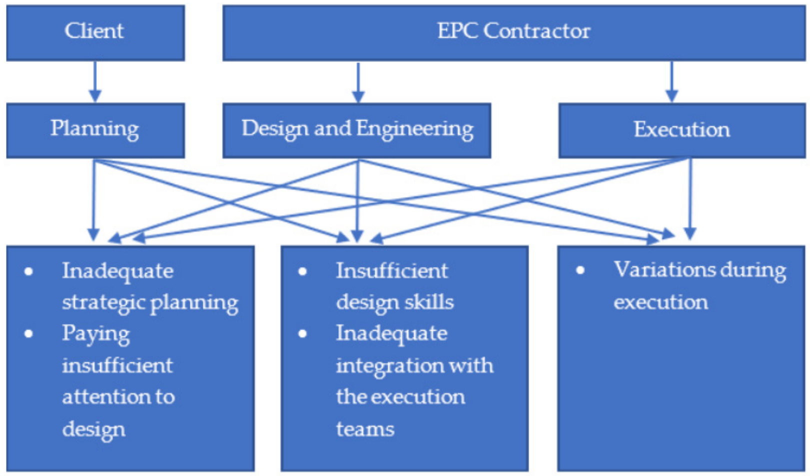

Figure 3. Driving factors of design changes.

- Planning phase: The study shows that clients' inadequate strategic planning is one of the main reasons for design changes. Strategic planning refers to the overall understanding of the project, including, but not limited to, an adequate project portfolio, sufficient information and resources, clear expectations and stakeholder alignment [45]. Another key finding is that insufficient attention to design causes design change. This refers to clients not paying enough attention to design details and being unwilling to pay more for design input [46].
- Design and engineering phase: Lack of design ability is a leading factor in design changes. In addition, when the design team lacks integration with implementation teams, it can lead to various design change issues. Without collaboration among all aspects of engineering, procurement and construction, an EPC project cannot achieve its maximum deliverables. These findings align with the study conducted by Deep et al. [47] who identified that trust, commitment and reliability are the enablers of collaboration which facilitate teamwork and enhance project productivity.
- Execution phase: Variations during execution can also cause design changes when the actual market or site conditions cannot meet design requirements—for example, changes in soil texture, impact of climate change, underground conditions or changes to market supply.

4.2. Design Change Impacts

- Design change impacts projects: Design change can have minor or significant direct impacts. Little change has no or negligible influence on the project iron triangle, but significant design change significantly reshapes the iron triangle.
- Design change impacts stakeholders: It was found that design change has a reciprocal impact on stakeholders.
- Design change impacts communities: Design change also has a far-reaching impact on communities, meaning the general public, local business owners and residents are affected.

4.3. Design Change Management

Participants suggested including the Early Contractor Involvement (ECI) component in the project process to improve the design change management. Further, they addressed the importance of enhancing integrations between design and project execution teams. The findings of the study show a need to strengthen stakeholder cooperation. When participants were asked to comment on improving team capabilities or selecting talent, they often mentioned soft skills. Participants commonly said soft skills included communication skills, problem-solving skills, a proactive attitude, time management skills, documentation skills, and interpersonal skills. Participants also referred to these as emotional intelligence.

5. Discussion

5.1. Driving Factors of Design Changes

5.1.1. Planning Phase

Clients often lack strategic planning ability, which hindered project success and caused design change issues. Strategic planning is about accurately planning for access to resources required during the project [48]. For example, participant 2 (Project Manager) pointed out, "*Client received inadequate geotechnical information from their overseas design company, which had no New Zealand design experience. It resulted a part of the project was designed on swamp, which caused design change*". Similarly, participant 6 (Architect) commented that "*A project can fail due to client's incompetency. They may have insufficient resources, [sic] unclear expectations*". Therefore, it is evident from both the architect and project manager's perspectives that a client's lack of ability in planning is one of the driving factors of design changes.

The foundation of design is based on integrated strategic planning, not just specific functional requirements. First, the client must determine the company's business scope and expertise and how it achieves its operational objectives. Next, the client needs to define who benefits from its business activities. Last, the client must assess strengths and weaknesses related to how those activities are carried out. Research shows that clients often cannot implement points two and three. These two points demonstrate a client's ability to leverage a wide range of stakeholders in the project and push them to achieve its objectives [49]. This ability also refers to the capacity of the clients to amass appropriate resources, which requires clients' in-depth understanding of stakeholders and experience in the industry; thus, in order to prevent and manage risks, including design risks. The strategy should not only assume that any design change driver will increase the project's complexity if combined with other attributes [50], but it should also contain appropriate countermeasures.

Strategic planning in an EPC project involves aligning values, cultural and social stability, geographical aspects and regulations between clients and contractors [51]. It goes far beyond functional specifications. The client must align with stakeholders, establish an adequate project portfolio, ensure there are sufficient resources, create clear and practical expectations, and have detailed reporting, documentation and assessment guidelines in place. The client must be forward looking when interacting with internal and external resources. If the client is unaware of the risk factors, they will miss risk assessment during the planning phase, which will result in original or conceptual assumptions being incorrect, which, in turn, could necessitate design change.

It was found that clients undervalue the importance of design during the planning phase. The interviews revealed that clients tend to move projects quickly at the beginning or control design cost rather than design quality. However, a quick start does not ensure fast delivery; saving on design does not guarantee a project coming on time and budget. Furthermore, as shown in Figure 4, a significant negative relationship exists between the ability to influence cost over time and the cost of change [52]. The ability to influence cost over time reduces dramatically along the project lifecycle. The later the variations are enacted, the higher the influence on cost. Therefore, it is critical to consider design a priority and g enough budget and effort be allocated to planning and design in the conceptual planning phase.

Prioritising design value and importance during the planning phase means clients can evaluate design firms' abilities early before handing in final design works. The client should then be able to adjust the design budget as necessary. Early design quality evaluation reduces the design change risk [53]. However, current practice favours clients evaluating design work and approving payments based on delivery time rather than the quality of delivery. A mechanism must be in place that enables a client to assess design ability in the early project phase and allows an EPC contractor to review a client's preliminary plan and suggest appropriate solutions to issues detected. Such a mechanism would allow for an early joint risk assessment so that uncertainties and improved design quality can be kept to a minimum. The client and EPC contractor would have enough time to align design time, budget and solutions.

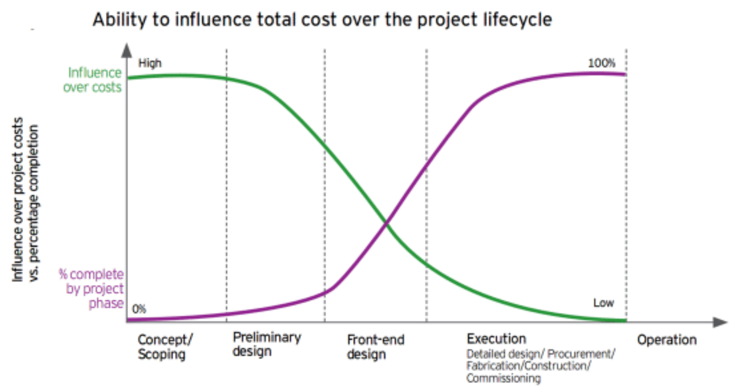

Figure 4. Ability to influence cost over time and the cost of change [52].

5.1.2. Design and Execution Phase

Lack of design ability directly results in design errors on drawings or calculation mistakes on bills of quantities. For example, participant 6 (architect) gave an example of an engineer who miscalculated the head of the window, which was lower than the client expected. A lack of design ability refers to inadequate design/engineering capability, design resource constraints, irresponsible design attitude or poor documentation management. High-quality design means comprehensive and complete design drawings and relevant documents [54]. A number of flaws in the design process can negatively impact the outcome. Firstly, inadequate design ability is likely to mean failing to meet the project purpose, functional requirements or technical specifications, which would directly result in design errors and omissions [55]. Inadequate design ability is not limited to a lack of technical design skills; it could also mean a lack of knowledge of New Zealand's procedures, regulations and standards, or building consent and resource consent processes. Secondly, design resource constraints could increase design errors. These may refer to a lack of dedicated design time, limited design resources or insufficient funds for design—for example, experienced architects may be spread across multiple projects, or one designer may be overloaded. Design resource constraints harm design quality and delivery time [55]. Insufficient time or/and money negatively impact wellbeing and productivity, as people make hasty decisions or mistakes when under pressure [56]. Thirdly, negative attitudes and irresponsibility also increase the possibility of design change. Fourthly, the absence of documentation management increases the likelihood of changes. Timely and effective document management reduces the need to modify requirements already agreed upon [22]. Therefore, the EPC contractor should proactively increase design team competency in hard and soft skills to improve design quality.

Design variations on site can be reduced by intensive collaboration between the design and execution teams. During the design phase, the designer should seek advice from sourcing and construction experts about materials and site practice. When there is a disagreement, it is critical that both teams can check site conditions to reach an agreement. A later design change is reduced because both teams have reviewed and approved the initial design. If a designer is knowledgeable of on-site conditions, the chance of change orders during the execution phase is minimised. A construction team raises a change order when differences are discovered between site conditions and design requirements [56]. The construction team will also improve buildability by working closely with designers. Overall, integrated working utilises design and execution experiences, thus improving design quality [50].

5.2. Design Change Impacts

Design change has three types of impacts: the direct effect on a project, reciprocal and complementary effects on stakeholders, and a far-reaching impact on the community. There is a positive direct relationship between a project and design change. Minor design change indicates fewer effects on cost, scope and schedule. The project has fewer risks and a higher chance of success. For example, participant 7 (client) recalled, *"An extra 40% budget was giving in to the project to fix the design issues. The design errors cost about one million dollars' worth of effort to get it redone"*. In addition, participant 3 (project manager) said, *"The project was behind two years, five million USD was added to the project".* Therefore, both clients and project managers believe that design changes have significant impacts on project delivery outcomes. There is a common and complementary effect between design change and stakeholders. To a large extent, the joint efforts of stakeholders can reduce design changes, although this requires adequate communication. A minor design change has less influence on stakeholders. For example, landowners' and material suppliers' commitments reduce the risk of design scope changes, and unchanged designs ensure landowners' and suppliers' profitability. When stakeholders and project clients have aligned objectives and values, changes to the conceptual plan are less likely. Design change can be effectively reduced when stakeholders are directly involved in projects [45]. Therefore, engaging and aligning with stakeholders during the early project phase and enhancing their collaboration throughout the project lifecycle is essential.

It is also found that design change has a far-reaching effect on the community and environment. For example, participant 9 (quantity surveyor) noted, *"Because of the design change, the project was delayed a couple of months, the local residents had to wait a much longer time to visit the medical centre"*. In addition, participant 1 (project manager) provided another similar example, outlining the design change effects on the community. Participant 1 said, *"The roading and bridge recovery project was definitely critical to reconnect the public's lifelines after the earthquake"*. According to the three pillars of sustainability, all economic activities sit within the pillars of society and government [57]. For example, design changes to a roading project affect residents' daily transportation and negatively affect local house prices. Significant design changes reduce project profitability and contribute to a decline in regional economic development, thus resulting in a loss of investor confidence and reducing regional capital investment. In New Zealand, the local government plays a governance role in ensuring that business activity has minimal negative influence on society or the environment. Therefore, the policy must remain consistent with development trends, and there needs to be systematic reviews and adjustments of regulations in order to facilitate industrial practice.

5.3. Design Change Management

5.3.1. Enhancing Stakeholder Cooperation

Participants recommended strengthening stakeholder alignment and cooperation to improve strategic planning. For example, participant 11 (council engineer) said, *"Communication with council before application is effective for getting approval.* In the same way, participant 1 (project manager) said, *"We were highly relying on the communication adviser and council to deal with low business and the landowner for the land dispute, as council has better relationship and power".* Therefore, from both the engineer's and project managers' perspectives, communication was is essential for enhancing stakeholder cooperation.

Strategic planning is understanding where an organisation is going [58]. It is more important for an organisation to understand the impacts of its business activities. An increasing number of infrastructure projects require clients and their contractors to operate in various cultural and socio-economic environments and deal with the complexities that arise in the international environment [59]. The growing demand for sustainability also requires companies to meet higher standards in order to achieve economic, social and environmental goals. Therefore, strategic planning begins with understanding how the project fits into a complex society and environment.

The purpose of strategic planning is to define the feasibility and scope of the project, which are the basic design principles. Firstly, the project developer or client should consider various stakeholders, which include internal and external individuals or organisations interested in and are affected by the project, and government authorities. Secondly, as early as possible, the client should proactively communicate with stakeholders in planning so that values and objectives are in alignment. This includes partnering with a consulting company and involving an EPC contractor early on. Early engagement with key stakeholders can reduce project risk and design change risk. Thirdly, the client should consider social and eco-environmental impacts as much as the profit model [60]. Full consideration of all stakeholder perspectives will ensure the effectiveness of the feasibility study and design stability [61]. Finally, the client and EPC contractor should maintain intensive communication with stakeholders throughout the project and keep them updated on any changes. For example, clients or contractors could organise a pre-application meeting with the local council before submitting a design amendment proposal. It is an efficient way for both designer and council to understand each other's point of view and avoid duplicated approvals. In addition, it is important to cooperate with a council, as council networks can help the project team provide justifiable solutions. In summary, enhancing cooperation with stakeholders improves strategic planning, thus ensuring the accuracy of feasibility reports and design requirements.

5.3.2. Including Early Contractor Involvement (ECI) Components

Participants recommended including Early Contractor Involvement (ECI) components in current practice to reduce design change. For example, participant 5 (architect) noted, *"I always tell the client to slow down the design and get an in-depth site investigation, and engage the contractor in early"*. This is consistent with the responses received from participant 3 (project manager) who said, *"Design quality should always be weighted more than the design schedule; the client should allow more time at the beginning of the project for a good design"*. ECI establishes an early collaborative period that allows clients and EPC contractors to integrate preliminary plans and designs. Such integration allows both parties to take an early risk assessment of conceptual plans that form a coherent design solution. This is an additional design development phase between the conceptual and preliminary planning phases. ECI has been successfully applied in many countries to maximise design efficiency. Figure 5 presents some international project applications with ECI.

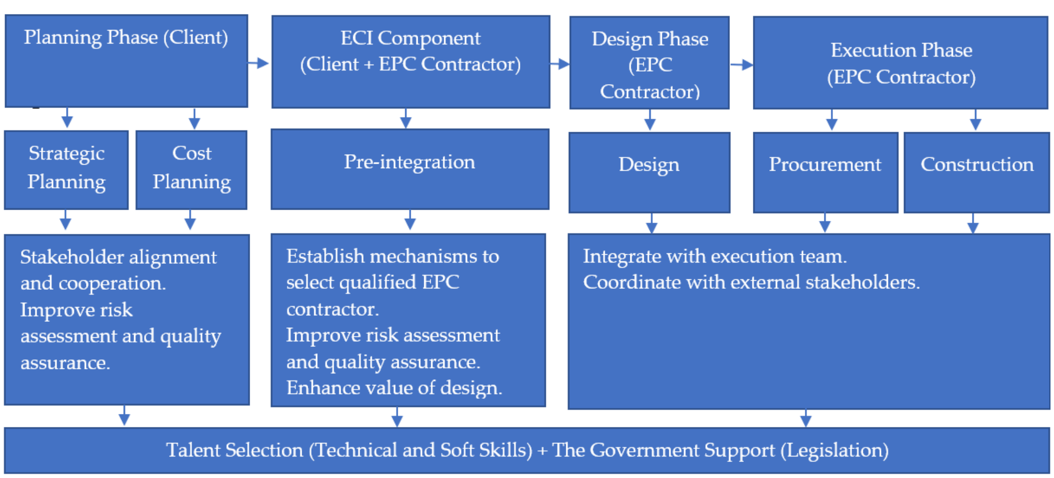

Figure 5. Recommendations for design change management.

The ECI process seeks to leverage the contractor's construction knowledge so as to mitigate design risk from a client's perspective. EPC contractors have greater expertise in buildability, materials, field practices and methods than clients and consultants [62].

Thus, EPC contractors can make recommendations regarding the limitations or availability of specific resources or site conditions, thus improving the effectiveness of the design investment [63]. The client has the opportunity to adjust plans and budgets to improve the overall effectiveness of project delivery [64].

From an EPC contractor's perspective, ECI also adds value and creates opportunities for EPC contractors. During the ECI phase, EPC contractors demonstrate their ability to integrate resources and identify and resolve technical difficulties, which help them build relationships and earn clients' trust. A client may reduce commercial terms and conditions and provide more opportunities for more capable contractors. At the same time, contractors can improve the effectiveness of design investment and ensure better risk management [63]. After reviewing a client's project plan, if a contractor decides there is too much risk and withdraws their proposal, this forces the client to re-examine the project's feasibility.

Despite the advantages of ECI, there are some issues that need to be discussed. Firstly, ECI requires sufficient time given to EPC contractors for accurate pricing and the design proposal. Secondly, the contractor needs to get paid for any additional work they undertake. Thirdly, early involvement reduces the likelihood that a client will transfer risks to an EPC contractor. Therefore, the EPC contractor will not accept the jointly identified risks into the scope and raise a disclaimer. Additionally, clients may worry about losing a fair price by involving contractors and sharing sensitive information during the project development. Another issue, according to Rahman and Alhassan [63], is that EPC contractors and clients (or consultants) may be unable to reach agreements over design after ECI, and the client may lose the opportunity to select a contractor from the market. Last but not least, ECI requires a concept and culture change which may be difficult for some industry people to embrace [62]. New Zealand's current legislation must also be adjusted to facilitate the implementation and popularisation of ECI.

Aside from the overall perspective of reducing project risk and design changes, there is also a need to introduce ECI in order to improve project results. ECI will provide an opportunity for deep alliances between two project teams, thus reducing complexity and helping both parties arrive at a coherent solution. A two-way selection in the ECI process creates a more sound, fair, and open mechanism for the client and the EPC contractor. ECI does not contribute to increasing the speed of project development, but to a certain extent it provides quality assurance, controls the project's overall risk, avoids future disputes with contractors, and reduces negative societal impacts. Construction Industry Institute [65] research has shown that ECI for EPC projects can reduce costs by 4–8% and 10–15% in time over the entire project lifecycle.

ECI guarantees the advanced adjustment of the design budget and improvement in design quality. Higher design quality means fewer design changes and a positive impact on project results. Including ECI components in the project management process reduces the risk of design changes and minimises adverse effects on the project, stakeholders and community.

5.3.3. Improving Internal Integration during Design and Execution

Participants suggested integrating the design and execution teams to improve designability and buildability and reduce design change risk during the design and execution phases. For example, participant 12 (client) said, *"It is important for the designer to align with the construction team for practical solutions"*. According to participant 3 (project manager), *"It would be much better to have integrated coordination between designers and execution teams to ensure to maximise input of knowledge from all experts"*. Therefore, it is evident that both clients and project managers believe in the importance of improving internal integration during design and execution phases of construction projects.

Hard skills: Participants suggested improving designability by enhancing internal integration between design and execution by using a model-driven approach to align the two teams. The sequential handover of tasks does not best suit the complexity of construction and infrastructure projects, as communication stops after the transfer of tasks.

An integrated model fosters a culture of co-design and co-execution. The EPC contractor provides a two-way communication environment that allows the designer and constructor to collaborate and exchange options. This way, designers receive timely feedback from execution specialists during the design phase. They can improve design accuracy and reduce design change by having information on procurement and construction experts' market and site practices [66]. This allows the designer to take a self-adaptive approach during the design phase to improve design quality. From a risk management perspective, utilising internal resources and reviewing design drawings created by the execution team will reduce design errors. Allocating construction resources during the design phase reduces design change risk and protects site engineering costs and delivery time [67]. From an execution perspective, builders can improve project buildability by having a designer's support on-site to solve site issues promptly. Collaboration with a designer can help create a streamlined process and reduce construction costs [67]. Moreover, interactive learning experiences and pre-alignment between teams also improves relationships and positively impacts company culture.

Soft skills: All parties work on a project to deliver an overall outcome; all project teams are interrelated. Therefore, it is essential to look to all project teams for improvements. For example, participant 6 (architect) said, *"People should have the attitude to accept challenges and a willingness to solve problems"*. Likewise, participant 1 (project manager) mentioned that *"technical issues are no longer a problem when people are willing to put in more effort"*. Soft skills, also referred to by participants as 'emotional intelligence and 'cognitive skills', relate to people's ability to recognise, understand, manage and reason with emotions [68]. These skills are not a prerequisite for getting the job but are, in fact, essential. Participants recognised such skills as critical for dealing with complicated issues when working under pressure [69]. Participants considered soft skills as equally important as hard skills [70]. For example, technical issues can become commercial issues, and practical communication skills are critical for solving problems.

The top eight soft skills recognised by participants as equally important as hard skills are can-do and positive attitude; practical communication skills; interpersonal skills; resilience (risk-taking and coping well under pressure); time management skills; documentation skills; problem-solving skills; and quick learning skills.

6. Recommendations

As shown in Figure 5, the recommendations for improving design change management are drawn from the perspectives of clients and EPC contractors according to project phases—planning, design and execution. These recommendations focus on improving overall design change management.

Planning phase: Clients need to enhance stakeholder alignment and cooperation during the planning phase. The project client should consider existing and future challenges and engage all stakeholders early in the conceptual phase. The client should organise milestone meetings with internal and external stakeholders to keep them informed and aligned with strategic decisions and formal approval. This stabilises the conceptual plan and improves the feasibility study, thus reducing design changes caused by changes to the plan. If there is any change, including design change, the client should engage stakeholders and update them regarding solutions.

Between the planning and design phases: The client and the EPC contractor should actively promote Early Contractor Involvement (ECI) implementation into the project process. This stage extends the handover time between the user and the contractor, which makes it a more in-depth cooperation model. It breaks contractors' traditional passive acceptance mode and replaces it with a win–win, mutually beneficial cooperation mode. This ensures fuller, more specific handovers of design work from users to contractors. This process should begin with a well-developed evaluation mechanism for EPC contractors. The aim is to prioritise the importance of design and enhance risk assessment. During the ECI phase, the client can adjust the concept proposal and feasibility study to reduce the risk of design change. Clients must allocate additional time and budget for ECI activities and control design quality through progress payments. The application of ECI will ultimately benefit all project stakeholders, relevant stakeholders, and the community and environment.

Design and execution phases: The EPC contractor needs to improve design team and execution team alignment and integration during the design and execution phases. The EPC contractor could establish design quality management KPIs for the design and execution teams. The execution team should support designers during the design phase and assess design quality and sign off risk control. Designers should also work closely with constructors on site and be given the authority to approve design changes under a certain price level.

The EPC contractor should also engage stakeholders and update them on any solutions, including design changes.

Skill sets: The client and EPC contractor should select talent with strong technical and soft skills for the project team, regularly evaluate and assess team performance, and provide training when needed. Some critical skills are recommended as essential soft skills:

1. Can-do and positive attitude;
2. Effective communication skills;
3. Interpersonal skills;
4. Resilience (risk taking and coping well under pressure);
5. Time management skills;
6. Documentation skills;
7. Problem-solving skills;
8. Quick learning skills.

Government support: New Zealand's current legislation also needs to be adjusted to facilitate the implementation of ECI in infrastructure projects. Based on the speed of social development and the importance of infrastructure projects and project experience, the industry must promote more reasonable and compliant operating procedures, including detailed bidding rules and specific requirements for EPC contractors. In this way, project management and risk avoidance can be better promoted so as to maximise social and environmental advantages and benefit more people. Local councils could play a more significant role by requiring detailed drawings before project approval, thus forcing early coordination and promoting close collaboration within the EPC contractor team. This is a conceptual change process, and by increasing requirements, the industry will adopt more complete applications with better project quality assurance.

7. Limitations

This study focused only on design risk and did not consider other forms of project risk. Project risks can come from any aspect and relate to uncertainties in the project lifecycle. These include delivery risk, cost risk, government risk, and market risk. There is a need to explore risk control for these aspects. This study did not include all stakeholders' views and presented limited perspectives. Some key stakeholders, such as project developers, financing institutes and landowners, were not included in the study.

Further research may consider interviewing more stakeholders to improve the validity of these research findings. This study had a limited sample size (n = 13) and interviewed only a few participants of each occupation. This means there was a lack of extensive views from different occupations. Further study may extend the interviews to enlarge the sample size of each position.

8. Conclusions

Design changes are a common feature of construction projects internationally. New Zealand is not an exception. Due to the increasing number of infrastructure projects in New Zealand and the need for customers to reduce their own risk, it is predicted that more owners will choose an EPC project delivery model. In EPC mode, the user plans the project and then transfers all risks to the EPC contractor responsible for the overall turnkey solution's design, procurement, and construction. This study aimed to investigate the causes and implications of design changes in order to improve design change management practices. Participant interviews reveal the main reasons for design changes: clients' inadequate strategic planning and insufficient attention to design; EPC contractors' insufficient design capability; and variations between construction conditions and design. These changes have resulted in significant project delays and cost overruns and have negatively impacted local economies and community life. The interviewees suggested several design change management improvements. They recommended strengthening strategic alignment with stakeholders in the planning stage to ensure that the design needs and scope do not change substantially. They also recommended ECI be added between the planning and design phases so that the EPC contractor could review planning feasibility and provide solutions to perceived issues to the client.

The client could then improve the planning scheme and adjust the design cost and requirements. During the design stage, the EPC contractor should strengthen the integration with its execution team to enhance design quality with input from execution experts. The design team should cooperate with the construction team to improve design change effectiveness and efficiency during the construction stage. Both owners and EPC contractors should focus on selecting professionals with high technical and soft skills to cope with the complexity of infrastructure projects and the high-pressure nature of project execution. New Zealand's current legislation also needs to be adjusted to facilitate the early involvement of contractors on infrastructure projects, thus reinforcing council requirements for resource and building consent.

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