Impacts of Cultural and Social Factors on Cost and Time in Management of Engineering, Procurement and Construction Projects: A Case Study

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ABSTRACT

Indigenous communities in Canada face significant barriers to accessing healthcare infrastructures that align with their cultural and social preferences. Existing healthcare construction project managements often overlook this problem with Indigenous communities, resulting in designs that fail to foster trust, inclusivity, and accessibility. This thesis study was motivated by tackling this problem with the proposition that considering social and cultural preferences to healthcare facilities of Indigenous communities is important to the success of such construction projects. It is noted that such projects have three stakeholders, namely Engineering (E) including design, Procurement (P), and Construction (C), EPC for short, and they may not be under the same managerial governance. The main methodology taken in this study is to build a simulation system or simulator for decision making in EPC project management by using the tool called System Dynamis (SD), initially developed at Sloan Management School at MIT, and to conduct a case study – construction of a hospital in an Indigenous community.

The SD model evaluates the feasibility of incorporating Indigenous design elements—such as natural light, circular layouts, and eco-friendly materials—while maintaining cost efficiency, time management, and resource optimization. The model dynamically simulates interactions between variables such as material usage, energy efficiency, design stability, stakeholder coordination, and performance indices over a 24-month construction timeline.

Simulation results reveal that timber is the most effective construction material for meeting Indigenous preferences, excelling in waste reduction, energy efficiency, design stability, cost savings, and schedule adherence. Timber also supports sustainable practices and enhances stakeholder collaboration, making it a viable choice for culturally responsive healthcare infrastructures. Conversely, concrete and steel exhibit higher material waste, lower energy efficiency, and reduced performance indices, creating challenges in cost and schedule compliance.

The findings emphasize the importance of early engagement with Indigenous communities to integrate their preferences and perspectives, fostering collaboration and respect. This approach ensures project outcomes align with cultural and social expectations while promoting equity and inclusivity. Furthermore, the study contributes to advancing EPC project managements by

illustrating how Indigenous preferences and sustainable practices can improve healthcare infrastructure development, ultimately enhancing accessibility and resilience in Indigenous communities.

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Table 0.1 Abbreviation of Phrases

Abbreviation	Phrase
EPC	Engineering, Procurement and construction
SD	System Dynamic
SPI	Schedule Performance Index
CPI	Cost Performance Index
CLD	Casual Loop Diagram
SFD	Stock and Flow Diagram
GWP	Global Warming Potential

CHAPTER ONE
INTRODUCTION

1.0 Background and Motivation

In most construction industries, general contracting as often used in construction is used to handle the planning and coordination of the entire project (Kabirifar & Mojtahedi, 2019). It is widely known over the past decades that the construction industry is a complex industry with regards to its components such as the supply chain, the products, and processes (Kabirifar & Mojtahedi, 2019). One of the most significant complexities in construction arises from contractors operating in unfamiliar environments, such as the reserve areas, and these contractors' also lack the knowledge of the customs, regulations, and culture of these environments (Nguyen & Watanabe, 2017). It is confirmed that this lack of understanding may hinder the project's success despite the contractor's capabilities (Chipulu et al., 2014; Wang et al., 2016). The customs, regulations, and culture of the customer and their environment as mentioned could affect the decision making process, so stakeholders such as EPC companies must understand their customer's expectations and preferences and use them as a guide to improve their performance and success (Lilien, 2016).

For the purposes of this study, EPC project is clearly defined, and the need of the customer's perspective or expectations in EPC projects are essential part of customer's satisfaction, especially when enhancing intercultural understanding and promoting culturally delivering an appropriate healthcare construction that would now be top priorities among the areas of construction projects (Chatwood et al., 2017). Both in the past and presently, Indigenous populations have long had poor access to healthcare, and the physical characteristics of the institutions they use often reinforce colonialist attitudes (Davy et al., 2016; C. Martin, 2014). The customers communities for whom these health initiatives were meant for sometimes rejects the project initiatives because of cultural exclusion that has lasted for generations (C. Martin, 2014). Customers in this study are referred to as the Indigenous people. Therefore, it is necessary to critically reevaluate Indigenous behavioral and social characteristics and traditional building patterns in the present (C. Martin, 2014).

Overtime, several EPC projects phases have been performed in an unfamiliar environment by several professionals and non-professionals (Reichheld & Sasser, 1990). According to Bajomo et al. (2022), the term "engineering" in the EPC contract refers to the professional design and selection of equipment and materials. "Procurement" involves the planning and acquisition of these materials, while "construction" encompasses tasks such as installation, commissioning, and technical training. Additionally, EPC integrates the planning, organization, and management of a project's implementation (Wang & Zhang, 2013).

To better understand the current state of EPC, an EPC model project's general contractor is given the authority to oversee all or a portion of the design, procurement, construction, and trial operation under the terms of the contract (Chen et al., 2011; Xia et al., 2011). Contracts in the context of the study are the types of contracts that vary depending on the extent of the work involved (Chen et al., 2011; Xia et al., 2011). For instance, full-service project general contracting, design-purchasing-construction general contracting, design-construction general contracting, design-purchasing general contracting, and purchasing-construction general contracting are examples of these types of contracts that play a pivotal role in delivering complex, infrastructure-heavy projects (Chen et al., 2011; Xia et al., 2011). The separation of these contracts is driven by the increasing complexity and scale of modern construction projects, which require specialized expertise and a more structured approach to project management. As projects grow larger and more intricate, the traditional integrated EPC model can lead to inefficiencies and heightened risks. For example, the simultaneous execution of engineering, procurement, and construction activities may cause misalignment among teams, resulting in performance deviations and project delays. This division into distinct phases ensures greater precision and coordination across all stages of the project lifecycle (Habibi et al., 2019; Micheli & Cagno, 2016). By separating these phases, organizations can focus on optimizing each component individually, thereby enhancing overall project performance and reducing the likelihood of costly overruns (Kabirifar & Mojtahedi, 2019). However, EPC has been seen as a developed process to effectively manage project connections, streamline procurement and construction processes, and adeptly resolve conflicts, seamlessly integrating with the general contractor's responsibility for overseeing the project's cost, duration, quality, and safety (Chen et al., 2011; Kabirifar & Mojtahedi, 2019; Xia et al., 2011).

In addition, the construction industry has many characteristics common to manufacturing and service industries (Yang & Peng, 2008). Another factor that plays a pivotal role in the EPC project managements is customer satisfaction. According to Othman et al. (2004), maintaining customer satisfaction is one of the most important factors of keeping a project's success in the construction industry. Customer satisfaction is a psychological state or feeling generated from the customer's experience of his/her assessment of the experience (Bilro et al., 2023; Oliver, 1980). In the construction industry, customer perspective demands on contractor performance are contractual duties, obligations, and responsibilities. Subcontractors, material suppliers, designers, and construction managers have never prioritized the opinions of their clients (Kubal, 1996). More satisfaction cannot be attained by any one project member alone. Regardless of the goods or services a company offers relating to construction, ensuring the greatest level of customer (or client) satisfaction is obviously an essential responsibility (Kärnä et al., 2004; Kubal, 1996; Yang & Peng, 2008). Finally, a company's success hinges on efficiently executing construction projects in the competitive market, driven by the industry's rapid growth (Chidambaram & Tamilmaran, 2020).

Healthcare construction project management is among the most complex disciplines to design, construct, and operate within the EPC industry. These project management are particularly challenging due to the high costs associated with hospital design and construction, which constitute the largest portion of healthcare facility expenditures (Martin et al., 2008). In response, healthcare facility owners have increasingly prioritized efficient operations and urged the industry to explore ways to enhance project delivery (Kahn, 2010). Study highlights that making critical decisions during the early stages of project development is vital for achieving better outcomes (Atkinson et al., 2006; Ballard et al., 2003). However, delays in construction remain a severe and chronic issue, significantly impacting project performance (Hazzan et al., 2009). Given these complexities, the definition phase of healthcare project managements often spans several years, serving as a critical period for articulating needs and translating them into actionable design criteria (Ballard et al., 2003).

So, to improve cost and time performance and gain a competitive edge in EPC businesses, stakeholders must comprehend the expectations and preferences of their customers (Anderson et al., 1997; Kärnä et al., 2009; Othman et al., 2004), including recognizing the impact of cultural and social factors within service systems (Wang et al., 2016). Moreover, grasping the significance of Indigenous healthcare construction is essential, as Indigenous patients feel more comfortable and understood when treated by healthcare providers from their own communities. Cultural determinants, including the need for healthcare to understand and respect local beliefs and preferences, play a significant role. Indigenous peoples often find mainstream health care unwelcoming and culturally unsafe (Davy et al., 2016).

When it comes to healthcare construction for Indigenous communities, these challenges are compounded by the need to incorporate cultural and social considerations into design and planning. Emphasizing indoor-outdoor connectivity, geometric symbolism, and traditional design elements not only enhances overall well-being but also fosters a holistic approach to healthcare (Verderber et al., 2020). Furthermore, anecdotal evidence suggests that the construction of healthcare significantly influences Indigenous individuals' decisions regarding healthcare utilization, appointment attendance, and treatment experiences (Haynes et al., 2019). Therefore, there is an urgent need for a critical re-evaluation of healthcare construction design, considering Indigenous behavioral and social factors in the construction projects. Additionally, it is vital to conduct a thorough analysis of cost and time management to assess the feasibility of constructing healthcare facilities that integrate these culturally significant features. Recognizing and addressing these cultural and social factors is crucial for both construction businesses and healthcare providers to effectively meet the needs of their respective communities and clients.

Despite efforts to address healthcare disparities, there remains a significant gap in understanding the role of circumpolar architectural and health-related perspectives in Indigenous communities' healthcare provision. While existing study acknowledges the rejection of colonialist healthcare policies and the cultural disconnections, there is limited exploration of how Indigenous behavioral and social factors intersect with vernacular construction traditions and the healing role of the natural landscape in shaping healthcare. Therefore, comprehensive study is urgently needed to explore these aspects in greater depth, providing insights that can guide the development of culturally responsive healthcare interventions tailored to the unique needs and preferences of Indigenous communities, while also evaluating the feasibility in terms of cost and time management of construction projects.

The motivation of this study is to develop a knowledge-based model of cultural and social factors that are related to healthcare construction. Building healthcare facilities for Canada's Indigenous communities requires navigating a challenging landscape influenced by social, cultural, and historical elements. Compared to non-Indigenous populations, Indigenous communities experience notable health disparities, which are made worse by colonial legacies, systematic racism, and a lack of proper healthcare infrastructures. In order to address these discrepancies, the Truth and Reconciliation Commission of Canada has emphasized the necessity of culturally acceptable healthcare practices, stressing that medical professionals need to be aware of the historical injustices that Indigenous communities have experienced. Building healthcare facilities that are attentive to the requirements of Indigenous peoples and culturally safe requires an understanding of these issues. Within the construction project managements, it is imperative to look into the social and cultural elements that greatly influence Indigenous healthcare construction initiatives. Through detailed examination and analysis, I seek to illuminate the social and cultural factors, as well as the cost and time considerations, that influence the effectiveness and sustainability of Indigenous healthcare construction. Furthermore, my goal is to design policies that are in line with the requirements and preferences of Indigenous communities by creating a detailed SD model based on these insights, thereby encouraging equitable access to high-quality healthcare services.

In this research study, there are specific questions that needed to be answered,

Question 1: How does the social and cultural factors integrate into EPC projects for healthcare construction management?
Question 2: What methods and tools should be used for modelling to evaluate the impact of cultural and social preferences on cost, time, and quality?
Question 3: How can the policies and systems identified in this study improve project outcomes in EPC projects?

To answer the above general question, insights from SD modelling, investigating social and cultural factors and their impact on cost and time management of construction projects for Indigenous people will be studied. In addition, a healthcare case study analysis of Indigenous people would be used as a test. In return, this study aims to provide policies for construction companies to better align their projects with Indigenous perspectives and needs.

1.1 Research Study Objectives and Scope of the Thesis

The overall objective of this proposed study is focused on understanding social and cultural factors of users of a facility that have significant impacts to the success of EPC firms and to incorporate these factors in the design and operation management of EPC. A particular healthcare construction project in the past will be taken to assist in this study. An impatient and waiting room design construction for Indigenous communities will be taken as a user community. To realize this overall objective, the following specific objectives will be pursued:

Objective 1: Social and cultural preferences will be defined through an effective technical approach tailored to Indigenous healthcare construction project managements.

Objective 2: System dynamics thinking effectively simulates the complexities of construction projects, addressing the interactions between cost, time, social and cultural variables.

Objective 3: The effectiveness of each social and cultural preference will be evaluated, and optimal conditions for each variable will inform policy development for stakeholders.

By addressing these specific objectives and study question, the study aims to contribute to the effective investigation of construction projects and the development of culturally sensitive healthcare facility for Indigenous communities, ultimately promoting their well-being and access to quality healthcare services.

The organization of this thesis is outlined below in Figure 1.1 to provide a clear structure for the subsequent chapters:

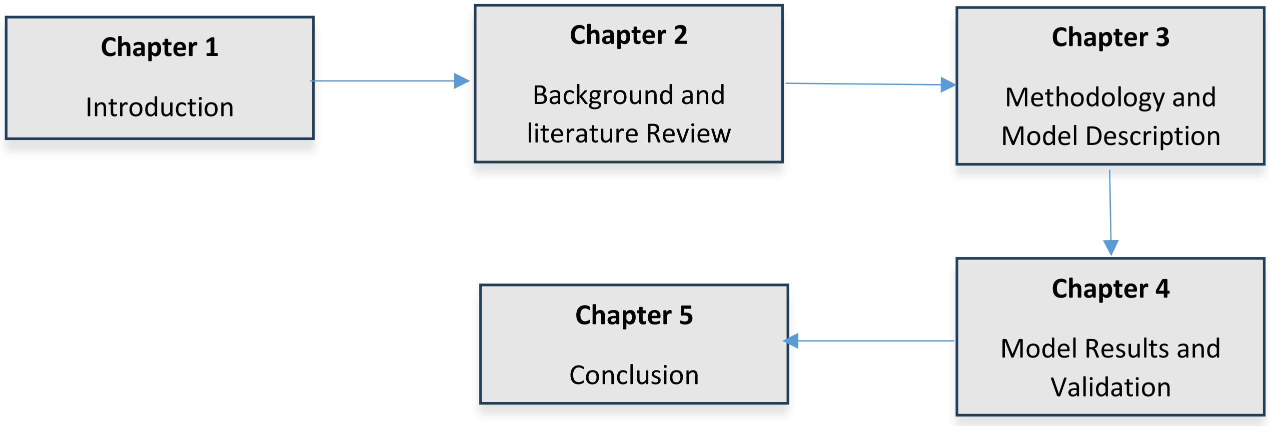

Figure 1.1 Organization of Thesis

CHAPTER TWO

BACKGROUND AND LITERATURE REVIEW

2.0 Literature review

In today's rapidly evolving construction industry, characterized by the burgeoning scope and scale of projects, the EPC method has emerged as a prominent approach in international markets. The noteworthy increase in local and international competition over the last decade has emphasized the importance for construction companies in EPC projects to broaden their focus beyond technical proficiency (Gonzalez, 2019). There is a significant risk that contractors undertake in EPC projects, emphasizing the importance of understanding and managing customer perspectives (Bartikowski & Walsh, 2011; Chidambaram & Tamilmaran, 2020).

Stern et al. underscore the significance of the preference-belief theory in explaining social phenomena within this context, emphasizing the interplay between social and cultural preferences, and consumer perspective (Cialdini et al., 1990). It should be noted that the performance of the construction sector in EPC project management significantly influences long-term economic growth and stability, prompting endeavors to enhance productivity and project success rates (Alshihre et al., 2020). Therefore, comprehending these social dynamics becomes imperative. This is particularly evident in the healthcare construction industry, where effectively managing customer perspectives has become essential (Friesner et al., 2009; Hallowell, 1996; Y. Zhang & Zhang, 2014).

The healthcare construction industry has increased substantially in recent years due to higher numbers of chronic diseases, overpopulation, an increase in the elderly population, and the lack of healthy lifestyle choices, especially for Indigenous communities (Gonzalez, 2019). Without control of healthcare construction, there is a lack of clarity regarding unique perspectives, interests, histories, and contexts that Indigenous people bring to their healthcare experiences and the ways by which they inform optimal care provision for themselves and their families (Conway et al., 2017; Kashid et al., 2011; Turpel-Lafond & Johnson, 2021).

The history of institutionalized healthcare, persistent racism and discrimination against Indigenous peoples, and a lack of knowledge about their distinct life experiences are also issues that are receiving more attention (Gonzalez, 2019; Phillips‐beck et al., 2020; Turpel-Lafond & Johnson, 2021). Putting Indigenous health and wellbeing in context is part of a larger, expanding conversation about decolonizing healthcare and health. Research and policy on a global scale have concentrated on giving Indigenous government authority over healthcare. Indigenous viewpoints on healthcare take into account a strong bond with custom, community, and the environment (Sherwood & Edwards, 2006; Smith & Lavoie, 2008).

The design and implementation of healthcare facilities reflect not just a place for medical treatment but a holistic approach to healing, incorporating cultural practices and preferences. A recent study on waiting room and patient room construction design preferences highlights several key findings relevant to Indigenous healthcare design (O'Rourke et al., 2022). Studies indicates that Indigenous communities place significant importance on elements that foster comfort, inclusivity, and cultural respect (O'Rourke et al., 2022). They preference spaces that reflect their cultural heritage, achieved through traditional artwork, culturally significant colours, and motifs, creating a sense of belonging and respect (O'Rourke et al., 2022). The spatial arrangement is critical, with preferences for layouts providing both communal and private areas to facilitate social interaction and support while offering solitude when needed (O'Rourke et al., 2022). Integrating natural elements such as plants, water features, and natural lighting is highly preferred, reflecting their deep connection to nature and creating a calming environment (O'Rourke et al., 2022). Engaging Indigenous communities in the design process is crucial to ensure that the spaces meet their needs and preferences, fostering a sense of ownership and ensuring cultural appropriateness. In conclusion, waiting room design for Indigenous healthcare facilities should prioritize cultural sensitivity, spatial flexibility, natural elements, comfort, accessibility, and holistic well-being, creating a welcoming and healing environment.

Numerous studies have proposed diverse metrics to evaluate project performance, focusing on aspects such as schedule growth, cost growth, and design deficiencies or changes (Pocock et al., 1996). Metrics for cost, schedule, and quality performance have also been incorporated to provide a broader perspective of the management (Konchar & Sanvido, 1999). Management, in the context of project execution, refers to the process of planning, organizing, leading, and controlling resources to achieve specific goals efficiently and effectively. A manager plays a pivotal role in this process by overseeing the various aspects of project execution, including planning, scheduling, execution, and decision-making. The manager's ability to coordinate these elements is crucial for the successful delivery of projects, particularly in complex environments such as construction projects (Carter & Fayol, 1986). Quantitative metrics, such as cost and schedule growth, and qualitative measures, including user expectations and owner satisfaction, have been employed to effectively compare projects (Molenaar et al., 1999). A more extensive evaluation framework has been developed to encompass cost, schedule, safety, user satisfaction, quality, building functionality, and environmental and commercial performance (Chan et al., 2004). The "commonly acknowledged performance" framework integrates metrics for cost, schedule, safety, defects, and satisfaction, offering a holistic approach to performance assessment (Cho et al., 2010). Certain project delivery methods have been shown to foster more integrated and cohesive teams, leading to improved outcomes in cost, schedule, and quality. These outcomes were assessed using a comprehensive range of metrics, including unit cost, cost and schedule growth, schedule intensity, delivery and construction speed, operation and maintenance costs, system quality, and the frequency of callbacks or start-up challenges (Franz et al., 2017). In general, any construction project's management team should generally focus on things like project controls, scheduling and estimating, construction technologies, construction contracts, project management, and customer needs (Lavy & Fernández-Solis, 2010).

2.1 System Dynamic (SD) approach in construction management

The SD approach, initially introduced by Jay W. Forrester in the 1960s, is a robust management methodology designed to model and simulate complex real-life systems. It provides valuable insights into the intricate nature of systems and the implications of strategic decision-making and policy execution. At its core, SD relies on causal feedback loops, which can either balance or reinforce the relationships among system variables, thereby offering a comprehensive understanding of how systems evolve over time (Richardson, 2011). The concept of feedback allows past behaviors within a system to influence future actions, a feature that is particularly useful in dynamic and interconnected environments. Within this computer-based simulation framework, differential equations are graphically represented, and discrete steps are calculated over a predetermined time frame, enhancing the ability to predict and analyze system behavior (Sterman, 2000).

The SD methodology is particularly suitable for systems characterized by variables that change over time and where dynamic feedback is well recognized as a critical factor. It provides a holistic perspective of the system's evolution, illustrating the interactions both within the system and with external factors (Van Ackere et al., 1997). For organizations, this approach aids in identifying delays and disruptions that could impact customer orders, operational processes, and long-term revenue. By focusing on the factors affecting a system's dynamic behavior, SD offers a simulation framework to examine the impact of specific conditions, assumptions, or contexts on system performance (W. J. Zhang & Wang, 2016). In the context of construction projects, particularly in healthcare construction, SD has proven to be an effective methodology for analyzing and managing complex systems. These projects often involve dynamic interactions among numerous variables, which significantly influence outcomes (De Marco et al., 2016; Kabirifar & Mojtahedi, 2019). By emphasizing feedback loops, time delays, and interdependencies among components, SD facilitates a deeper understanding of the construction process (De Marco et al., 2016; Kabirifar & Mojtahedi, 2019). A feedback loop is a system structure where the output from one element eventually influences the input to that same element (Richardson, 2011). Using tools such as causal loop diagrams (CLDs) and stock and flow diagrams (SFDs), the methodology enables the visualization of relationships between elements like construction productivity, material selection, and design considerations. This visualization empowers stakeholders to make informed decisions, ensuring that the dynamic complexities of construction projects are effectively managed (Santoso et al., 2022; Wuni & Shen, 2022). The achieved outcomes are especially valuable when addressing the unique challenges of healthcare construction projects serving Indigenous populations in Canada.

2.1.1 Building Performance

Circular shapes play a pivotal role in Indigenous architectural preferences, both functionally and symbolically. As demonstrated in studies, almost 80% of participants preferred semi-circular group seating over linear seating in rows, with older participants showing an even greater preference for this arrangement. Comments such as, "The round seating areas . . . I like that. It's easy for the family to sit down and have a yarn," (O'Rourke et al., 2022) highlight the cultural importance of circular spaces in fostering inclusivity and communal interactions.

Circular designs also draw inspiration from the symbolic geometry of the medicine wheel, a fundamental representation of interconnectedness, balance, and healing. Indigenous cultural practices, such as pit houses commonly used in British Columbia, embody this principle. Pit houses were traditionally circular, utilizing earth, timber, pine needles, grass, and bark, aligning with Indigenous sustainable practices and connection to the land (Lacava et al., 2024).

From a construction perspective, the integration of circular shapes with modular construction methods enhances flexibility and sustainability. Circular-shaped construction is 1.28 times more efficient in formwork compared to rectangular construction. Also, Modular construction enables prefabricated components to be assembled on-site, reducing waste, cost, and construction time. This technique ensures adaptability for future modifications, aligning with Indigenous principles of resilience and environmental stewardship (Jayawardana et al., 2023; Lacava et al., 2024; MacKenbach et al., 2020). Furthermore, radiality, inspired by the medicine wheel, supports spatial comprehension and strengthens ties to traditional cultural knowledge. By integrating cultural symbolism with modern construction techniques, circular and modular designs effectively address the social, cultural, and practical needs of Indigenous healthcare environments (Kyrö et al., 2019; Wuni & Shen, 2022).

2.1.2 Natural Light and Building Orientation

Natural light plays an essential role in the psychological and physical well-being of healthcare facility users, particularly in Indigenous communities that prefer a strong connection to nature. Studies have demonstrated that 68% of participants have nature views with maximum light from large windows, emphasizing the importance of creating visual access to the outdoors. One participant aptly noted, "Open spaces. Views and big windows... views not of a/c or building walls next door—that makes you feel 'off.'" (O'Rourke et al., 2022). This highlights how thoughtful window placement and design enhance emotional well-being and create a sense of openness.

To optimize natural light, a high window-to-wall ratio (WWR) is recommended. This design strategy ensures adequate daylight penetration, reducing the reliance on artificial lighting and creating a welcoming atmosphere (O'Rourke et al., 2022; Sultana et al., 2023). Additionally, large windows designed with thermal insulation maintain indoor comfort without compromising energy efficiency, making them suitable for cold climates. The placement and orientation of these windows are critical; south-facing windows in northern cold regions capture maximum sunlight during winter months, contributing to passive heating and reducing energy costs (Sultana et al., 2023).

Studies underscores that building performance, including thermal efficiency and occupant comfort, is intricately connected to the interplay between window-to-wall ratio (WWR) and building orientation, with their influence typically ranging between 0.05 to 0.1 percent (Natural Resources Canada (NRCan), 2012; Veillette et al., 2021). A 0.4 window-to-wall ratio in a south-oriented building results in a 0.27% increase in natural light penetration (Veillette et al., 2021).

Using the integration of such design elements not only aligns with Indigenous preferences for natural light and openness but also ensures sustainable energy management. Facilities that incorporate these features foster an environment that reflects the cultural preferences of connectivity and respect for the natural world (Meshref et al., 2023; O'Rourke et al., 2022).

2.1.3 Material Selection

The choice of materials in healthcare construction has far-reaching implications for environmental sustainability, cultural relevance, and economic feasibility. Indigenous communities have historically utilized local and natural materials, such as timber, earth, grass, and bark, in their architectural practices (Nash et al., 2021). For example, traditional pit houses were built with these materials, reflecting ecological harmony, resource efficiency, and resilience against harsh climatic conditions (Lacava et al., 2024; Nash et al., 2021; Verderber et al., 2020). Preferences for these materials persist today, as demonstrated by survey findings showing that 57% of participants preferred a warm wood interior finish over plain white. Additionally, 95% of participants who expressed a preference for wood finishes selected it as their top choice (Nash et al., 2021).

The use of local materials not only reduces transportation-related emissions but also supports regional economies, reinforcing the self-sufficiency of communities. Architect Laurie Baker, renowned for sustainable and cost-effective designs, emphasized the importance of using materials that are both eco-friendly and responsive to local climatic needs (Sultana et al., 2023). This aligns closely with Indigenous practices that prioritize materials capable of withstanding extreme weather conditions, such as heavy snow, cold winds, and fluctuating temperatures.

Incorporating natural materials like timber and earth into modern construction also serves as a form of cultural reconciliation. By integrating traditional materials into healthcare facilities, architects can honor Indigenous heritage and create spaces that resonate with cultural identity. Additionally, these materials offer practical benefits, such as thermal insulation and durability, making them ideal for long-term use in diverse environmental settings (Lacava et al., 2024; Nash et al., 2021; Verderber et al., 2020).

In modern healthcare construction, the environmental performance of primary construction materials such as timber, steel, and concrete is critically analyzed to align with sustainability goals. When considering Global Warming Potential (GWP) measured in kg CO_2-eq./m^2, timber emerges as the most sustainable option. For a 10 m span, timber yields a GWP of -34.30, significantly outperforming steel (25.55) and concrete (20.76). Similarly, for a 25 m span, timber maintains a GWP of -39.90, again surpassing steel (47.96) and concrete (39.29). The negative GWP values for timber highlight its capacity to act as a carbon sink, a critical advantage in reducing the environmental impact of construction (Hegeir et al., 2022).

2.1.4 Cost Management

Cost management in construction projects is driven by several interrelated factors, including material type, material waste, design changes, building orientation, and cost waste. Optimal material selection plays a critical role in minimizing costs by reducing waste and rework, ensuring resources are used efficiently. Material waste, when properly managed, decreases disposal costs and limits the need for additional materials, directly improving the Cost Performance Index (CPI), which measures cost efficiency by comparing earned value to actual cost (Waliulu & Adi, 2021).

Design changes, particularly errors or frequent revisions, contribute significantly to cost waste by requiring additional resources and increasing project complexity. Early-stage mitigation of design errors through improved coordination among stakeholders reduces these inefficiencies (Laovisutthichai et al., 2022). Proper building orientation also plays a crucial role by reducing cost waste, as a well-oriented building can maximize energy savings and operational efficiency (Hossain et al., 2020; Johnsson et al., 2020). Additionally, effective stakeholder coordination improves material selection, actual time, actual cost, design changes, and building orientation. Improved material selection reduces inefficiencies in time and cost management, leading to smoother project coordination. (Jamil & Fathi, 2016; Sarhan et al., 2017). Savings, as an outcome variable, reflect the cumulative effect of efficient cost management practices. Reducing material waste, cost inefficiencies, and design changes leads to higher savings, as indicated by a high CPI (Waliulu & Adi, 2021).

2.1.5 Time Management Factors

Time management in construction projects depends on minimizing delays, optimizing schedules, and ensuring efficient resource utilization. Key influencing factors include material type, material waste, actual cost, building orientation, and stakeholder coordination. High-quality material selection accelerates project completion by reducing inefficiencies and rework, ensuring processes are executed smoothly (Jamil & Fathi, 2016; Sarhan et al., 2017). Material waste, if not properly managed, contributes to project delays due to resource shortages, spoilage, and the need for additional replacements, making efficient practices essential for timely execution (Journal Of & Ngineering, 2016). Building orientation also plays a pivotal role in time management by improving energy efficiency, streamlining processes such as heating, cooling, and natural lighting, and ultimately reducing delays caused by operational inefficiencies (Harbaoui & Khalfallah, 2022). The Schedule Performance Index (SPI) measures time efficiency by comparing earned value to planned value. High SPI values, reflecting on-schedule or ahead-of-schedule performance, can be achieved through improved coordination, material efficiency, and early resolution of design changes (Waliulu & Adi, 2021). Stakeholder coordination is essential for timely decision-making and reducing delays arising from miscommunication, design revisions, and misaligned objectives. Effective management of design changes, supported by enhanced collaboration, minimizes disruptions and streamlines workflows, improving actual time and overall schedule performance (Jamil & Fathi, 2016; Laovisutthichai et al., 2022). By addressing these parameters, the project can optimize time management practices, reduce inefficiencies, and ensure successful and timely project delivery.

CHAPTER THREE

METHODOLOGY AND MODEL DESCRIPTION

3.0 Introduction

The methodology employed in this study aimed to systematically address the complexities involved in healthcare construction project managements for Indigenous communities. Initially, utilized secondary data for social and cultural preferences specific to Indigenous people is collected. This step was essential to gaining a nuanced understanding of the unique requirements and expectations that these communities hold regarding healthcare facilities. By leveraging existing literature, reports, and studies, the identify key social and cultural factors that impact the design was unidentified, functionality, and effectiveness of healthcare infrastructures for Indigenous populations.

Following the data collection phase, the development of causal loop diagrams and stock-and-flow diagrams to model the entire healthcare construction project management was proceeded. These diagrams provided a visual simulation for mapping the interdependencies between critical variables such as cost, time, and social and cultural factors. The causal loop diagrams helped in visualizing the dynamic relationships and feedback loops that could influence the project's success. Meanwhile, the stock-and-flow diagrams facilitated an understanding of the project's progression over time, illustrating how inputs were transformed into outputs and allowing for the simulation of different scenarios.

By analyzing these models, it was aimed to assess the feasibility and potential impacts of constructing a healthcare facility that aligns with the social and cultural preferences of Indigenous communities. This methodology enabled a detailed analysis of the conditions necessary for effective time and cost management throughout the project lifecycle. The insights gained from this approach were intended to inform evidence-based recommendations that support the development of culturally sensitive healthcare infrastructures, thereby promoting equitable access to quality healthcare services for Indigenous populations.

3.1 SD Model Development and Formulation

SD modeling has become a powerful tool for analyzing and managing the complexities of construction projects. It provides a structured simulation to examine the dynamic behavior of systems over time, considering feedback loops, nonlinear interactions, and inherent time delays typical of large-scale projects (Love et al., 2002). At its core, SD operates on the principle that a system's structure dictates its behavior. In the context of construction project management, this implies that the interactions among various components—such as resources, schedules, and quality—are central to determining project outcomes (Love et al., 2002).

As illustrated in Figure 3.1, the SD modeling approach is characterized by an iterative, cyclic process that explicitly integrates critical outcomes as essential elements of understanding. As Richardson and Pugh (1997) highlight, "the model is a means to an end, and that end is understanding." This methodology emphasizes that the primary goal is not merely to create a model, but to enhance comprehensive comprehension of the problem under investigation and the broader system in which it exists. By treating the model as a dynamic tool for insight generation, SD allows researchers and practitioners to explore complex systemic interactions, revealing nuanced relationships and potential intervention points that might otherwise remain obscured. The approach transforms modeling from a static representational exercise into a sophisticated analytical process that continuously refines understanding through iterative exploration and reflection (Richardson & Pugh, 1997).

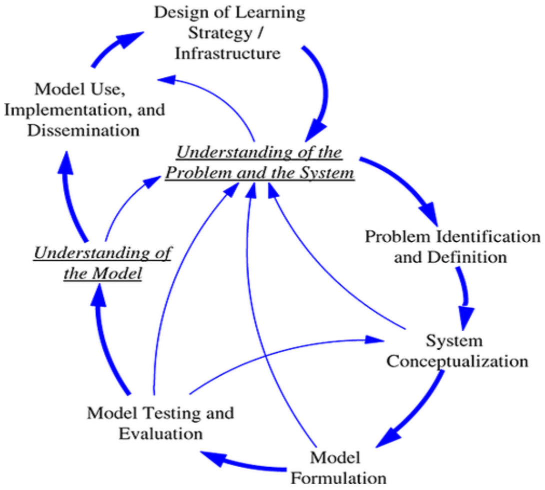

Figure 3.1 Development of the SD model (Richardson & Pugh, 1997)

The core components of an SD model are illustrated in Figure 3.2, at the center is the **stock**, which represents the accumulation of a resource or entity. This stock is influenced by two key flows: **inflow**, which adds to the stock, and **outflow**, which depletes it. These flows are regulated by associated variables—**Variable 1** impacts the inflow, while **Variable 2** affects the outflow. The arrows connecting the components represent the feedback loops and dependencies within the system. This structure highlights how changes in one part of the system ripple through to influence overall dynamics, providing insights into how different factors interact over time.

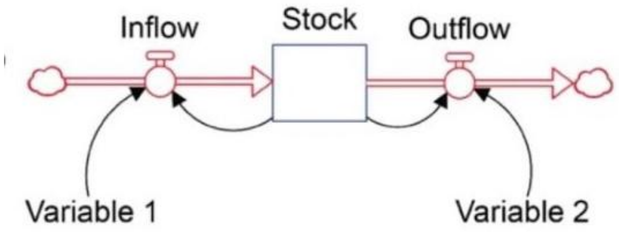

Figure 3.2 Core components of SD model

Building on this framework, this case study applies these principles to define the technical aspects of Indigenous social and cultural preferences in healthcare construction. By applying the SD model, we define the technical aspects of these preferences, illustrating how various factors interact within the system to shape design and decision-making in Table 3.1.

Table 3.1 Technical aspects of Indigenous social and cultural preferences in healthcare construction

Preferred (Expectation)	Preferred (Structure)
Increasing Sunlight	Increasing window-to-wall ratio
Increasing Sunlight	Adjusting building Orientation
Eco-friendly construction material	Wood is a main source of material
Fostering inclusivity and communal interactions	The circular shape of the design

Table 3.2 below further expands on this framework by outlining the key stock and flow variables in the SD model. These flow variables represent dynamic processes that drive system changes, capturing essential activities and interactions that shape healthcare construction outcomes.

Table 3.2 Flow variables in the SD model

Flow Variables		Units
Building performance	The operational efficiency of the circular-shaped building with the modular construction method in terms of less energy and material usage and more functionality.	Score
Material Type	Using materials that align with reducing environmental impact as a core Indigenous preference, with less needed quantity of usage and less cost. (timber, concrete, steel)	Score
Building Orientation	The physical alignment of the building and windows to the south for maximizing the natural light impacts energy use and workflow.	Score
Window-to-wall ratio	Maximizing windows to wall ratio to 0.4 to increase natural lighting and connection to nature.	Score
Base Budget	The original budget was based on the needs of the project.	Canadian Dollar
Contract Time	The total planned duration of the construction project.	Month
Percentage of Contingency Cost	The portion of the budget allocated for contingency costs is expressed as a percentage of the total budget.	Percentage

These flow variables reflect the actionable components of the model, enabling the simulation of interventions and their effects on system dynamics over time.

The stock variables in this study represent key accumulations within the system. This information can be found in Table 3.3.

Table 3.3 Stock variables in the SD model

Stock Variable		Units
Actual Time	The total duration taken to complete a construction project.	Month
Material waste	Accumulated waste from materials used in construction.	TON
Actual Cost	Total expenses incurred to complete a construction project.	Canadian Dollar
Design Errors	Mistakes in construction plans or drawings.	Percentage
Energy Efficiency	The level of energy optimization achieved during construction and operation.	Percentage
Coordination among stakeholders	The level of alignment and collaboration between project participants.	Percentage
Schedule Performance Index (SPI)	Measures the efficiency of time management against planned.	Score
Saving	The amount of money in optimization of time, cost, and resources without compromising the quality, cultural sensitivity, or functionality of the construction project.	Percentage
Contingency Cost	Funds are set aside for unforeseen costs, such as unexpected issues during construction.	Canadian Dollar
Cost Performance Index (CPI)	Measures the efficiency of actual cost against planned budget.	Score

These stock variables provide a foundation for understanding the long-term impacts of design and cultural considerations on healthcare construction project outcomes.

Together, the stock and flow variables form a cohesive simulation that captures the interplay between design choices, cultural preferences, and project outcomes. This model facilitates a deeper understanding of how construction projects can be tailored to meet the social and cultural needs of Indigenous communities, ensuring sustainable and effective healthcare solutions.

3.2 Causal Loop Diagram

The first step in developing the SD model is constructing a Causal Loop Diagram (CLD). Causal Loop Diagrams (CLD) are widely used in systems dynamics to visualize and analyze the feedback relationships within a system. They highlight cause-and-effect pathways and provide insights into how variables influence one another. A typical CLD consists of variables linked by arrows indicating causation, with each link labelled as either positive or negative to indicate the nature of the relationship. Feedback loops in CLDs are either reinforcing or balancing, which helps model dynamic systems and predict outcomes (Sterman, 2000). A balancing loop stabilizes a system by counteracting changes and driving it towards equilibrium, such as managing resource allocation in construction projects while a reinforcing loop amplifies changes, often leading to exponential growth or decline, such as productivity gains in a construction project (Richardson, 2011; Sterman, 2000)

Creating an effective CLD involves careful selection of variables, avoiding ambiguities like self-referential links, and keeping diagrams clear by limiting clutter. Important loops can be emphasized for better readability. The process often starts with defining the problem, system boundaries, and variables based on rigorous literature reviews and stakeholder discussions. Tools like Vensim or Stella can facilitate the creation of CLDs. These diagrams are particularly useful in understanding problems like healthcare access and sustainability by capturing the social, economic, and environmental feedback mechanisms involved in decision-making processes (Sterman, 2000).

With using Vensim software in this study, the causal loop diagram highlights the dynamic interactions between key variables such as material type, building orientation, coordination among stakeholders, energy efficiency, material waste, time, cost and performance metrics like SPI, CPI, and savings. These variables influence the success of construction projects, particularly in balancing cost, time, and quality.

Figure 3.3 illustrates the CLD diagram of healthcare construction for Indigenous people based on the social and cultural aspects.

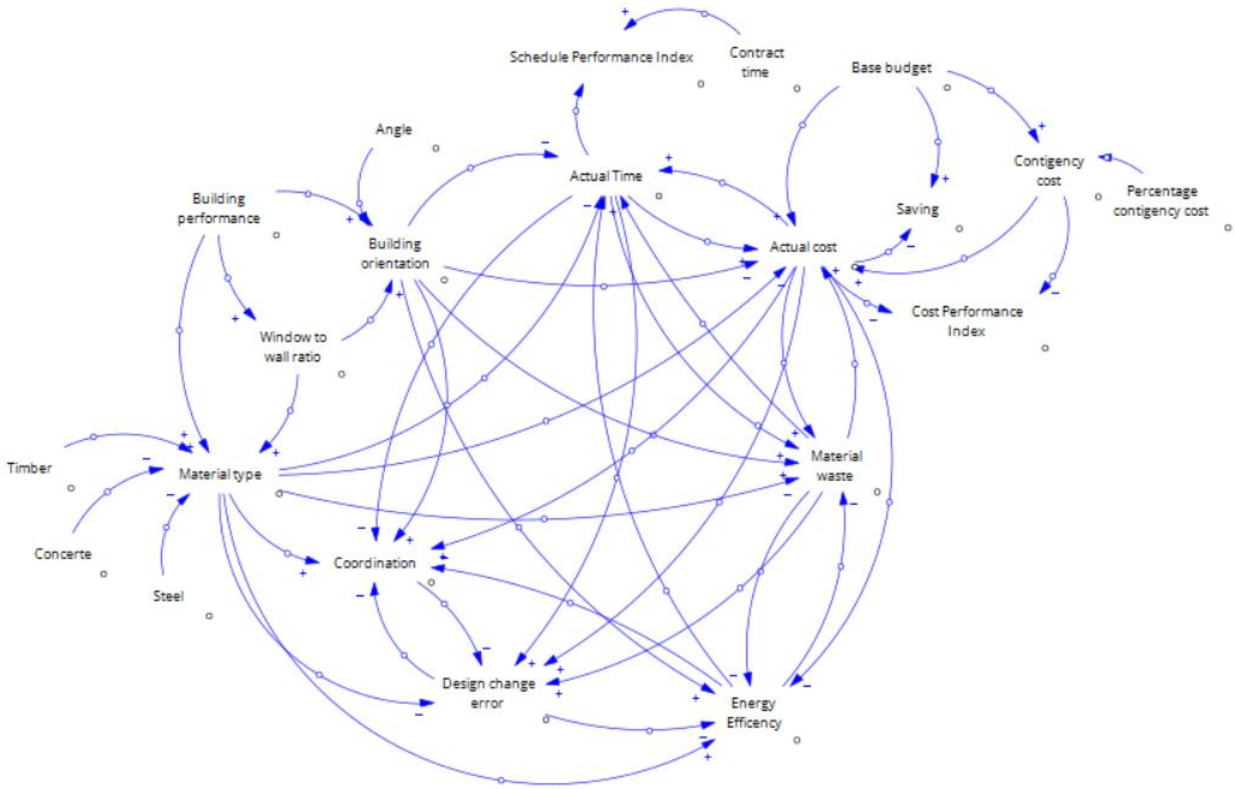

Figure 3.3 CLD of healthcare construction for Canadian Indigenous communities

3.3 Stock and Flow Diagram

Following the development of the Causal Loop Diagram (CLD), the next step in constructing the SD model is creating the Stock and Flow Diagram (SFD). SFDs provide a quantitative representation of the system by illustrating how resources accumulate and deplete over time. This enables numerical analysis and simulation, making them particularly valuable for optimizing resource allocation in healthcare and assessing construction project timelines. By building on the feedback relationships identified in CLDs, SFDs offer a more detailed view of system dynamics, capturing the timing and magnitude of changes. To enhance their effectiveness, researchers emphasize aligning SFDs with data collection efforts and ensuring clarity, making them actionable tools for policy-making and system improvements (Barbrook-Johnson & Penn, 2022; Sterman, 2000).

These equations can range from simple mathematical operations like addition, subtraction, multiplication, and division to more complex functions involving parameters that shape interactions between variables. Once the stocks, flows, and influencing factors are defined mathematically, the simulation begins by setting initial stock values and calculating changes in them over iterative time steps, driven by their corresponding flows (Barbrook-Johnson & Penn, 2022).

In this study, the stock and flow diagram represents the dynamic, quantitative layer of the system described in the causal loop diagram, adding structure to the abstract feedback relationships. While the causal loop diagram focuses on feedback loops—both reinforcing and balancing—between factors like Building Performance, Energy Efficiency, Coordination, and Material Type, the stock and flow diagram translates these qualitative interdependencies into measurable variables that evolve over time. It serves as a bridge between conceptual understanding and actionable simulation, laying the groundwork for policy experimentation and optimization. Figure 3.4 illustrates the Stock and flow diagram of the cost and time management of the construction of healthcare for the Indigenous community based on the social and cultural factors:

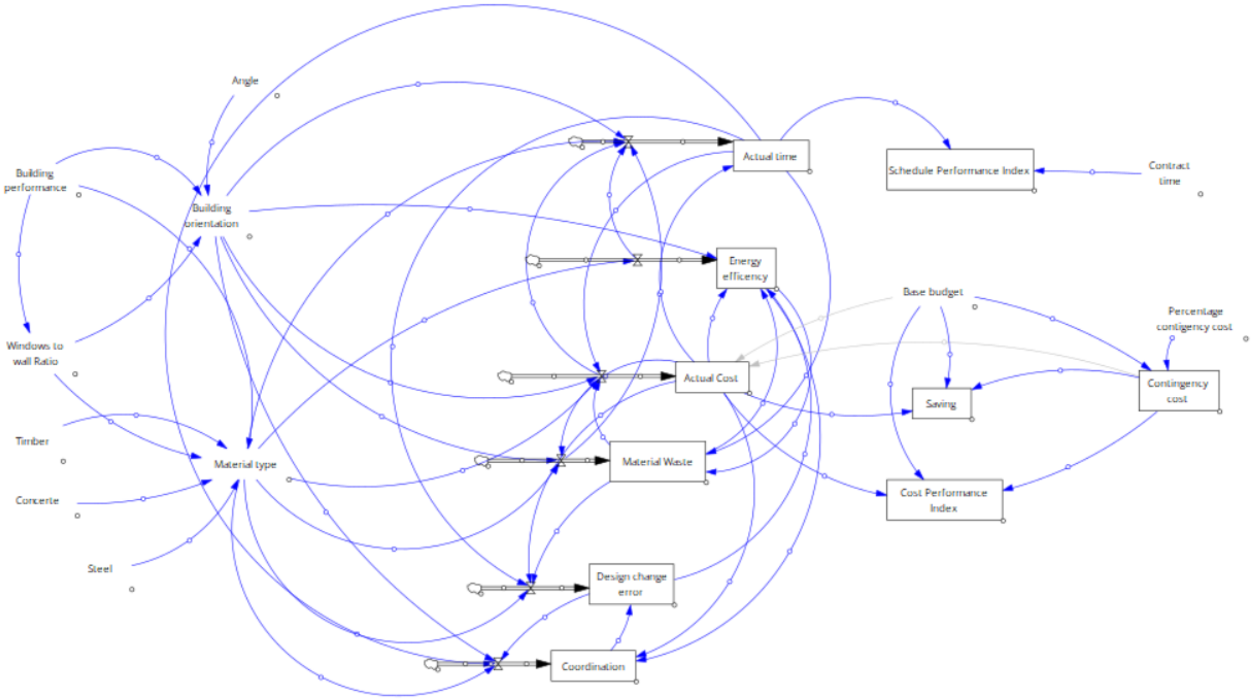

Figure 3.4 SFD of healthcare construction for Canadian Indigenous communities

The equation for each flow is constructed as follows:

Change of Energy efficiency and sustainability = (Material type / Material waste) + (Material type/ Design changes) + (Building orientation/ Cost waste)

Change of coordination among project stakeholders = (Material type/ Time waste) + (Material type/Cost waste) + (Material type / Design changes) + (Building orientation/ Energy efficiency)

Change of Design errors in drawings = - (Material type /Material waste) - (Material type /Time waste) - (Material type /Cost waste) - (Material type /Coordination among project stakeholders)

Change of Actual Time = - (Material type /Material waste) - (Material type / Cost waste) - (Building orientation/ Energy efficiency)

Change of Actual Cost = - (Material type /Material waste) - (Material type /Time waste) - (Building orientation / Material waste)

Change of Material waste = (Material type / Cost waste) - (Material type /Time waste) - (Building orientation / Time waste) - (Building orientation /Energy efficiency)

SPI = (Contract time - Actual time)/Contract time

CPI = ((Base budget + Contingency cost) - Actual Cost) / (Base budget + Contingency cost)

Saving = ((Base budget + Contingency cost) - Actual Cost) / 100

(Meshref & Ibrahim, 2024)

Furthermore, initial values of variables in the SFD are listed below in Table 3.4:

Table 3.4 Initial values of SFD variables

Variables	Score	Unit
Building performance	0.38	Score
Window-to-wall ratio	0.24	Score
Material type	-0.22 – 0.8	Score
Building orientation	0.05	Score
Cost	60000000	Canadian dollar
Time	24	Month
Design changes error	35	Percentage
Energy efficiency and sustainability	60	Percentage
Coordination among project stakeholders	80	Percentage
Material waste	20	Percentage
Percentage of Contingency Cost	5	Percentage

The scores for building performance, window-to-wall ratio, material type, and building orientation range between -1 and 1, as indicated by the literature review. The design change error is estimated at 35%, energy efficiency is at 60%, stakeholder coordination is 80%, and material waste is 20%. The entire construction project is projected to be completed within 24 months, with a planned cost of 60 million Canadian dollars, based on the best estimates for Canadian Indigenous healthcare construction.

3.4 Conclusion

The study has made meaningful strides in developing a dynamic simulation to address the complexities of healthcare construction project managements designed for Indigenous communities. The study incorporated secondary data from academic literature, government reports, and industry case studies, focusing on material usage trends, cost dynamics, and timelines from both Canadian projects. Using CLDs and SFDs, the methodology captured the complex interdependencies among variables, such as cultural preferences for natural light, circular layouts, and eco-friendly materials. CLDs facilitated qualitative mapping of feedback loops, highlighting the interactions influencing the key variables. SFDs complemented this by providing a quantitative framework to model how resources like budget and time evolve throughout the project lifecycle. This integrated approach enabled a dynamic evaluation of how cultural preferences can be implemented while maintaining cost and time efficiency, offering actionable insights for sustainable and culturally sensitive healthcare infrastructure development.

CHAPTER FOUR

MODEL RESULTS

4.0 Introduction

The development of a system dynamics model provides an insightful approach to evaluating whether the social and cultural preferences of Indigenous communities can be effectively incorporated into healthcare construction project managements. This model examines the complex interactions between cost, time, and resource management while prioritizing critical social and cultural factors unique to Indigenous populations.

These factors include preferences for natural light, circular layouts, and the use of eco-friendly materials. By integrating these design preferences into the modeling framework, the study aims to explore the conditions under which these elements can be successfully achieved within the constraints of project budgets and timelines. The focus of this study is to assess the feasibility of meeting these preferences by analyzing the savings trends for key construction materials—concrete, steel, and timber—over a 24-month period. The model dynamically integrates variables such as material usage patterns, cost dynamics, and time constraints to simulate realistic project outcomes. By evaluating these interdependencies, the analysis identifies scenarios where Indigenous cultural and social preferences can be met without compromising project efficiency.

4.1 Results

Analysis of the SD Model's Behavior for Material Waste

The analysis of material waste over time for steel, concrete, and timber reveals that there is a significant difference in their efficiency as shown in Figure 4.1. Timber emerges as the most efficient material, showing the greatest reduction in waste over 24 months, reaching 19.0945. This indicates that timber is highly effective in minimizing material waste, making it a sustainable choice for construction. In contrast, concrete and steel exhibit minimal reductions in waste, with concrete reaching 20.1464 and steel reaching 20.1469. These small changes suggest that concrete and steel are less efficient in terms of waste reduction compared to timber.

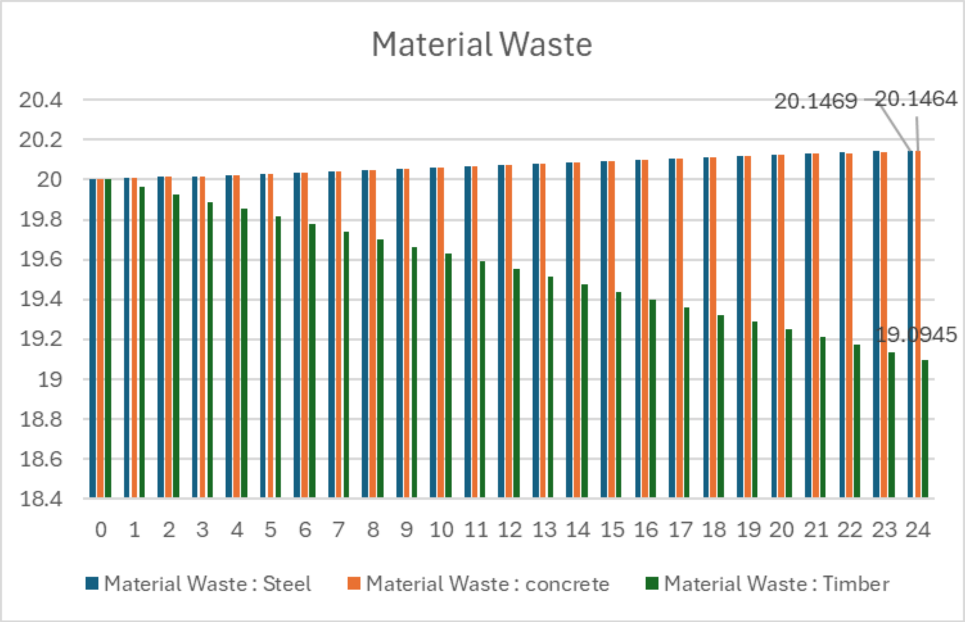

Figure 4.1 Analysis of the SD Model's Behavior for Material Waste

Analysis of the SD Model's Behavior for Energy Efficiency

Figure 4.2 provides a combined analysis of Energy Efficiency across different building materials (concrete, steel, and timber) over time, we need to consider how each material performs in terms of energy usage efficiency.

The data shows a decreasing trend in energy efficiency for all materials over the 24-month period. Timber exhibits the highest energy efficiency, consistently maintaining 61.5691 throughout the timeline. For concrete, the energy efficiency is 59.5832 at the end, indicating a slight decline in efficiency. Steel shows a similar trend, with energy efficiency values decreasing to around 59.5822 by the end of the period. This trend suggests that both concrete and steel have a gradual decrease in energy efficiency over time, while timber remains relatively stable. This analysis supports the idea that timber construction, particularly in a circular-shaped building with a south orientation and a 0.4 window-to-wall ratio, is more energy-efficient compared to concrete and steel.

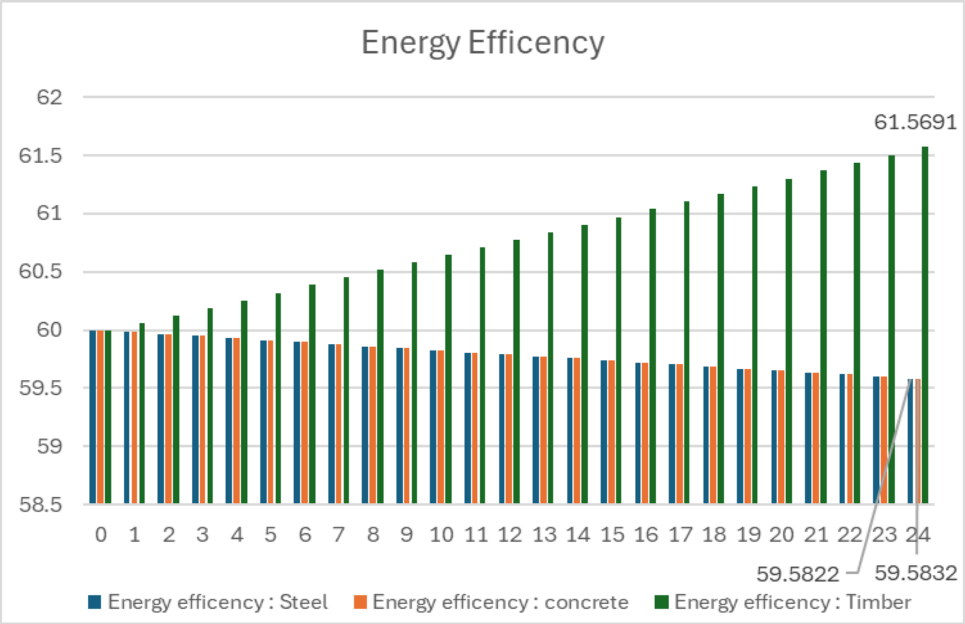

Figure 4.2 Analysis of the SD Model's Behavior for Material Waste

Analysis of the SD Model's Behavior for Design Change Error

The data presented in Figure 4.3 shows design change error over time for steel, concrete, and timber revealing significant differences in their performance. Timber shows the greatest reduction in design change error over 24 months, reaching 32.9328. This indicates that timber is the most stable material in terms of design changes, making it a reliable choice for construction. In contrast, concrete and steel exhibit minimal reductions in design change error, with concrete reaching 35.5537 and steel reaching 35.555. These small changes suggest that concrete and steel are less stable in terms of design changes compared to timber. Therefore, for a circular-shaped, south-oriented building with a 0.4 window-to-wall ratio, timber would be the most stable material, while steel would be the least stable.

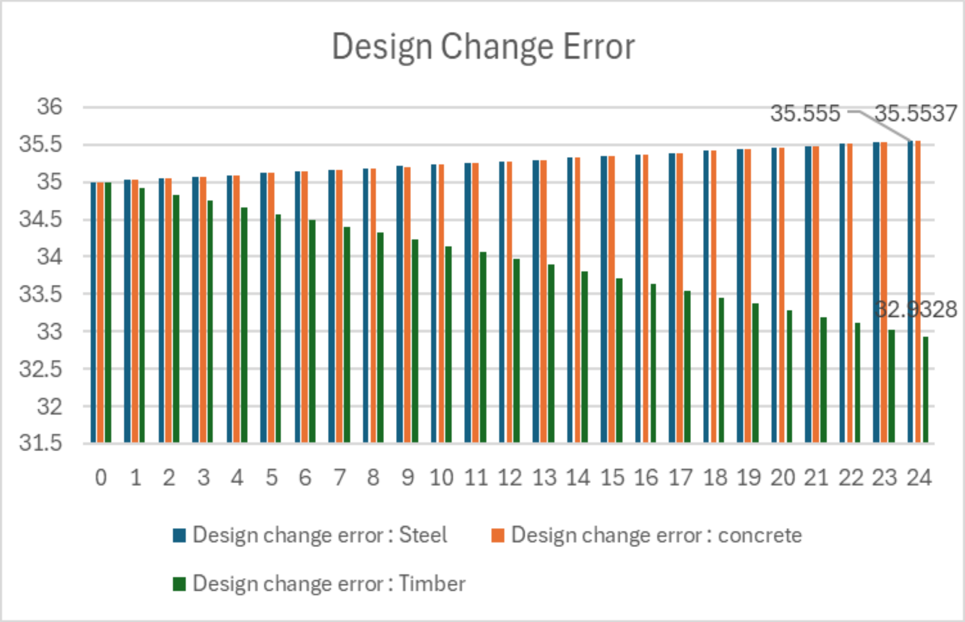

Figure 4.3 Analysis of the SD Model's Behavior for Design Change Error

Analysis of the SD Model's Behavior for Coordination among Stakeholders

Over the 24-month period, timber demonstrates a consistent improvement in coordination among stakeholders, reaching a final value of 81.4238 in Figure 4.4. This positive trend indicates that timber facilitates better collaboration and communication over time, making it increasingly effective for construction projects. In contrast, both concrete and steel show a gradual decrease in coordination, with final values of 79.6491 and 79.6482, respectively. These declining trends suggest potential challenges in maintaining effective stakeholder coordination especially with Indigenous customers using concrete and steel. Therefore, for a circular-shaped, south-oriented building with a 0.4 window-to-wall ratio, timber emerges as the most effective material for ensuring strong coordination among stakeholders, while steel appears to be the least effective.

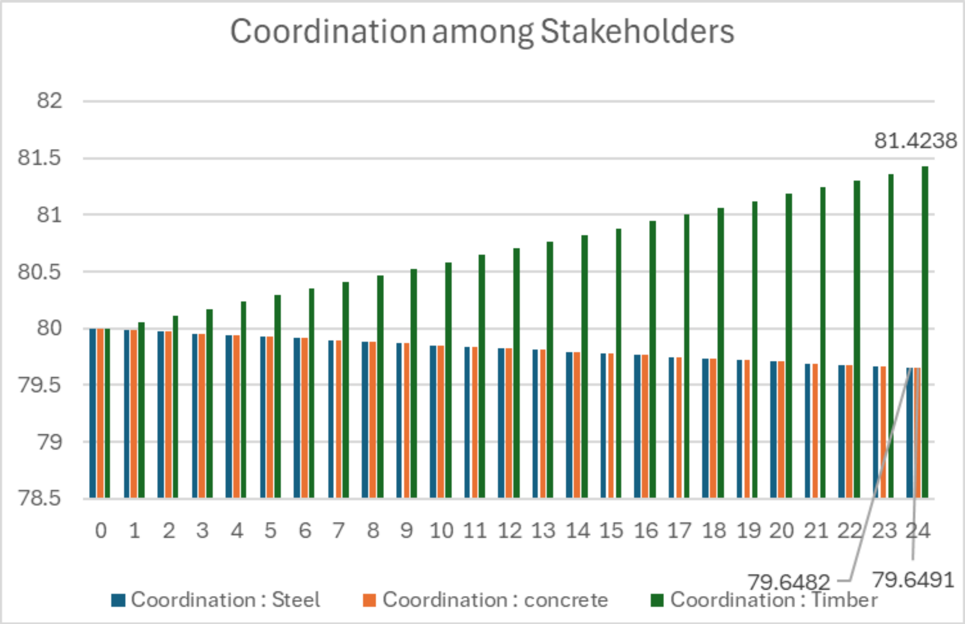

Figure 4.4 Analysis of the SD Model's Behavior for Coordination among Stakeholders

Analysis of the SD Model's Behavior for CPI

As summarized in Figure 4.5, the analysis of the Cost Performance Index (CPI) over time for steel, concrete, and timber reveals distinct trends in their cost efficiency. Timber shows a consistent improvement in CPI, reaching a value of 3.00E-08 by the 24th month. This positive trend indicates that timber becomes increasingly cost-efficient over time, making it a favorable choice for construction projects.

In contrast, both concrete and steel exhibit a gradual decline in CPI, with concrete reaching -6.71E-09 and steel reaching -6.73E-09 by the 24th month. These negative trends suggest that concrete and steel become less cost-efficient over time.

Therefore, for a circular-shaped, south-oriented building with a 0.4 window-to-wall ratio, timber stands out as the most cost-efficient material, while steel appears to be the least cost-efficient.

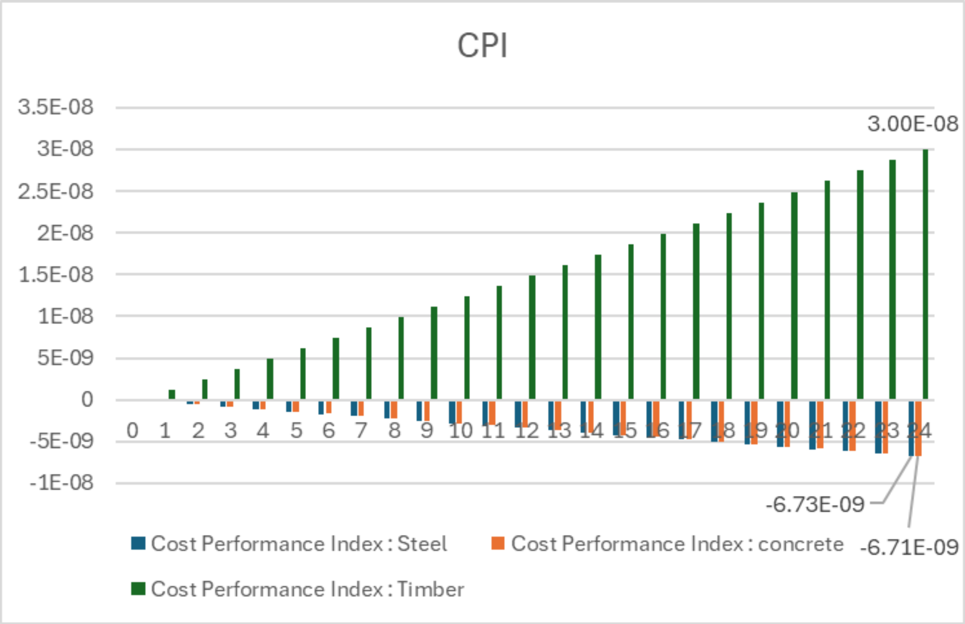

Figure 4.5 Analysis of the SD Model's Behavior for CPI

Analysis of the SD Model's Behavior for SPI

To analyze the Schedule Performance Index (SPI) and the actual time data together, we need to consider how well each material (steel, concrete, and timber) adheres to the planned schedule and completes the project over time. In Figure 4.6, the SPI values reveal that timber projects perform better in terms of schedule adherence, with a positive trend indicating improving schedule performance as the months progress. SPI values for timber increased up to 0.0442404, reflecting a reduction in delays over time. In contrast, both concrete and steel show negative SPI trends, indicating that these projects are consistently behind schedule throughout the 24-month period. The SPI value for concrete is -0.00839768 after 24 months of construction, while steel is -0.00842375. As a result, timber projects were completed in less time, with an actual completion time of 22.9382 months, which are closer to the planned 24 months. Concrete and steel projects experience minor delays, with actual times of 24.2015 months for concrete, and 24.2022 months for steel. Overall, timber construction shows better time and schedule performance compared to concrete and steel, particularly in a circular-shaped building with a south orientation and a 0.4 window-to-wall ratio.

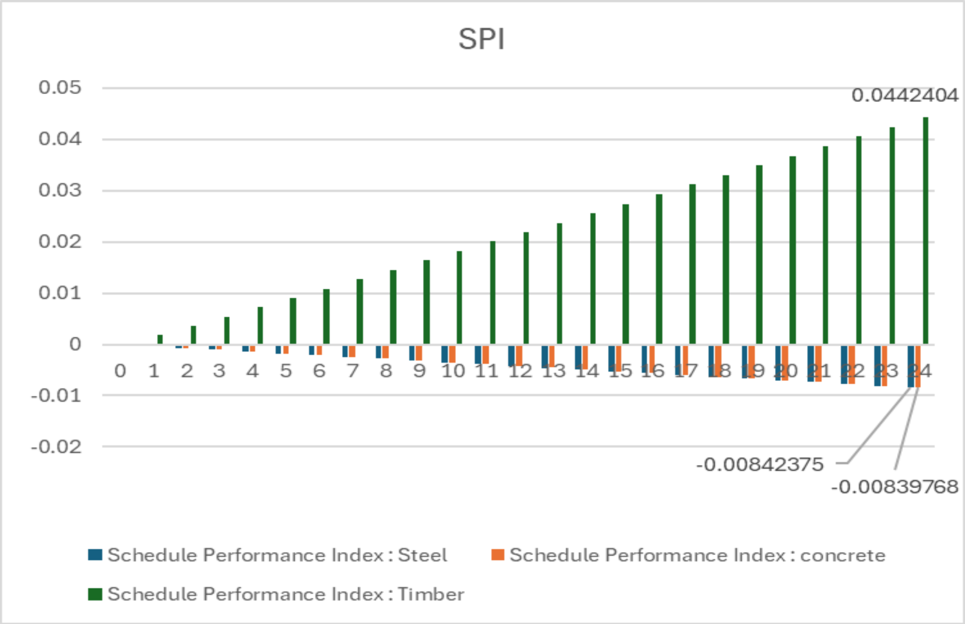

Figure 4.6 Analysis of the SD Model's Behavior for SPI

Analysis of the SD Model's Behavior for Saving

The dataset illustrates the savings trends for concrete, steel, and timber over a 24-month construction period in Figure 4.7. Both concrete and steel exhibit negative savings, indicating increasing costs or losses as the project progresses. Interestingly, the savings trends for concrete and steel are nearly identical throughout, suggesting similar cost dynamics. In contrast, timber demonstrates a positive savings trend, with costs decreasing steadily over time, reaching a peak saving of 0.0189135 by the 24th month, while Concert and steel are -0.00422801 and -0.00423947. At every time point, timber outperforms concrete and steel in cost savings, suggesting it may be the most economical material choice for this project with considering SC aspects of Indigenous people in the construction.

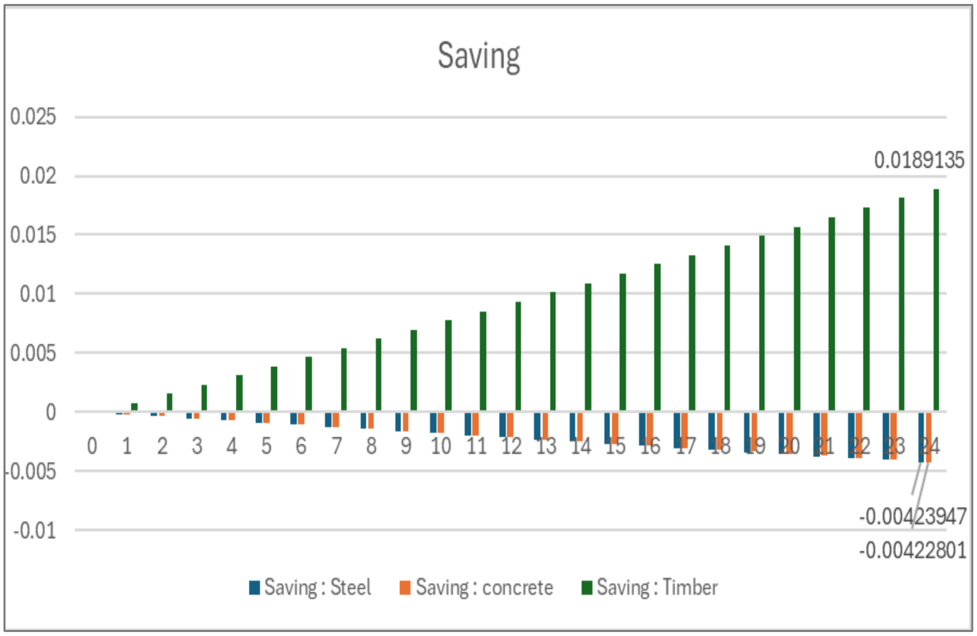

Figure 4.7 Analysis of the SD Model's Behavior for Saving

4.2 Validation and Sensitivity Analysis

4.2.1 Introduction

To evaluate the reliability and robustness of the results in this study, a comprehensive sensitivity analysis was conducted using the Monte Carlo simulation method. This analysis focused on three critical construction materials—steel, concrete, and timber—over a 24-month timeline. The objective was to assess the impact of uncertainty and variability on performance metrics, ensuring the validity and reliability of the findings. A ±30% variability range was applied to each variable to simulate potential increases and decreases. This range allowed for the exploration of a broad spectrum of scenarios.

Randomization was carried out using a triangular distribution formula, which was chosen for its ability to effectively model minimum, maximum, and most likely values. Each simulation incorporated standard deviation as a key measure to capture the dispersion and variability in the data, providing a statistical basis for assessing the reliability of results. Standard deviation was used to evaluate how much the simulated outcomes deviated from the mean performance, highlighting the degree of consistency across different scenarios. This enabled a nuanced understanding of the potential variability and risks associated with each material.

To achieve statistical robustness, 1,000 simulations were performed for each month of the 24-month timeline, covering each of the three materials. The inclusion of many simulations ensured that the results were not significantly influenced by outliers or extreme values, strengthening the reliability of the analysis. This approach provided a comprehensive dataset, allowing for a detailed examination of performance trends under varying conditions.

The analysis was conducted sequentially for each material—steel, concrete, and timber—to account for their unique properties and behaviors. Monthly simulations were evaluated independently to capture material-specific variability and trends. For each material, standard deviation was used to measure the spread of results within the variability range, offering insights into which materials demonstrated greater stability or were more prone to fluctuations.

By integrating standard deviation into the Monte Carlo simulations, this analysis provided a robust framework for evaluating the reliability of the results. Fluctuations in performance metrics were examined in relation to the standard deviation to determine whether they remained within acceptable ranges. This reinforced confidence in the stability of the findings despite the applied variability.

Validation of Energy Efficiency

Timber

Based on the analysis in Figure 4.8, the sensitivity analysis of energy efficiency versus standard deviation (STD) over a 24-month period for a system dynamics model. The orange bars illustrate energy efficiency, while the blue bars represent the standard deviation.

The energy efficiency values, shown by the orange bars, exhibit a gradual increase throughout the period analyzed. Starting at approximately 60.06 in month 1, the energy efficiency consistently rises to about 61.57 by month 24. This upward trend suggests continuous improvements in the system’s energy performance over time, reflecting potential optimization efforts or advancements in energy management strategies.

STD values, represented by the blue bars, remain relatively steady, ranging between approximately 7.19 and 7.65. The stable STD indicates that the variability or uncertainty in the system’s energy efficiency predictions does not significantly fluctuate across the 24 months. This stability implies that the model maintains a reliable and consistent level of prediction accuracy for energy efficiency.

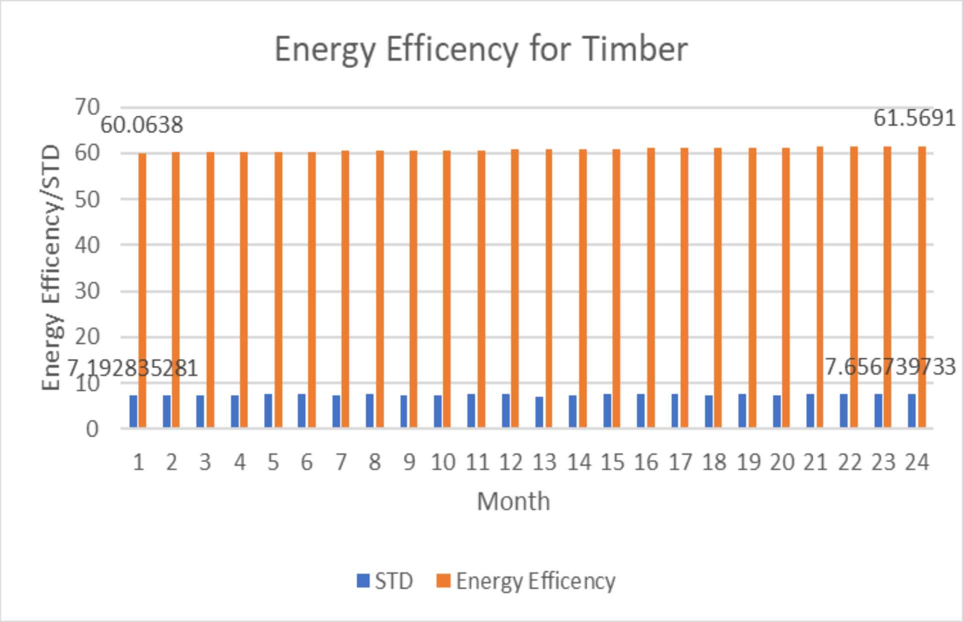

Figure 4.8 Validation of Energy Efficiency for timber

Concrete

The energy efficiency, represented by the orange bars, begins at approximately 59.98 in month 1 and gradually decreases over time, reaching 59.58 by month 24. This consistent decline indicates a slight but steady reduction in the energy performance of the system with concrete material over the period analyzed.

STD fluctuates within a very narrow range, starting at 7.3171 and slightly decreasing to 7.6528 by Month 24 in Figure 4.9. This indicates a stable variability of energy efficiency values, suggesting that fluctuations in energy efficiency are consistent and predictable. The small range of variation in the STD reflects reliability and precision in the dataset, further demonstrating the robustness of the observed trends over time.

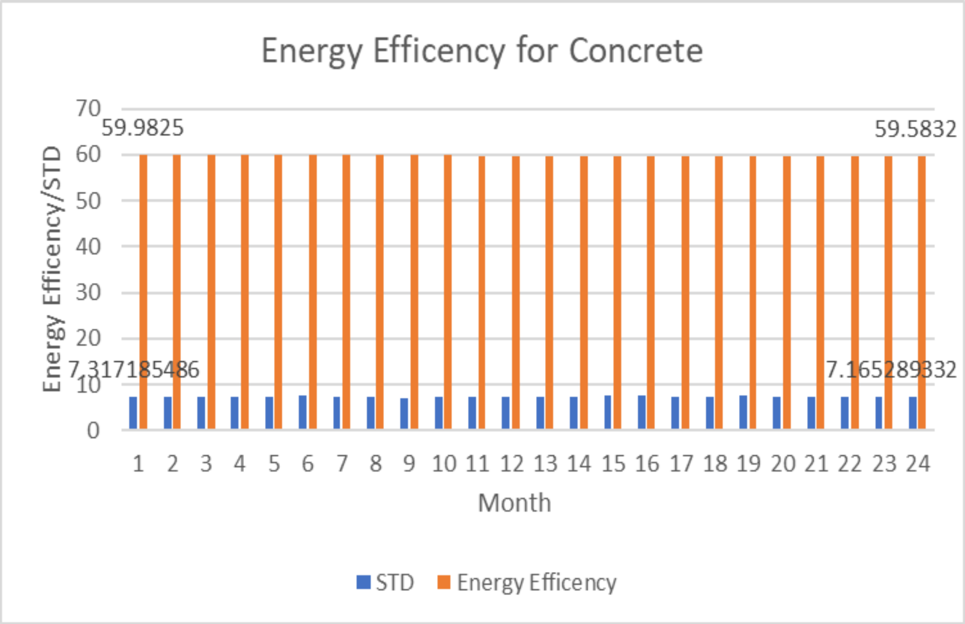

Figure 4.9 Validation of Energy Efficiency for Concrete

Steel

The energy efficiency, represented by the orange bars in Figure 4.10, starts at a value of 59.99 in month 1 and gradually decreases to 59.59 by month 24. This indicates a slight decline in the energy performance of steel over the period analyzed, reflecting a marginal reduction in efficiency.

STD, shown by the blue bars, begins at 7.27 in month 1 and reduces to 7.26 by month 24. This minimal decrease in STD suggests predictable and consistent fluctuations in energy efficiency. in the reliability of the energy efficiency predictions for steel.

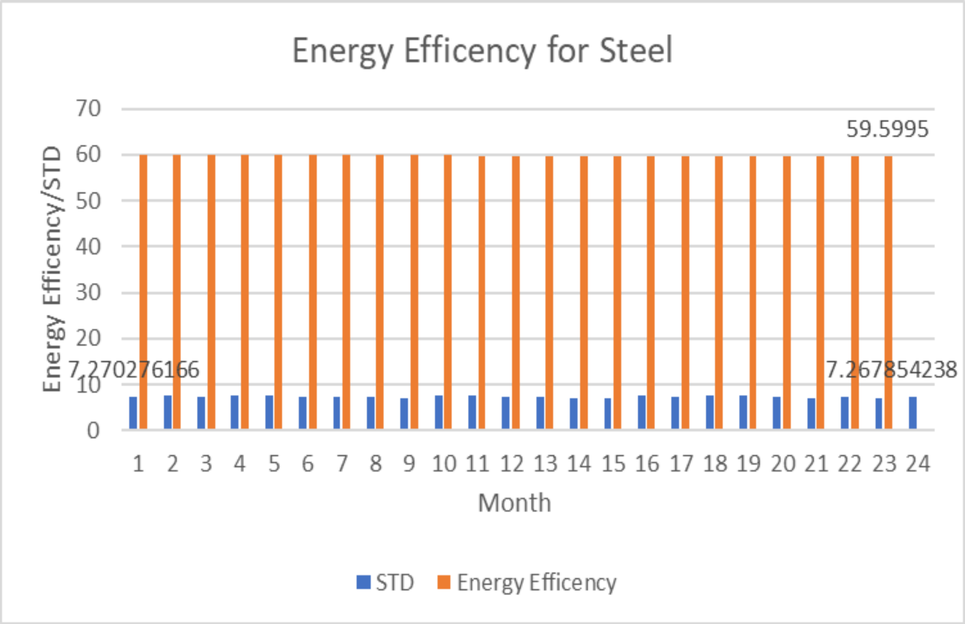

Figure 4.10 Validation of Energy Efficiency for Steel

Validation of Material Waste

Timber

The material waste, shown by the orange bars, starts at a value of 19.96 in month 1 and steadily decreases to 19.09 by month 24 in Figure 4.11. This trend indicates a gradual reduction in material waste for timber over the analyzed period, suggesting improved material utilization or efficiency.

STD, represented by the blue bars, begins at 2.42 in month 1 and slightly decreases to 2.35 by month 24. This reduction in STD reflects a marginal improvement in the consistency and reliability of the material waste data.

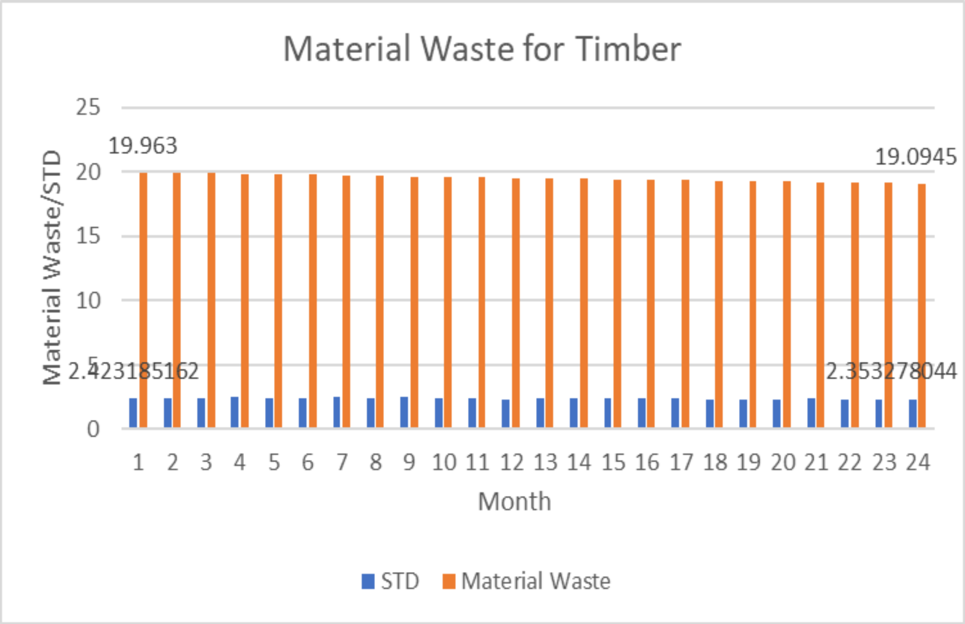

Figure 4.11 Validation of Material Waste for timber

Concrete

The material waste begins at 20.0061 in month 1 and steadily rises to 20.1464 by month 24. This trend signifies a gradual increase in material waste for concrete, possibly indicating inefficiencies in material usage or external factors contributing to waste generation over time.

Based on the analysis in Figure 4.12, STD starts at 2.3581 in month 1, fluctuates slightly throughout the analysis period, and ends at 2.3668 in month 24. While the variations in STD are relatively small, they suggest stable and predictable data over time.

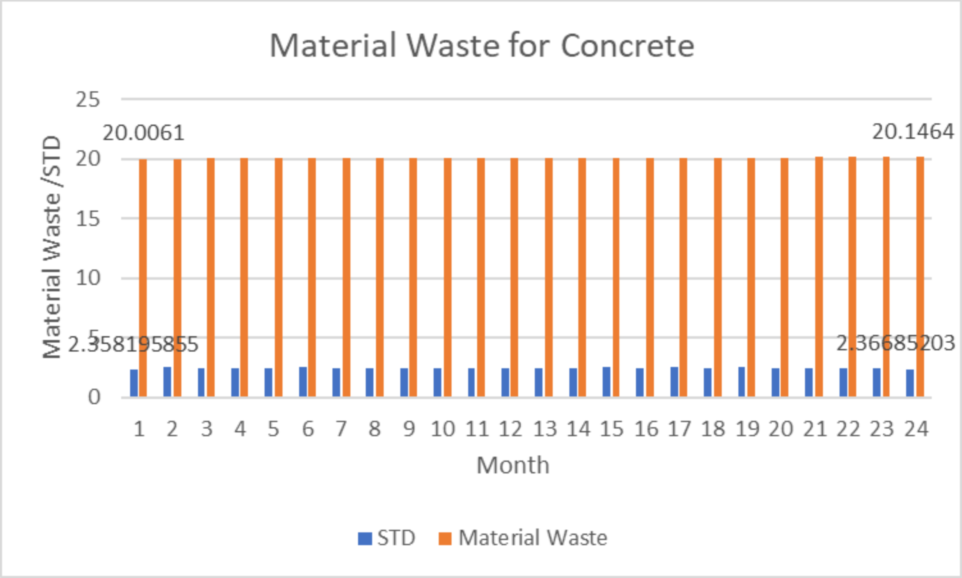

Figure 4.12 Validation of Material Waste for Concrete

Steel

As depicted in Figure 4.13, the analysis of material waste for steel over a 24-month period reveals a consistent upward trend in waste production. The material waste starts at 20.0062 in Month 1 and rises steadily to 20.1469 in Month 24, indicating an overall increase. This gradual rise suggests potential inefficiencies in steel material utilization or external factors contributing to increased waste over time.

STD of the material waste fluctuates throughout the observed period. It begins at 2.4141 on Month 1 and ends at 2.4175 in Month 24. These fluctuations indicate that no significant outliers are observed. As a result, the STD for material waste of steel is consistent.

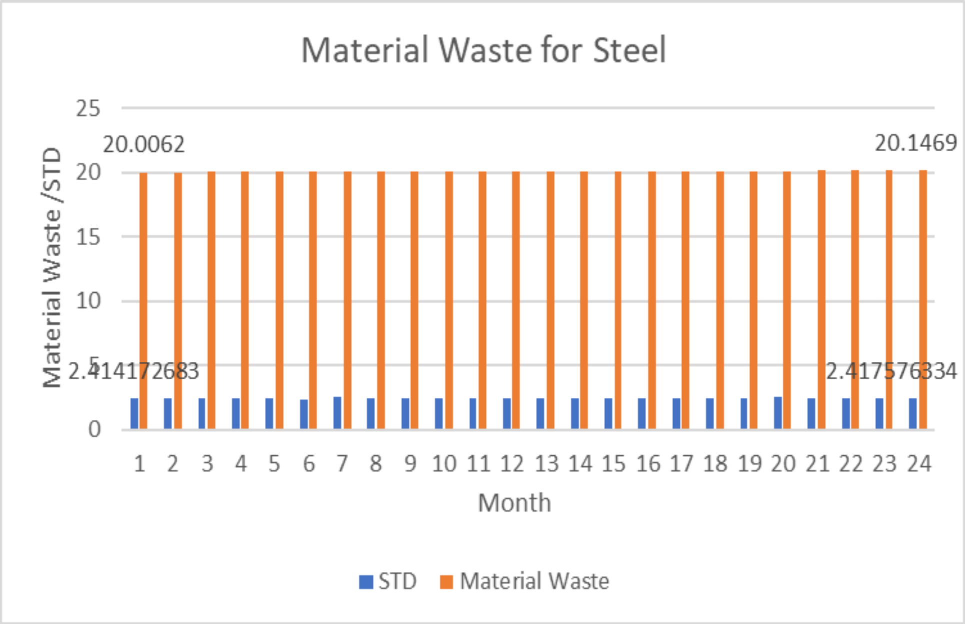

Figure 4.13 Validation of Material Waste for Steel

Validation of Design Change Error

Timber

The analysis of the Design Change Error for timber indicates a gradual decrease in values over the 24 months as shown in Figure 4.13. Starting at 34.92 in month 1, the error decreases to 32.93 by month 24. This trend suggests an improvement in design accuracy over time, as the error associated with design changes becomes smaller. The decline indicates that utilizing timber leads to fewer discrepancies in design, which may enhance overall project efficiency.

For sensitivity analysis, the STD values for Design Change Error are relatively stable, starting at 4.30 in month 1 and ending at 4.01 in month 24. The minimal variation in STD throughout the period signifies that the observed decrease in Design Change Error is consistent and reliable. This stability further confirms that the trend toward reduced errors with timber is not influenced by significant variability, reinforcing the suitability of timber for improving design change accuracy in the project.

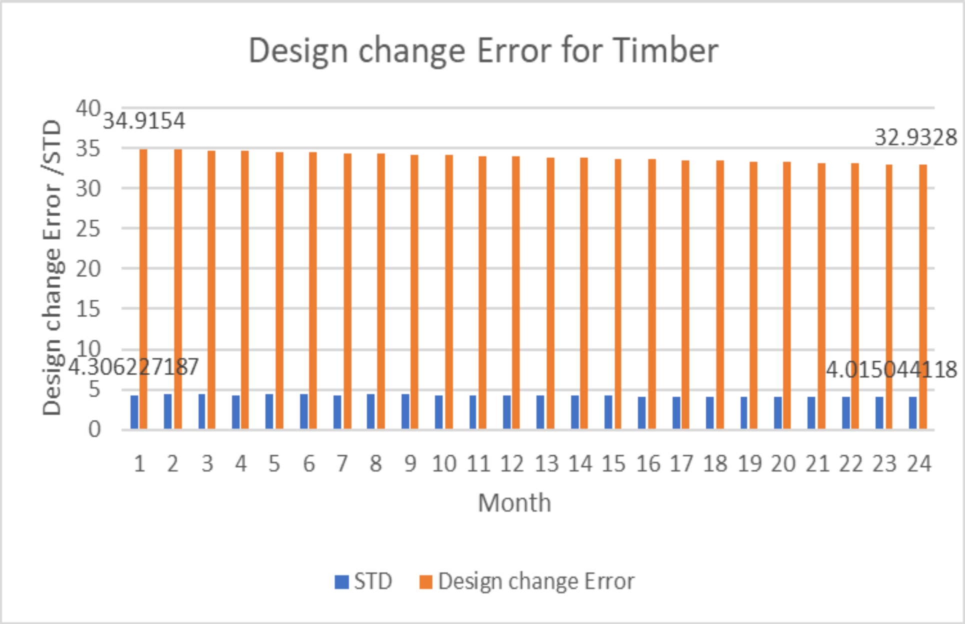

Figure 4.14 Validation of Design Change Error for Timber

Concrete

The analysis of the Design Change Error for concrete shows a relatively stable trend throughout the 24-month period. Figure 4.15 illustrates the error starts at 35.02 in month 1 and slightly increases to 35.55 in month 24. This minimal variation suggests that while concrete may experience some design change errors, the increase is not substantial enough to indicate significant challenges over time.

For sensitivity analysis, the STD values remain consistent, starting at 4.28 in month 1 and ending at 4.30 in month 24. The stability of these STD values indicates that the Design Change Error for concrete is reliable and does not exhibit high variability. This consistency supports the conclusion that the slight increase in error over time is predictable and manageable.

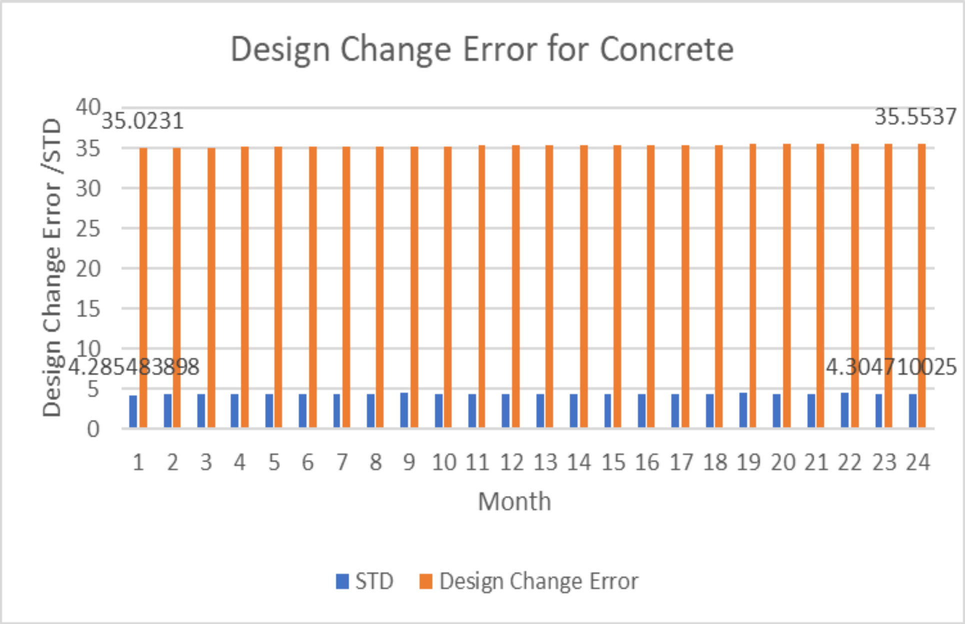

Figure 4.15 Validation of Design Change Error for Concrete

Steel

The Design Change Error for Steel shows an increasing trend throughout the 24-month period, starting at 35.0232 in Month 1 and reaching 35.555 in Month 24. This consistent upward movement suggests that the frequency or magnitude of design changes gradually increases over time. The trend demonstrates a steady rise, with minimal variation, highlighting a continuous and uniform progression of the design change error across the observed timeline.

STD remains relatively stable, ranging from 4.3955 to 4.4505 throughout the 24 months in Figure 4.16. This variability indicates that the fluctuations in the design change error are consistent and predictable. The stability of STD suggests minimal outlines in the data, supporting the reliability of the observed trends. The uniformity in STD also reflects consistent sensitivity across the analysis period, reinforcing the precision of the results.

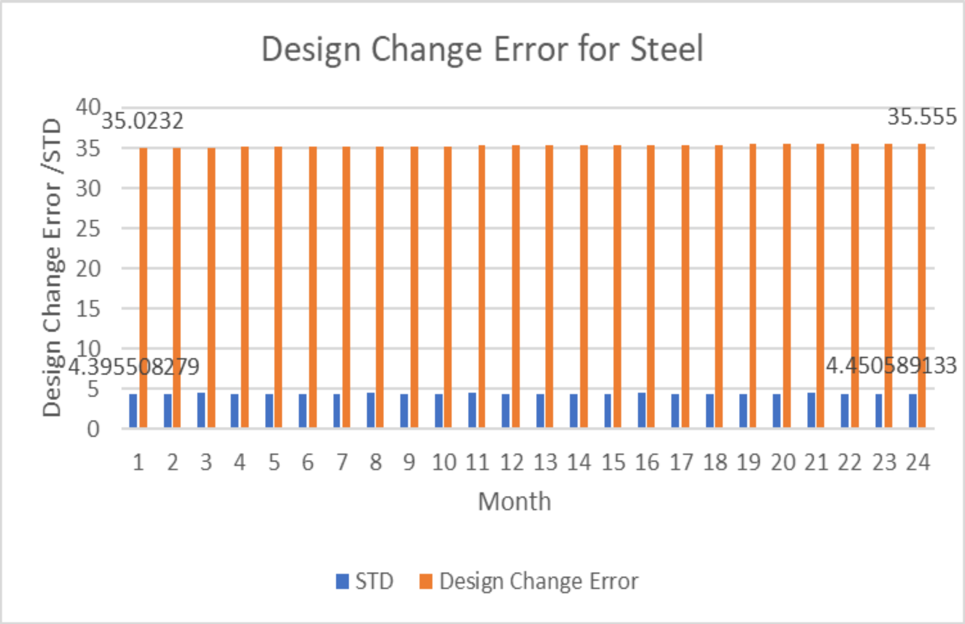

Figure 4.16 Validation of Design Change Error for Steel

Validation of Coordination among stakeholders

Timber

Based on the analysis in Figure 4.17, coordination among stakeholders for timber demonstrates a positive trend over the 24-month period. Initially, the coordination value was 80.0579, and it increased to 81.4238 by Month 24. This increase indicates that the use of timber fosters enhanced collaboration and alignment among stakeholders over time. Such improvement is a favorable outcome, suggesting that timber is a beneficial material choice for projects requiring strong stakeholder coordination.

For the sensitivity analysis, the STD was used to validate the stability of the results. The STD values ranged from a minimum of 9.9810 in Month 1 to a maximum of 10.0232 in Month 24. Although there were slight variations in STD, the overall changes were relatively consistent, ensuring the reliability of the observed upward trend. The stability of the standard deviation values further supports the conclusion that the increase in coordination is robust and unaffected by significant inconsistencies, making timber a viable option for optimizing stakeholder coordination.

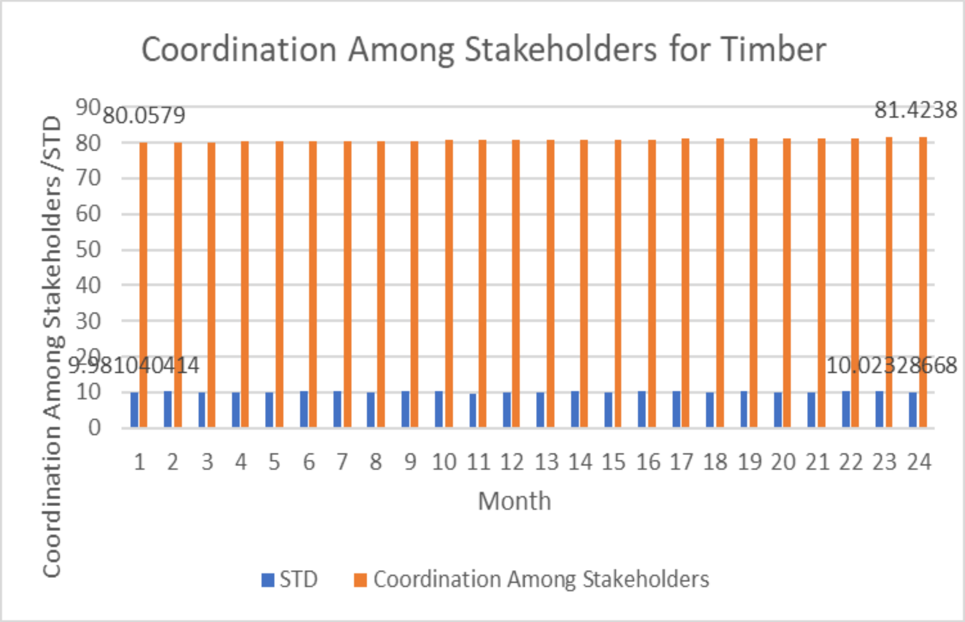

Figure 4.17 Validation of Coordination among Stakeholders for Timber

Concrete

The analysis of coordination among stakeholders for concrete reveals a decreasing trend over 24 months, with an initial value of 79.9853 and a final value of 79.6491 in Figure 4.18. This decrease indicates that the use of concrete is not optimally support consistent stakeholder coordination.

The sensitivity analysis, based on the STD evaluates the stability of these results. The STD ranged from a minimum of 9.5939 in Month 9 to a maximum of 10.2765 in Month 7, with the initial STD of 10.0212 slightly increasing to 9.8368 by Month 24. The relatively small variation in STD values suggests that the results are stable and consistent throughout the analysis period. Stability in the standard deviation indicates that while coordination decreased, the trend is reliable and not significantly impacted by random fluctuations.

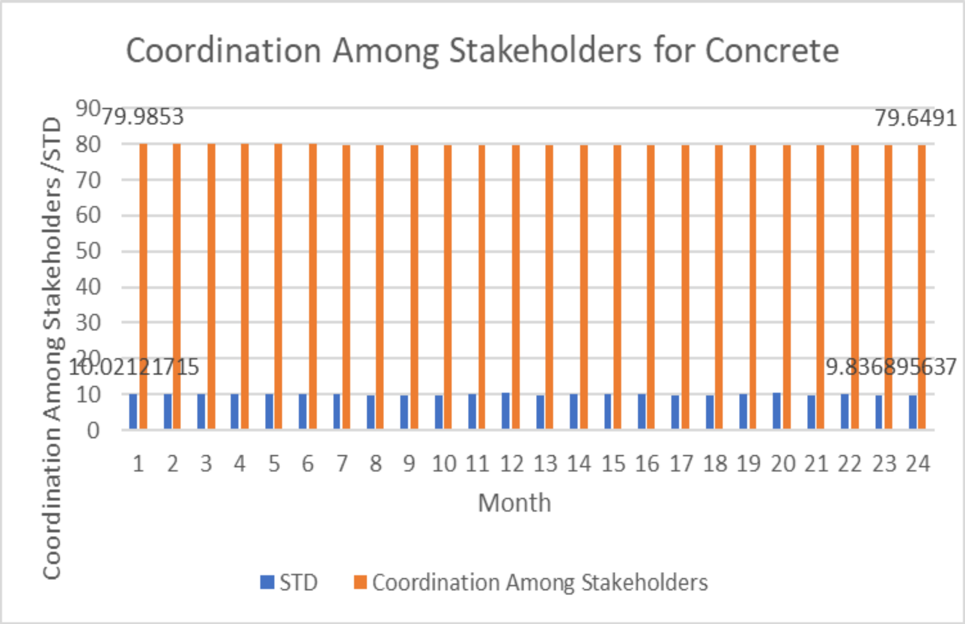

Figure 4.18 Validation of Coordination among Stakeholders for Concrete

Steel

The analysis of coordination among stakeholders for steel shows a slight reduction over 24 months in Figure 4.19. The initial value of coordination was 79.9853, which decreased to 79.6482 by Month 24, reflecting a reduction. While this decline is minimal, it still indicates a slight decrease in the efficiency of stakeholder collaboration when using steel. The observed reduction suggests potential inefficiencies that may need to be addressed to optimize project outcomes.

The sensitivity analysis, conducted using the STD, assesses the stability of the results. The STD values ranged from a minimum of 10.0397 in Month 1 to a maximum of 10.0400 in Month 12. Despite these variations, the overall changes in STD were minimal. This stability in standard deviation values reinforces the reliability of the observed trends in coordination among stakeholders. The analysis confirms that while there is a slight decline in coordination over time, the results are consistent and unaffected by significant fluctuations.

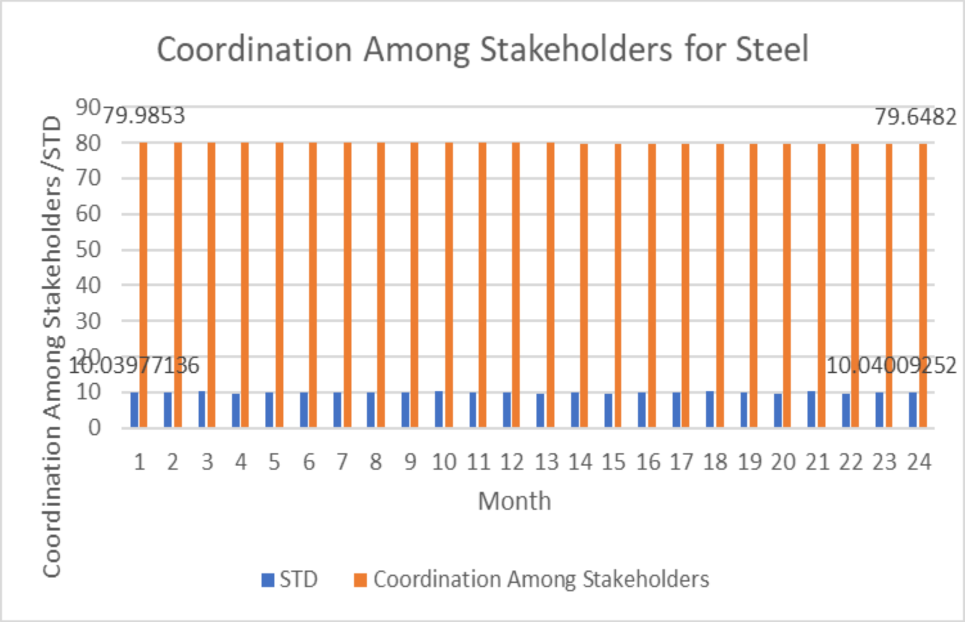

Figure 4.19 Validation of Coordination among Stakeholders for Steel

Validation of SPI

Timber

The analysis of the SPI for timber reveals a consistent upward trend across the 24-month period. Starting at 0.0018 in month 1 and progressively increasing to 0.0442 in month 24, the SPI values indicate steady improvements over time. This growth signifies that the use of timber in the analyzed context contributes to enhanced schedule performance. The consistent increase demonstrates a positive trajectory, with no significant fluctuations or declines, reflecting strong reliability in schedule adherence when using timber.

In terms of sensitivity analysis in Figure 4.20, the STD values also exhibit a gradual increase, beginning at 0.0018 in month 1 and reaching 0.0054 by month 24. Despite this incremental rise, STD values remain relatively low throughout the analysis period, indicating that the results for SPI are stable. The controlled variability suggests that the improvements in SPI are not heavily influenced by external factors, affirming the robustness of the outcomes. Thus, the sensitivity analysis supports the conclusion that timber contributes to both reliable and consistent schedule performance improvements over time.

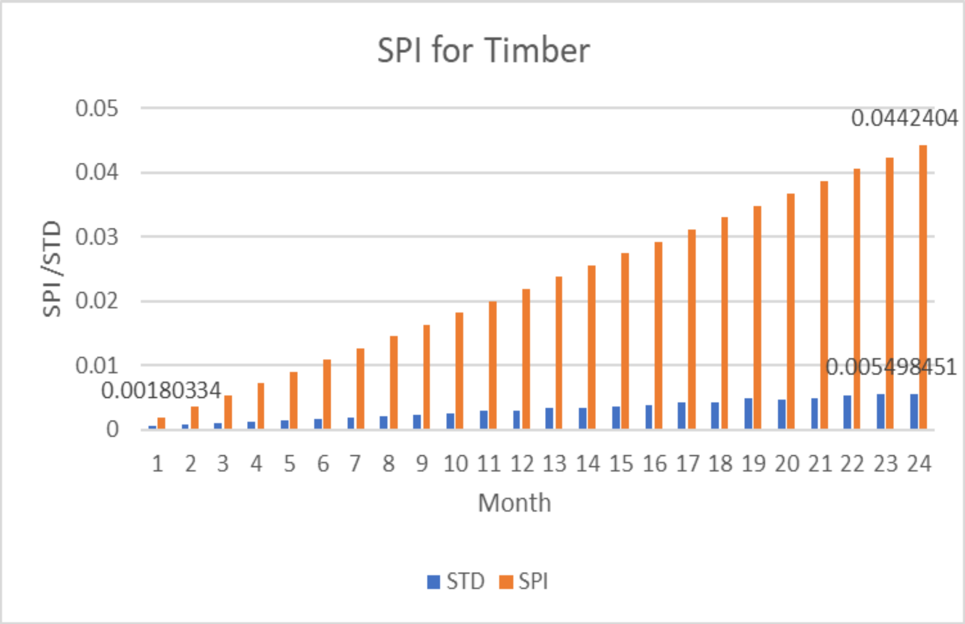

Figure 4.20 Validation of SPI for Timber

Concrete

Figure 4.21 illustrates the analysis of the SPI for concrete indicates a consistent decline over the 24-month period. Starting at -0.00025 in month 1, the SPI progressively decreases to -0.00805 by month 24. This consistent downward trend signifies that the schedule performance using concrete is not optimal. The decline implies increasing delays or inefficiencies in the schedule, highlighting a negative impact of using concrete on project timeline adherence.

For sensitivity analysis, the STD values for SPI increased steadily from 0.00037 in month 1 to 0.0043 in month 24. While the STD values indicate growing variability over time, the overall increase remains relatively controlled. This suggests that the observed decline in SPI is reliable and consistent, with minimal influence from external fluctuations. The sensitivity analysis confirms that the results are stable, further validating the conclusion that using concrete has a detrimental effect on schedule performance.

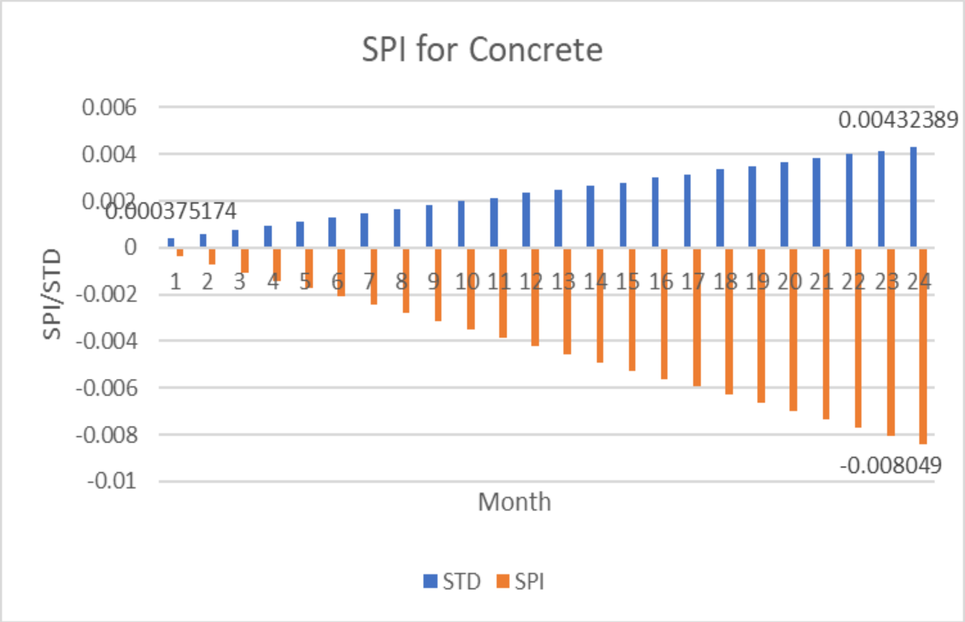

Figure 4.21 Validation of SPI for Concrete

Steel

The analysis of the SPI for steel reveals a consistent negative trend over the 24-month period in Figure 4.22. Starting at -0.00035 in month 1 and gradually decreasing to -0.00842 by month 24, the SPI values indicate a steady decline in schedule performance. This downward trajectory suggests that the use of steel may lead to schedule inefficiencies, potentially caused by factors such as longer lead times, complex fabrication processes, or dependencies on external tasks like welding and assembly. While the trend highlights performance challenges, it remains linear and predictable, implying that delays are systematic rather than random, providing planners with the opportunity to forecast and address potential issues proactively.

In terms of sensitivity analysis, the Standard Deviation (STD) values also exhibit a gradual increase, starting at 0.00038 in month 1 and reaching 0.00435 by month 24. Despite this increase, the STD values suggest that variations in SPI are stable and controlled. This stability reinforces the notion that the schedule performance issues associated with steel are consistent and predictable, enabling mitigation strategies to be developed effectively.

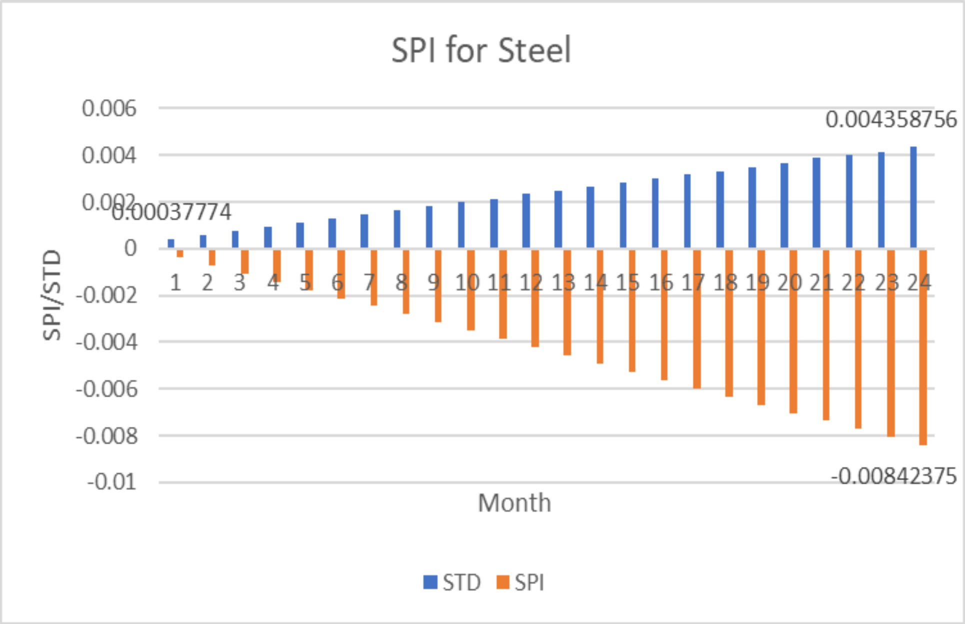

Figure 4.22 Validation of SPI for Steel

CPI

Timber

The analysis of the CPI for timber reveals a steady upward trend throughout the 24-month period. Based on the analysis in Figure 4.23, starting at 1.22402E-09 in month 1 and increasing consistently to 3.00214E-08 by month 24, the CPI values indicate continuous improvements in cost efficiency over time. This growth suggests that the use of timber contributes to cost-effective project management, likely due to its ease of assembly, lightweight properties, and sustainable sourcing options. The positive trajectory of CPI values highlights reliable cost performance, making timber an economically viable material for construction projects. This consistent improvement underscores its suitability for projects with tight budgets and cost-efficiency requirements.

In terms of sensitivity analysis, the STD values also show a gradual increase, starting at 3.6977E-10 in month 1 and reaching 3.88893E-09 by month 24. While this rise suggests increasing variability over time, the absolute values remain very low, indicating that the cost performance metrics are stable and not significantly influenced by external factors. The low variability reinforces confidence in the predictability of timber's cost performance, supporting its robustness and reliability in construction projects.

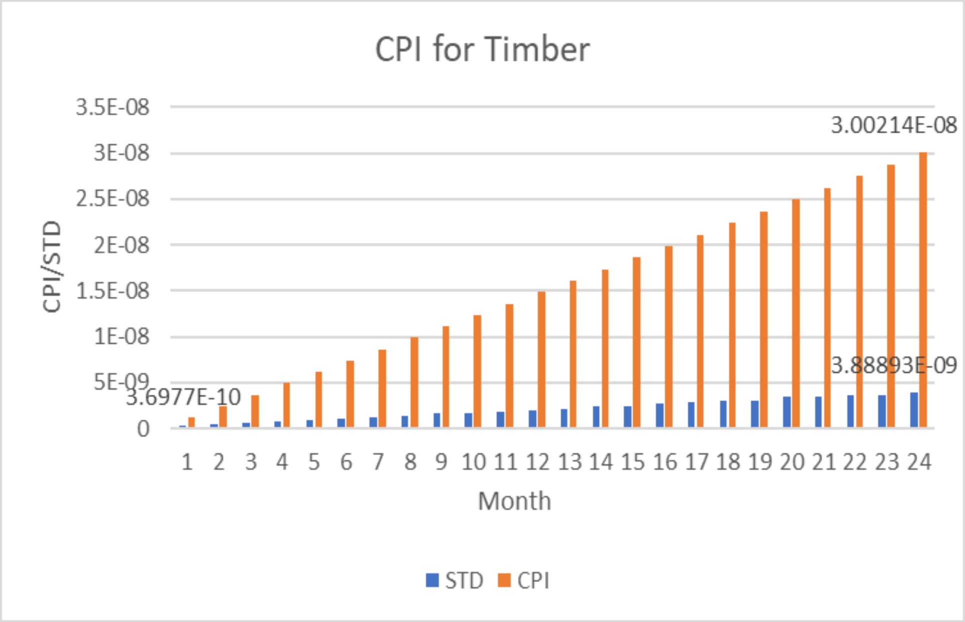

Figure 4.23 Validation of CPI for Timber

Concrete

The analysis of the CPI for concrete reveals a steady downward trend over the 24-month period. As summarized in Figure 4.24, starting at -2.80687E-10 in month 1 and decreasing to -6.71113E-09 by month 24, the CPI values suggest consistent cost inefficiencies throughout the timeline. This negative trajectory implies that the use of concrete in the analyzed context may be associated with higher costs or overruns, potentially due to factors such as material handling complexity, curing time requirements, and labor-intensive processes. The continuous decline highlights challenges in maintaining cost efficiency, which may necessitate improved planning strategies or process optimizations to enhance economic performance when using concrete.

In terms of sensitivity analysis, the STD values exhibit a gradual increase, starting at 3.01899E-10 in month 1 and reaching 3.44367E-09 by month 24. While this increase in variability reflects growing uncertainties over time, the absolute values remain relatively low, indicating that the cost inefficiencies are stable and predictable rather than erratic. This controlled variability suggests that external factors influencing CPI performance are manageable, but the consistent decline in CPI values highlights an ongoing need for cost control measures to mitigate long-term budget risks.

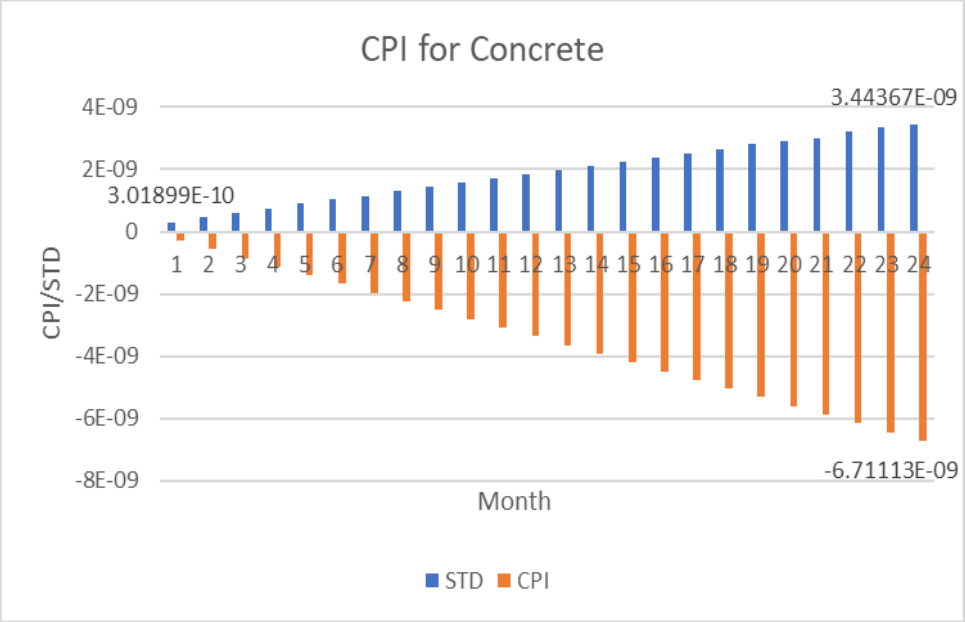

Figure 4.24 Validation of CPI for Concrete

Steel

The CPI for steel in Figure 4.25 shows a consistent downward trend over the 24-month period, starting at -2.81451E-10 in month 1 and decreasing to -6.72933E-09 by month 24. This negative trajectory indicates a steady decline in cost performance, suggesting increasing deviations from the planned budget over time. The results highlight a persistent pattern of cost inefficiency, requiring closer examination of contributing factors.

The STD values for steel exhibit a gradual increase, beginning at 2.97895E-10 in month 1 and reaching 3.47246E-09 by month 24. This steady rise in variability indicates growing fluctuations in cost performance measurements. Despite the increase, the incremental pattern suggests that the deviations are relatively stable rather than abrupt.

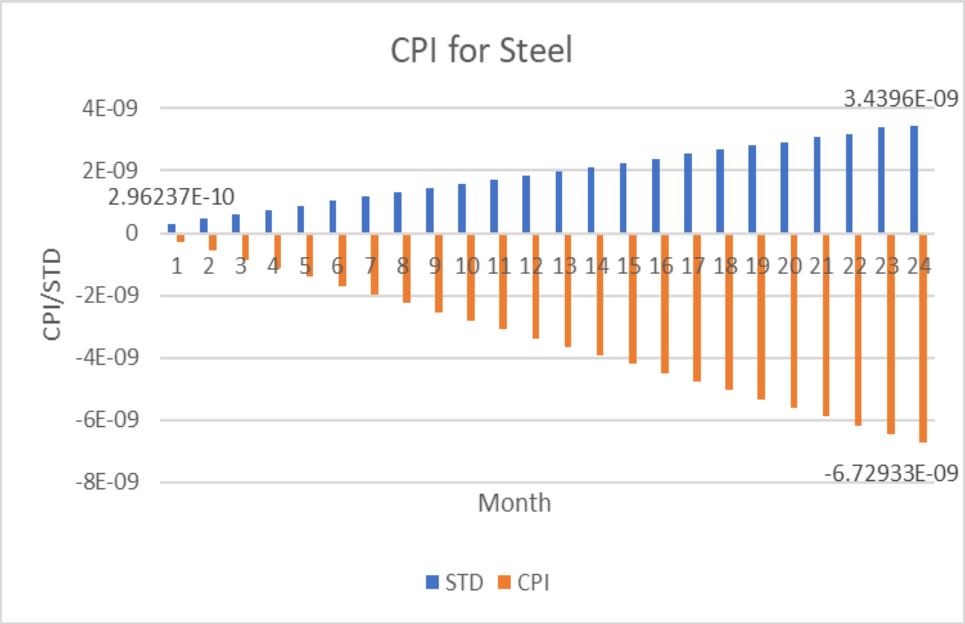

Figure 4.25 Validation of CPI for Steel

Validation of Saving

Timber

The Saving data for timber demonstrates a steady upward trend over the 24-month period, starting near zero in month 1 and reaching approximately 0.0189 by month 24 in Figure 4.26. This continuous increase suggests improving savings over time, potentially indicating more efficient cost management or reduced expenses related to timber usage as the timeline progresses.

The STD values for timber remain consistently low throughout the 24 months, with a slight increase reaching around 0.0023 by month 24. This pattern highlights stable and predictable improvements in cost efficiency.

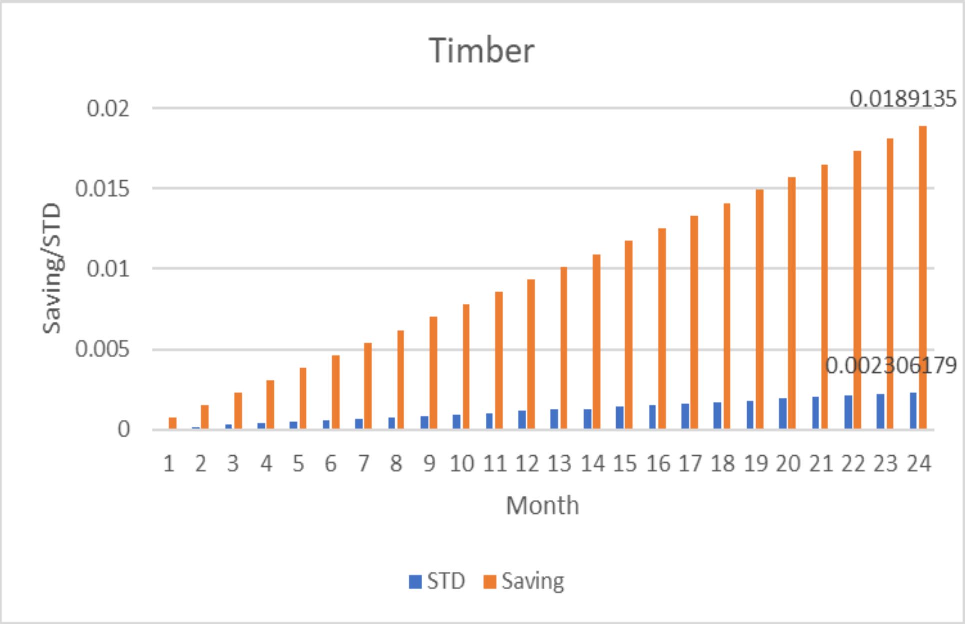

Figure 4.26 Validation of Saving for Timber

Concrete

The Saving data for concrete shows a consistent downward trend, starting close to zero in month 1 and declining to approximately -0.0042 by month 24 in Figure 4.27. This indicates increasing losses over time, suggesting inefficient cost management or rising expenses related to concrete usage as the timeline progresses.

In contrast, the STD values for concrete exhibit a steady upward trend, reaching approximately 0.0021 by month 24. This pattern reflects predictable and stable results.

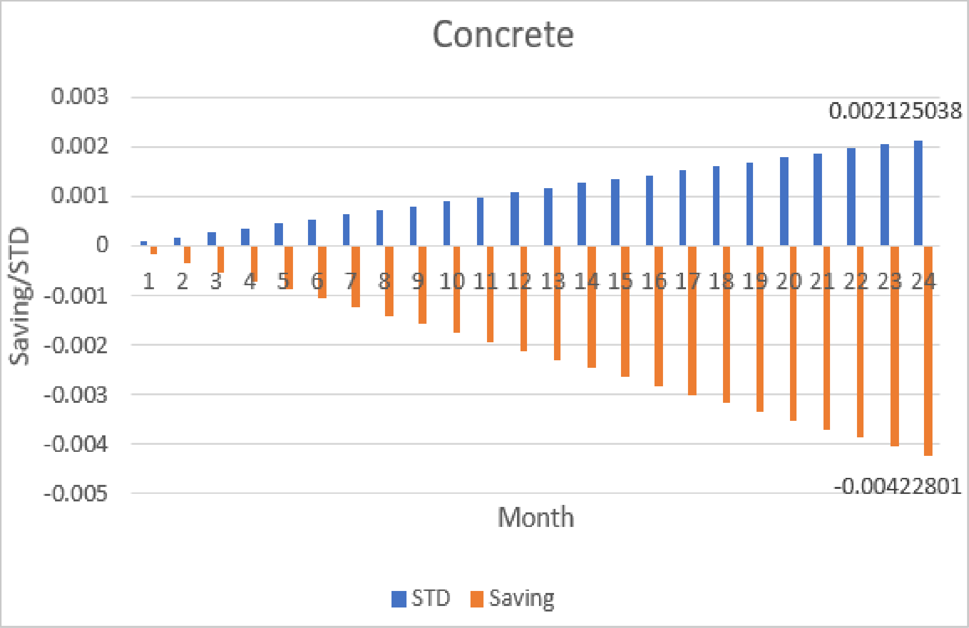

Figure 4.27 Validation of Saving for Concrete

Steel

The Saving data for steel exhibits a steady decline, starting near zero in month 1 and reaching approximately -0.0042 by month 24. This downward trend in Figure 4.28 indicates growing losses over time, reflecting cost inefficiencies or increasing expenses associated with steel usage as the timeline progresses.

Conversely, the std values for steel show a gradual increase, peaking at approximately 0.0021 by month 24. This steady rise in variability indicates growing fluctuations in Saving. Despite the increase, the incremental pattern suggests that the deviations are relatively stable rather than abrupt.

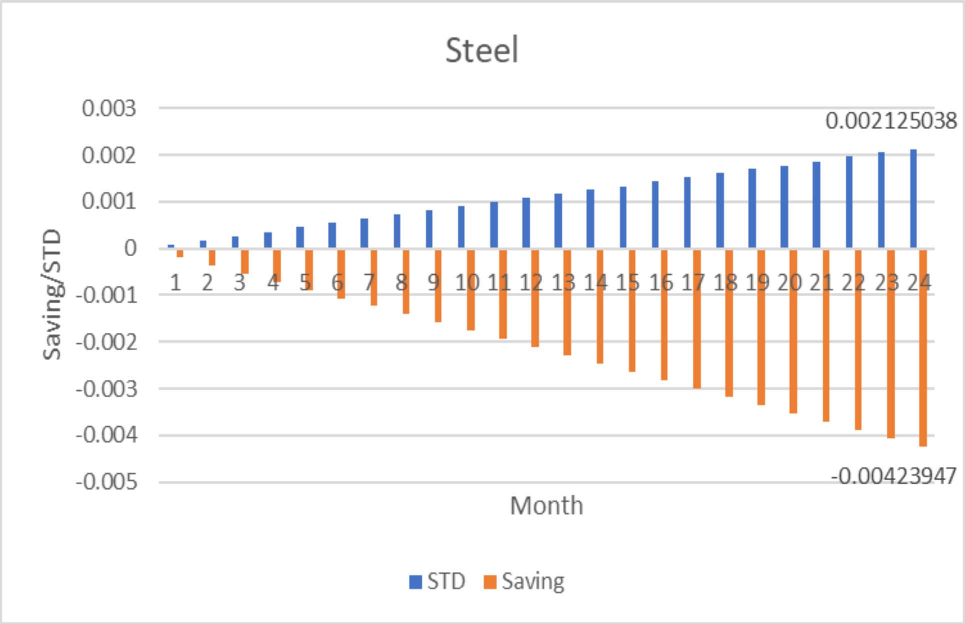

Figure 4.28 Validation of Saving for Steel

4.3 Conclusion

This research underscores the critical role of material selection in enhancing the sustainability and efficiency of healthcare construction projects designed for Indigenous communities. The system dynamics model illustrates that timber demonstrates superior performance compared to concrete and steel, particularly in minimizing material waste, improving energy efficiency, facilitating stakeholder collaboration, and optimizing cost and schedule management. The results indicate that a circular-shaped, south-oriented building with a 0.4 window-to-wall ratio, constructed primarily with timber, aligns with Indigenous cultural and social preferences while remaining economically viable. By integrating these considerations into the construction framework, this study highlights the necessity of culturally responsive infrastructure that supports long-term project effectiveness and sustainability.

In addition, the validation and sensitivity analysis confirm the reliability of the model, demonstrating its applicability across different scenarios. Monte Carlo simulations further support the conclusion that timber remains a stable and practical choice under varying project conditions, reinforcing its potential for sustainable healthcare construction.

CHAPTER FIVE

CONCLUSION

5.0 Overview and Conclusions

Within construction management parameters, this thesis has examined how cultural and social elements play a crucial role in influencing the planning and execution of healthcare facilities for Indigenous populations. This study underscores the necessity of culturally sensitive approaches that prioritize community preferences, well-being, and inclusivity in healthcare infrastructures by stressing the incorporation of Indigenous viewpoints. The specific research objectives (in chapter 1) are re-visited in the following:

Objective 1: Social and cultural preferences will be defined through an effective technical approach tailored to Indigenous healthcare construction project managements.

Objective 2: System dynamics thinking effectively simulates the complexities of construction projects, addressing the interactions between cost, time, social and cultural variables.

Objective 3: The effectiveness of each social and cultural preference will be evaluated, and optimal conditions for each variable will inform policy development for stakeholders.

To achieve these objectives, the following research activities were conducted:

For Objective 1, a thorough literature review was carried out to identify and define social and cultural preferences relevant to Indigenous healthcare infrastructure. This analysis informed the selection of key technical elements such as circular layouts, natural lighting, and sustainable materials. Through this review, essential design principles that align with Indigenous values were identified and integrated into the study framework.

For Objective 2, a system dynamics (SD) model was developed using Vensim to simulate interactions between cost, time, and quality, incorporating Indigenous cultural preferences. The model's feedback loops and causal links provided insights into long-term decision-making and project sustainability. This approach allowed for an in-depth understanding of how different variables influence construction outcomes and how policies can be tailored to support culturally responsive design.

For Objective 3, sensitivity analysis and scenario testing were conducted to evaluate the effectiveness of different cultural and social design choices. The impact of design parameters such as windows-to-wall ratio, building orientation, and material type on cost and time was analyzed to optimize policies for stakeholders. These analyses provided a data-driven foundation for decision-making in Indigenous healthcare construction projects.

The results of the study demonstrated that culturally aligned technical choices enhance project sustainability and financial viability. The iterative validation of the SD model proved its reliability in predicting construction project outcomes and trade-offs. Ultimately, this research provides a structured approach to integrating Indigenous perspectives into healthcare infrastructure planning, supporting long-term policy development.

5.1 Contributions

This study contributes to the broader discourse on Indigenous healthcare infrastructures by providing an evidence-based framework for policymakers, engineers, and stakeholders to design and implement culturally sensitive projects. The findings underscore the necessity of early engagement with Indigenous communities, emphasizing the value of participatory design processes that ensure alignment with community preferences, traditions, and social dynamics. The contributions address the following objectives:

For Objective 1, social and cultural preferences will be defined through an effective technical approach tailored to Indigenous healthcare construction project managements. Early and ongoing consultations with Indigenous communities throughout the project lifecycle for understanding their requirements and preference are essential. This includes participatory workshops, focus groups, and collaboration on decision-making processes to ensure cultural relevance and inclusiveness.

For Objective 2, system dynamics thinking effectively simulates the complexities of construction projects, addressing the interactions between cost, time, social, and cultural variables. Financial incentives or tax benefits promote the use of sustainable materials, such as timber, which demonstrates superior performance in cost, energy efficiency, and cultural alignment. Building codes and regulations incorporate standards that encourage circular layouts and designs reflecting Indigenous cultural preferences. Healthcare facilities adhere to design standards that optimize natural light exposure by increasing window-to-wall ratios and orienting buildings southward, especially in cold climates. Beyond reducing energy consumption for artificial lighting, maximizing natural light aligns with Indigenous cultural preferences for connecting with nature and has been shown to improve patient well-being and recovery rates. Incentives are offered for designs that achieve optimal daylighting while meeting energy efficiency goals.

For Objective 3, the effectiveness of each social and cultural preference will be evaluated, and optimal conditions for each variable will inform policy development for stakeholders. Initiatives focus on training construction stakeholders, including engineers, architects, and project managers, in culturally sensitive design practices. Workshops and certifications on Indigenous knowledge systems and sustainable construction methodologies bridge knowledge gaps and foster respect. Establishing policies that mandate post-occupancy evaluations to assess the long-term success of healthcare facilities is critical. Suggested optimal conditions for design include using timber for construction, increasing window sizes to enhance natural light, orienting buildings southward for better sunlight exposure, and adopting circular shapes in design to reflect Indigenous cultural preferences and improve spatial efficiency.

5.2 Limitations and Future Work

Despite its contributions, this study faced certain limitations. The reliance on secondary data posed constraints in terms of accuracy and comprehensiveness, potentially limiting the cultural precision of the model. Defining technical coefficients for circular building designs was particularly challenging due to limited data availability. Furthermore, the lack of primary data collection from Indigenous communities and Canadian construction stakeholders restricted the study’s ability to incorporate nuanced cultural and social preferences.

Future studies should prioritize collecting primary data directly from Indigenous communities and Canadian construction stakeholders through interviews, surveys, and participatory workshops. This approach will provide deeper insights into cultural preferences and validate model assumptions. Efforts should also focus on developing robust methodologies for calculating technical coefficients associated with circular building designs. Integrating climate resilience, energy efficiency, and adaptive reuse of materials into the model can further enhance its relevance.

By bridging engineering methodologies with cultural insights, this study offers a scalable framework that can be adapted for other marginalized communities globally. It establishes a foundation for fostering equitable access to high-quality healthcare services through sustainable and culturally respectful infrastructure. The findings contribute to broader discussions on equity, sustainability, and innovation in engineering practices, advocating for an inclusive and collaborative approach to infrastructure development.

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APPENDIX A – SYSTEMS DYNAMICS MODEL EQUATIONS

$$1 - Building\ Performance$$

$$= 0.8 * \left(\frac{163.2}{126.95}\right) * \left(\left(\left(\frac{4}{5}\right) + \left(\frac{3.5}{5}\right) + \left(\frac{3.2}{5}\right) + \left(\frac{2.9}{5}\right) + \left(\frac{2.5}{5}\right) + \left(\frac{2}{5}\right)\right)\right.$$

$$\left. - \left(\left(\frac{2.2}{5}\right) + \left(\frac{2.1}{5}\right) + \left(\frac{1.2}{5}\right)\right)\right)/13)$$

$$2 - Window\ to\ Wall\ Ratio = 0.57 * (0.4 + (0.1 * Building\ Performance))$$

$$3 - Building\ Orientation$$

$$= 0.68 * ((0.27 * -(cos(angle)) * Window\ to\ wall\ Ratio)$$

$$+ (0.2 * Building\ performance))$$

$$4 - Material\ type = 0.95 * IF\ THEN\ ELSE(Timber > 0 : OR : 0$$

$$> Timber, (((Building\ performance - 0.4) * Timber) + (Timber$$

$$* Windows\ to\ wall\ Ratio))\ , IF\ THEN\ ELSE(Concerte > 0 : OR : 0$$

$$> Concerte, (((Building\ performance - 0.4) * Concerte)$$

$$+ (Windows\ to\ wall\ Ratio * Concerte\ ))\ , IF\ THEN\ ELSE(Steel > 0 : OR : 0$$

$$> Steel, (((Building\ performance - 0.4) * Steel) + (Steel$$

$$* Windows\ to\ wall\ Ratio))\ , 0\ )))$$

$$5 - Timber = \ (5.1/2.56) * (((47.96/25)/(25.55/10))/((39.9/25)/(34.3/10))) * (165.23/145.66)$$

$$6 - Concrete = \ -(5.1/5.22) * (((47.96/25)/(25.55/10))/((39.29/25)/(20.76/10)))$$

$$* (165.23/160.49)$$

$$7 - Steel = \ -(5.1/5.1) * (((47.96/25)/(25.55/10))/((47.96/25)/(25.55/10)))$$

$$* (165.23/165.23)$$

APPENDIX B – RESULTS

1 - Outputs of the SD model in Vensim software