



Research Article

# A Cost–Benefit Analysis of Importing Complete Prefabricated Steel Structure Buildings from China to New Zealand

Kang Li<sup>1,\*</sup>, Ting Jing<sup>2</sup>

<sup>1</sup>Hangzhou Kenli Building Data Technology Co., Ltd., Hangzhou, Zhejiang province 311121, China

<sup>2</sup>Hangzhou TongMSK Engineering Design Co.,Ltd., Hangzhou, Zhejiang province 311200, China

\*Corresponding author: [ken.li@klsurveyor.com](mailto:ken.li@klsurveyor.com); Tel.: +86-0571-87090826; Fax: +86-0571-87090826

**Abstract:** The domestic construction industry in New Zealand has long been challenged by persistent material shortages and elevated construction costs. In contrast, prefabricated steel structure buildings from China—backed by substantial technological accumulation, mature industrial scale, and strong innovation capacity—have demonstrated clear competitive advantages in the global construction market. This has created strong strategic demand and structural opportunities for New Zealand to import such buildings. However, as prefabricated steel structure construction is a relatively emerging technology—particularly in the context of cross-border importation—there remains a notable lack of comprehensive research on its cost and benefit profiles, with even fewer empirical studies examining international import scenarios. To address this gap, this study integrates a whole-process cost–benefit analysis model with the grey relational degree method to evaluate and compare three construction approaches in New Zealand: (1) fully imported prefabricated steel structure buildings from China, (2) locally sourced and produced construction materials, and (3) traditional on-site concrete casting. The analysis systematically examines four key phases—design, production, transportation, and installation—and quantifies the synergistic effects of economic, environmental, and social benefits across these dimensions. The findings reveal that fully importing prefabricated steel structure buildings from China yields the lowest overall costs and delivers the most significant composite benefits, making it the most cost-effective and sustainable construction solution under the assessed conditions. This study provides valuable insights for overcoming supply-chain challenges in New Zealand’s construction sector and contributes to the broader discourse on global green building development and sustainable construction practices.

**Keywords:** Cost-Benefit calculation; Grey relational analysis; Prefabricated steel structure construction; Scheme comparison

## 1. Introduction

New Zealand confronts a severe housing shortage, exacerbated by rising demand for medium-density dwellings such as townhouses and apartments (Schindler, 2024; Shahzad et al., 2022). Systemic constraints within the construction sector—including supply chain inefficiencies and a documented skilled labor deficit of 30,000–50,000 workers—severely limit the capacity of conventional construction methods to meet this demand (Doan et al., 2021; Brown et al., 2020; Ongley, 2013). These challenges are further intensified by rising construction costs and project delays, creating a critical need for innovative building solutions. In this context, prefabricated steel structures have gained global prominence as a transformative approach, offering accelerated construction timelines, enhanced quality control through factory production, and reduced reliance on on-site labor (Gil-ozoudeh, 2024; Adeyemi et al., 2024).

Although prefabrication is still an emerging practice in New Zealand, recent policy shifts indicate growing governmental support (H. Chen and Samarasinghe, 2020). The 2024 amendments

to the Building Act, which recognize international material standards and streamline import procedures, aim to facilitate the adoption of off-site manufacturing technologies. Concurrently, China's prefabricated steel industry has achieved global competitiveness through technological advancement and economies of scale (Atkinson, 2024). However, the decision to adopt imported prefabricated systems often relies on subjective judgments or simplistic cost comparisons, overlooking broader performance criteria. A multi-faceted evaluation framework is therefore essential to objectively assess their viability (Chauhan et al., 2024).

Previous research on prefabricated structures has primarily followed four trajectories: (1) Cost analysis, focusing on factors influencing project economics and optimization models. Elhag et al., 2005 examined determinants of prefabrication costs (e.g., project design and segmentation), W. Chen et al., 2021 developed a cost optimization model for precast concrete panels, Ma'ruf et al., 2024 proposed a machine learning-based intelligent approach for design cost estimation through the identification of assembly features in 3D CAD models. (2) Benefit assessment, highlighting advantages such as waste reduction, shorter construction periods, etc. Yet, Balasbaneh et al., 2024 noted significant gaps in understanding the socioeconomic impacts of steel prefabrication. Sunindijo et al., 2023 demonstrate that prefabricated construction technology significantly enhances health and safety performance in Australian residential projects, highlighting its short-term benefits through reduced on-site labor duration and long-term advantages by minimizing manual handling, thereby improving workers' health outcomes. (3) Integrated cost-benefit analysis, employing life-cycle assessment (LCA) and life-cycle costing (LCC) to evaluate environmental and economic impacts. Cheng et al., 2023 employed a LCA methodology to analyze the environmental impacts and optimization potential of prefabricated components, integrating an LCA-based LCC approach to evaluate associated social and economic costs. J. Liu et al., 2025 integrated LCA, LCC, and carbon finance to evaluate steel structures holistically. (4) Multi-criteria decision-making, utilizing methods like grey relational analysis (GRA) to compare alternatives. S. Wang et al., 2023 used fuzzy grey relational analysis (GRA) method to evaluate prefabricated schemes, and the results demonstrated the method's broad applicability, while also offering a practical and sound reference for all stakeholders involved in prefabricated building scheme comparisons. C. H. Chen and Li, 2024 employed the GRA-TOPSIS methodology to evaluate and rank the weights and relative importance of cost-influencing factors in prefabricated residential buildings, and it provided a decision-making framework for optimizing and controlling costs in prefabricated housing projects.

Despite these contributions, significant gaps remain. First, existing studies seldom provide a holistic evaluation that simultaneously incorporates economic, environmental, and social dimensions—particularly concerning the importation of prefabricated systems into specific regulatory and geographic contexts like New Zealand. Second, no established model currently evaluates the cost-benefit implications of integrating Chinese prefabricated steel structures into New Zealand's built environment. To address these gaps, this study aims to address the following core research question: How do the whole-process costs and sustainability performance of imported prefabricated steel structures compare with those of locally produced prefabricated buildings and conventional construction systems in New Zealand? Therefore, this study develops an integrated analytical framework that combines whole-process cost-benefit analysis with grey relational analysis. The proposed framework is applied to a case study of a residential project in New Zealand, demonstrating its utility in quantifying net present value (NPV), payback periods, and sustainability metrics. Verification via GRA ensures a coherent ranking of alternatives based on both quantitative and qualitative criteria. By integrating architectural considerations—such as modular design flexibility, compliance with New Zealand's seismic standards—this study provides a comprehensive tool for developers, policymakers, and researchers seeking to advance sustainable construction practices.

## 2. Cost–Benefit Analysis Methodological Framework

To enable a comparative cost-benefit analysis, this study evaluates three distinct construction approaches: fully prefabricated steel structures imported from China (Scheme 1), localized material procurement and assembly (Scheme 2), and traditional cast-in-place concrete construction (Scheme 3). The selection aligns with prevalent international engineering collaboration models while addressing the specificities of the New Zealand market.

Scheme 1 serves as an offshore manufacturing benchmark, examining the technical feasibility of industrialized building systems via long-distance supply chains. Scheme 2 adopts a hybrid model (“international standard introduction + local implementation”) to assess the economic compatibility of Chinese GB 50017 and New Zealand NZS 3404 standards, particularly in seismic parameters and node detailing. Scheme 3 provides a baseline for traditional construction, facilitating quantification of prefabrication’s comparative advantages.

### 2.1 Constructability and Quality Analysis

#### 2.1.1 Constructability Analysis

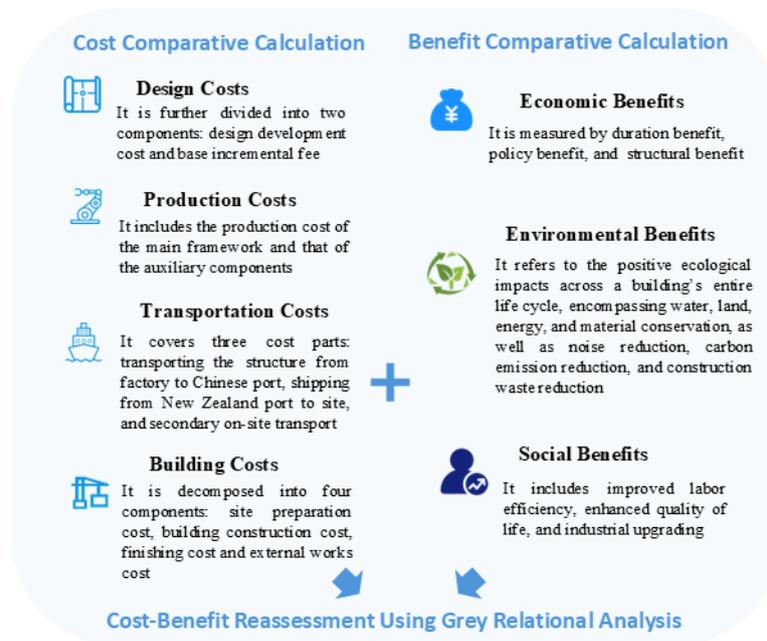
Prefabricated steel structures manufactured in China are typically designed in compliance with international standards (e.g., ISO, AISC) and can be customized to meet specific national building codes, such as New Zealand’s NZS 3404 Steel Structures Standard and the New Zealand Building Code. Key differences in seismic design requirements, connection details, and architectural preferences are thoroughly considered during the preliminary design phase. This proactive approach facilitates the early identification and resolution of potential constructability issues prior to manufacturing, ensuring that the final design is both compliant and practical for the local context. The principle of “fewer specifications, more combinations” is often adopted in the standardized design of components to enhance production efficiency and quality.

#### 2.1.2 Quality Assurance and Construction Efficiency

Chinese manufacturers serving the international market generally hold stringent international quality certifications (e.g., ISO 9001) and adhere to equivalent standards such as ASTM and AISC. The entire production process—from material procurement and fabrication to pre-assembly—is governed by rigorous Quality Control (QC) and Quality Assurance (QA) protocols. This ensures engineering design and production meet high standards of reliability and durability.

The Scheme 1 approach, which involves transporting fully assembled or large modular sections, fundamentally shifts the nature of on-site work in New Zealand to primarily assembly tasks. This methodology significantly reduces the on-site demand for skilled labor for activities such as cutting, welding, and fitting. This offers a distinct advantage in New Zealand, a market that frequently experiences shortages of skilled construction labor, by accelerating project timelines and mitigating risks associated with variable on-site workmanship.

Generally, the overall methodology comprises three main components, as illustrated in Figure 1 Cost Comparative Calculation (Equations 1–5), Benefit Comparative Calculation (Equations 6–14), and Cost–Benefit Reassessment Using Grey Relational Analysis (Equations 15–22).



**Figure 1** Technical methodology of the whole-process cost–benefit model

In the cost module, the total cost is categorized into four components corresponding to distinct project phases: design, production, transportation, and building. Each cost component is formulated by aggregating sub-items associated with specific project modules (e.g., main structure, finishing works). Finally, in accordance with conventional practice, the lifecycle cost is discounted to its present value. Within the benefit module, drawing on relevant literature, benefits are classified into economic benefits, environmental benefits, and social benefits. The underlying logic of each formula involves applying appropriate conversion coefficients to quantify these benefits. Similarly, following standard practice, the lifecycle benefits are discounted to their present value.

## 2.2 Cost Comparative Calculation Models Construction

According to previous research (L. Liu et al., 2025; Almashaqbeh and El-Rayes, 2022; Lou and Guo, 2020), The total cost of the building production and construction process is typically decomposed into four key components: (1) design costs ( $C_d$ ), (2) production costs ( $C_p$ ), (3) transportation costs ( $C_t$ ), and (4) building costs ( $C_b$ ). The whole-process Cost ( $LCC$ ) is calculated as Equation 1 below.

$$LCC = C_d + C_p + C_t + C_b \quad (1)$$

### 2.2.1 Design Costs

In Scheme 1, the design process is primarily managed by a local New Zealand-based agent. As shown in Equation 2, the associated design cost is typically calculated as a proportion of the overall production and construction expenses and is further divided into two components: (1) design development cost ( $C_{d1}$ ) and (2) base incremental fee ( $C_{d2}$ ).

$$C_d = C_{d1} + C_{d2} \quad (2)$$

Table 1 presents a comparative analysis of design costs across the three schemes. Notably, Scheme 1 demonstrates cost advantages through the use of localized design packages in New Zealand, which eliminate certification fees, reduce communication expenses, and minimize associated taxes. This results in a clear cost hierarchy where  $\alpha > \beta > \gamma$ .

**Table 1** Comparison of design costs across the three schemes.

Item	Scheme 1	Scheme 2	Scheme 3
Design Development Cost $C_{d1}$	$\alpha_1 C_{\text{main}} + \alpha_2 C_{\text{support}} + \alpha_3 C_{\text{in}}$ Where the proportions are: $\alpha = 5\%, 4\%, 2\%, 1\%$ , and $3\%$ respectively (due to standardized design by NZ design firms, localized adaptation, and lower markup rates)	$\beta_1 C_{\text{main}} + \beta_2 C_{\text{support}} + \beta_3 C_{\text{in}}$ Where the proportions are: $\beta = 8\%, 5\%, 3\%, 2\%$ , and $4\%$ respectively (due to the need for differentiated design, leading to higher markups for the main structure and client communication)	$\gamma_1 C_{\text{main}} + \gamma_2 C_{\text{support}} + \gamma_3 C_{\text{install}}$ Where the proportions are: $\gamma = 9\%, 6\%, 3\%, 2\%$ , and $4\%$ respectively (due to the need for differentiated design and being a concrete structure, leading to higher markups for the main structure and client communication)
Base Incremental Fee $C_{d2}$	Firm design costs, drawing review fees, etc.	Firm design costs, drawing review fees, etc.	Firm design costs, drawing review fees, additional structural reinforcement costs, etc.

### 2.2.2 Production Costs

The primary structural framework and auxiliary components of the building are decomposed to quantify their production costs, comprising the production cost of the main framework ( $C_{p1}$ ) and that of the auxiliary components ( $C_{p2}$ ). The total production costs are expressed as Equation 3:

$$C_p = C_{p1} + C_{p2} \quad (3)$$

As illustrated in Table 2, a comparative analysis of production costs across the three schemes is presented. The primary cost differentials among these models predominantly stem from variations in raw material costs, labor efficiency, and equipment costs. Generally, China demonstrates lower raw material and equipment costs compared to New Zealand. Furthermore, Scheme 1 achieves concentrated equipment cost savings through large-scale production via self-owned facilities.

**Table 2** Comparison of production costs across the three schemes.

Item	Calculation Formula	Scheme 1	Scheme 2	Scheme 3
Production Cost of Main Framework $C_{p1}$	$C_{\text{foundation}} + C_{\text{structural shell}} + C_{\text{st}}$	Where material costs incorporate New Zealand's import prices and tariffs; labor efficiency is 1.2 times the New Zealand standard;	Where material costs are local market procurement prices; labor efficiency meets New Zealand standard;	Where material costs are based on local prices for sand, gravel, and cement—typically higher than average; labor efficiency meets New Zealand standard;
Production Cost of Auxiliary Components $C_{p2}$	$C_{\text{foundation}} + C_{\text{structural shell}} + C_{\text{st}}$	and equipment depreciation accounts for self-contained machinery	equipment is locally rented.	equipment is concrete-specific equipment.

### 2.2.3 Transportation Costs

The primary mode of transporting prefabricated steel structure buildings imported from China is by sea. Accordingly, the transportation costs for Scheme 1 can be divided into three parts: (1)  $C_{t1}$ , the cost of loading and transporting the main structure and associated components from the manufacturing facility to the Chinese port; (2)  $C_{t2}$ , the cost of shipping the goods from the New Zealand port of discharge to the construction site; and (3)  $C_{t3}$ , the cost of secondary transportation within the construction site. The basic formula for calculating transportation costs is therefore as Equation 4:

$$C_t = C_{t1} + C_{t2} + C_{t3} \quad (4)$$

The comparison of transportation costs among the three schemes is presented in Table 3. For the other two schemes, the main transportation expense consists of local delivery within New Zealand. Generally, Scheme 3 outperforms Scheme 2 owing to standardized steel components, modular assembly flexibility, efficient loading/unloading operations, and superior road adaptability of prefabricated structures.

**Table 3** Comparison of transportation costs for three schemes.

Item	Scheme 1	Scheme 2	Scheme 3
Transportation Cost in China $C_{\tau 1}$	$d_{distance1} \times p_{freight\ rate1}$		
Import Cost $C_{\tau 2}$	$P_{customs\ fee} + d_{distance2}$		
Transportation Cost in New Zealand $C_{\tau 3}$	$d_{distance3} \times p_{freight\ rate3}$	$d_{distance4} \times p_{raw\ material\ freight\ rate4} + d_{distance5} \times p_{post-production\ freight\ rate5}$	$d_{distance6} \times p_{gravel,cement\ freight\ rate6} + d_{distance7} \times p_{mixer\ truck\ transportation\ cost}$

### 2.2.4 Building Costs

The construction process is divided into distinct phases, enabling the building costs  $C_b$  to be decomposed into four components, shown in Equation 5 site preparation cost  $C_{b1}$ , building construction cost  $C_{b2}$  (including structural, curtain wall, and roofing works), finishing cost  $C_{b3}$ , and external works cost  $C_{b4}$ :

$$C_b = C_{b1} + C_{b2} + C_{b3} + C_{b4} \quad (5)$$

A comparative analysis of the building costs for the three schemes is presented in Table 4. Scheme 1 primarily adopts an integrated installation approach, leading to substantial savings in site preparation, building construction, finishing works, and external works costs. In contrast, Scheme 3, which utilizes cast-in-place concrete construction, incurs the highest building construction costs among the three schemes.

## 2.3 Benefit Calculation Model Construction

Benefits are generally classified into two categories (Shen et al., 2019). Direct benefits, quantifiable in monetary terms, encompass aspects such as design and transportation costs (already incorporated into the cost model). Indirect benefits, which are difficult to quantify, span economic, environmental, and social dimensions throughout a building's life cycle, exerting sustained impacts on engineering projects (H. J. Wang, 2019). This section focuses on calculating the latter. Drawing upon the three major dimensions of sustainability (economic, environmental, and social) as delineated by Sarkar et al., 2023, this study constructs the Whole-Process

Benefit (LCE) Calculation Model, as formalized in Equation 6. Notably, this tripartite benefit framework aligns with the methodological considerations of prior seminal works (Li et al., 2014, S. Liu et al., 2022, Zhou et al., 2022), thereby ensuring theoretical consistency with established sustainability assessment paradigms in the field.

$$LCE = E_c + E_e + E_s \quad (6)$$

**Table 4** Comparison of building costs across three schemes.

Item	Scheme 1	Scheme 2	Scheme 3
Site Preparation Cost $C_{s1}$	$S_{site\ area1} \times (P_{land\ rent\ unit\ price} + P_{equipment\ rental}) \times T_{duration} + S_{other}$ Temporary storage of prefabricated components, site clearance, and component connections	$P_{equipment\ rental} \times T_{duration} + S_{site\ area2} \times P_{land\ rent\ unit\ price} + P_{temp\ utilities\ cost}$	$P_{equipment\ rental} \times T_{duration} + S_{site\ area2} \times P_{land\ rent\ unit\ price}$
Building Construction Cost $C_{b2}$	$(P_{crane\ rental1} + P_{skilled\ labor\ wage1}) \times T_{duration1}$ Integrated construction with lifting-only requirements	$(P_{crane\ rental1} + P_{skilled\ labor\ wage1}) \times T_{duration1} \times 1.2$ 20% additional building work	$(P_{crane\ rental1} + P_{skilled\ labor\ wage1}) \times T_{duration1} \times 1.24$ 24% additional building work
Finishing Cost $C_{b3}$	$(P_{crane\ rental2} + P_{skilled\ labor\ wage2}) \times T_{duration2}$ Interface treatment of prefabricated modules, localization adaptation, and detailed finishing	$(P_{crane\ rental2} + P_{skilled\ labor\ wage2}) \times T_{duration2} \times 2.15$ 2.15 times the additional finishing cost compared to Scheme 1's "fully furnished"	$(P_{crane\ rental2} + P_{skilled\ labor\ wage2}) \times T_{duration2} \times 2.15$ 2.15 times the additional finishing cost compared to Scheme 1's "fully furnished"
External Work Cost $C_{b4}$	$(P_{crane\ rental3} + P_{skilled\ labor\ wage3}) \times T_{duration3}$ Building of prefabricated landscaping elements	$(P_{crane\ rental3} + P_{skilled\ labor\ wage3}) \times T_{duration3} \times 1.05$ 5% additional building work compared to Scheme 1's "fully furnished"	$(P_{crane\ rental3} + P_{skilled\ labor\ wage3}) \times T_{duration3} \times 1.05$ 5% additional building work compared to Scheme 1's "fully furnished"

### 2.3.1 Economic Benefits

#### 1. Duration Benefits $E_{c1}$

Compared to cast-in-situ construction, prefabricated steel components are manufactured off-site in controlled factory environments, significantly reducing susceptibility to external environmental disruptions. This approach substantially shortens the construction period and yields considerable time-cost savings. Quantification can be achieved through Equation 7; Sales capital interest income  $E_{c11}$  and Rental income  $E_{c12}$ :

$$E_{c1} = E_{c11} + E_{c12} = \frac{\Delta d_1 k C'}{365} + \frac{\Delta d_1 R_0 M_0}{30} \quad (7)$$

Where:  $\Delta d_1$  is the construction duration reduction [days(d)],  $k$  is the annual interest rate during construction (%),  $C'$  is the construction financing/loan amount (NZD),  $R_0$  is the post-completion monthly rental income per  $m^2$  (NZD/ $m^2$ ),  $M_0$  is the total sales area ( $m^2$ ).

#### 2. Policy Benefits $E_{c2}$

Drawing on China's experience, governments have implemented a range of incentive policies to promote prefabricated construction, including tax and fee reductions, preferential land use

policies, expedited presale approvals, support for component transportation, and floor area incentives (Guo et al., 2025). Accordingly, with a focus on long-term sustainable development, this study assumes that the overall policy benefits are derived from a composite advantage resulting primarily from reduced construction duration and floor area incentives—the two most widely adopted measures, as given in Equation 8:

$$E_{c2} = E_{c21} + E_{c22} = \frac{\Delta d_2 k C'}{365} + (S_0 - B_0) M_0 \times \alpha \quad (8)$$

Where:  $\Delta d_1$  is the presale acceleration days due to policy incentives (d),  $S_0$  is the average building sales price (NZD/m<sup>2</sup>),  $B_0$  is the base land price (NZD/m<sup>2</sup>),  $\alpha$  is local government floor area bonus (%).

### 3. Structural Benefits $E_{c3}$

In residential buildings (typically high-wall-count structures), this increases effective usable area by approximately 4–8% compared to cast-in-situ systems. Structural benefits are calculated as Equation 9 below, where:  $\Delta\gamma$  is structural system-induced area utilization rate difference (%).

$$E_{c3} = \Delta\gamma S_0 \quad (9)$$

The economic benefits can be conceptualized as an aggregation of duration benefits, policy benefits, and structural benefits. Accounting for time value of money, the Discounted Net Present Value,  $NPV(E_c)$ , can be calculated as shown in Equation 10.

$$NPV(E_c) = NPV(E_{c1}) + NPV(E_{c2}) + NPV(E_{c3}) \quad (10)$$

### 2.3.2 Environmental Benefits

Environmental benefits refer to positive ecological impacts across a building's entire life cycle—from material production and construction to operation and end-of-life recycling. These benefits arise from specific technical features and construction methods, and manifest in multiple dimensions such as resource conservation, pollution reduction, ecological protection, and sustainable development.

Specifically, water conservation benefits  $E_{e1}$  are achieved through reduced construction-phase water consumption and optimized operational water utilization in prefabricated steel structures. Land conservation benefits  $E_{e2}$  include reduced land occupation, improved land-use efficiency, greater usable area, and longer service life. Energy conservation benefits  $E_{e3}$ , come from integrated insulation systems that improve thermal performance and reduce cracking risks. Material conservation benefits  $E_{e4}$  result from strict quality control and optimized material use in factory production. Compared to conventional methods, prefabricated steel structures reduce on-site particulate emissions by 5.04% (Aghasizadeh et al., 2022) and lower noise pollution by minimizing construction noise sources—contributing to dust and noise reduction benefits  $E_{e5}$ . Carbon emission reduction benefits  $E_{e6}$  cover the whole building life cycle, with 70–80% of emissions generated during operation. Construction waste reduction benefits  $E_{e7}$  are achieved through factory-based production, which significantly cuts on-site waste. Overall, the environmental advantages of prefabricated steel structures arise from the synergy of these elements, as captured in Equation 11.

$$E_e = E_{e1} + E_{e2} + E_{e3} + E_{e4} + E_{e5} + E_{e6} + E_{e7} \quad (11)$$

Accounting for the time value of money, the net present value of environmental benefits is calculated as Equation 12. This approach aims to quantify the economic value of environmental benefits over the whole process. It provides a comprehensive assessment of sustainable investment feasibility.

$$NPV(E_e) = NPV(E_{e1}) + NPV(E_{e2}) + NPV(E_{e3}) + NPV(E_{e4}) + NPV(E_{e5}) \quad (12)$$

$$+NPV(E_{e6}) + NPV(E_{e7}) = (E_{e1} + E_{e2} + E_{e3} + E_{e4} + E_{e5} + E_{e6}) \frac{(1+e)^{n-1}}{n(1+e)^n} + E_{e7}$$

Where:  $e$  is the discount rate reflecting time value of money (%),  $n$  is building lifespan (years), encompassing design, production, operation, and end-of-life recycling.

### 2.3.3 Social Benefits

The social benefits of prefabricated steel structures represent their broad positive effects on society across the whole building process, realized through industrialized construction methods. These include improved labor efficiency, enhanced quality of life, and industrial upgrading, as summarized in Equation 13. Specifically, Labor Efficiency Gains  $E_{s1}$  arise mainly from the combined use of factory prefabrication and on-site assembly, which lowers overall labor demand. Quality Enhancement  $E_{s2}$  comes from standardized factory production that ensures high precision and consistency in components, leading to higher construction quality compliance. Industrial Competitiveness Benefits  $E_{s3}$  derive from better coordination across supply chains, the generation of new jobs, and support for technological progress and international market access for enterprises.

$$E_s = E_{s1} + E_{s2} + E_{s3} \quad (13)$$

To properly account for the time value of capital in economic evaluations, we employ the net present value (NPV) methodology to quantify the long-term economic viability of these social benefits. The NPV calculation incorporates discounting factors to reflect the present worth of future benefits, as mathematically formulated in Equation 14. Specifically, the total NPV is derived from the summation of discounted values for each benefit component.

$$\begin{aligned} NPV(E_s) &= NPV(E_{s1}) + NPV(E_{s2}) + NPV(E_{s3}) \\ &= (E_{s1} + E_{s2} + E_{s3}) \frac{(1+e)^{n-1}}{n(1+e)^n} \end{aligned} \quad (14)$$

## 2.4 Cost-Benefit Reassessment Using Grey Relational Analysis

### 2.4.1 Construction of Original Matrix

Let Schemes 1-3 be denoted as economic evaluation schemes  $S_1$ ,  $S_2$  and  $S_3$ . Based on the measurement data from Equation 1 to 14, the original matrix  $A$  is constructed as follows Equation 15. In the matrix  $A$ , each row corresponds to three distinct alternative schemes, each row vector represents three distinct alternative solutions, while each column vector corresponds to specific cost and benefit metrics associated with these alternatives.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nm} \end{bmatrix} \quad (n = 3, m7) \quad (15)$$

The seven evaluation indicators in matrix  $A$  are classified into two mutually exclusive types: cost-type indicators, which are minimized in the optimal scheme, and benefit-type indicators, which are maximized. This identification of the solution that minimizes costs and maximizes benefits allows decision matrix  $A_0$  to be derived, as expressed mathematically in Equation 16.

$$A_0 = \begin{bmatrix} a_{01} & a_{02} & \cdots & a_{0m} \\ a_{11} & a_{12} & \cdots & a_{1m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \quad (16)$$

### 2.4.2 Normalization Procedure

Given the heterogeneous measurement units across fundamental evaluation criteria, we perform dimensionless treatment of decision matrix A using the ratio method. This generates the normalized decision matrix R. In other words, each element within matrix R is derived through a standardized transformation process following the methodology outlined in Equation 17.

$$z_{ij} = \left( \begin{array}{cc} \frac{a_{ij}}{a_{0i}} \text{ Benefit - type indicators} & \frac{a_{0j}}{a_{ij}} \text{ Cost - type indicators} \end{array} \right) \quad (17)$$

### 2.4.3 Indicator Weight Determination

Objective weighting methods often overlook the subjective preferences of implementers, which can create a gap between theoretical weights and practical needs (Kizielewicz et al., 2024; Deng, 2016). To address this, our study employs the expert scoring method for subjective weighting. A panel of domain experts assessed the relative importance of each indicator on a 10-point Likert scale, ensuring the weights are both technically sound and operationally feasible. Each indicator's weight ( $G_j$ ) was calculated as the arithmetic mean of the expert scores ( $G_{ij}$ ), normalized via Equation 18.

$$\alpha_j = \frac{G_j}{\sum_{j=1}^m G_j} \quad (j = 1, 2, \dots, m) \quad (18)$$

### 2.4.4 Reference Matrix Construction

As a fundamental analytical tool, the grey relational decision matrix measures the relational degree between alternative solutions and an ideal reference sequence, thereby facilitating scientific evaluation. The computational procedure, initiated with Equation 19 (Sun and Yang, 2003; Singh and Pandey, 2024), yields a relational coefficient. This coefficient is rooted in geometric pattern similarity analysis. A higher value denotes a closer alignment, indicating that a candidate's developmental trend is more consistent with the ideal state.

$$\lambda = \frac{|z_j^* - z_{ij}| + \eta|z_j^* - z_{ij}|}{|z_j^* - z_{ij}| + \eta|z_j^* - z_{ij}|} \quad (19)$$

Where:  $\eta$  is the resolution coefficient (typically set to 0.5) that modulates comparison sensitivity:

- $\eta = 0$  eliminates environmental influences,
- $\eta = 1$  preserves the original comparison environment.

$|z_j^* - z_{ij}|$  represents the global minimum deviation, set to 0, while  $|z_j^* - z_{ij}|$  denotes the global maximum deviation, set to 1. Subsequently, the overall grey relational degree matrix summarizing the evaluations for the three Schemes is determined as follows Equation 20:

$$\lambda = (\lambda_{ij})_{n \times m} = \begin{bmatrix} \lambda_{11} & \cdots & \lambda_{1m} \\ \vdots & \ddots & \vdots \\ \lambda_{n1} & \cdots & \lambda_{nm} \end{bmatrix} \quad (20)$$

### 2.4.5 Grey Relational Projection Values Computation

The grey relational projection value serves as a comprehensive metric that quantifies the similarity between alternative solutions and the ideal solution in terms of both geometric configuration and evolutionary trends. We achieved this by calculating the projection length of each

solution within the weighted grey relational space. Prior to computing these projection values, a critical preprocessing step involves normalizing the indicator weights to derive the importance weight vector for evaluation criteria. The grey relational projection weights  $\bar{\alpha}_j$  are derived from the importance weight matrix  $a_j$  as follows Equation 21:

$$\bar{\alpha}_j = \frac{\alpha_j^2}{\sqrt{\sum_{j=1}^m \alpha_j^2}} \quad (21)$$

The calculation of grey relational projection values necessitates the incorporation of indicator weights (as specified in Equation 18) to enhance the scientific rigor of the evaluation. This integrated approach, formalized in Equation 22, quantifies the comprehensive similarity between alternative solutions and the ideal reference by measuring their projection lengths within a weighted grey relational space. Specifically, larger projection values indicate stronger geometric and trend-wise alignment with the optimal solution across all considered criteria, while smaller values reflect increasing degrees of deviation from this benchmark (F. Wang et al., 2024; Men et al., 2003).

$$S_n = \sum_{j=1}^m \lambda_j \bar{\alpha}_j \quad (22)$$

### 3. Case Study

#### 3.1 Project Overview

For the implementation of the aforementioned methodology, this study examines a master-planned community in Hobsonville, New Zealand (Figure 2a & b), which integrates mixed-use facilities including retail, cafes, bars, parks, and schools. One representative residential unit, has a loan value of NZ\$2 million and a total floor area of 110 m<sup>2</sup>, spanning two above-ground stories (each 2.896 m high). The layout comprises three bedrooms—two on the ground floor and one upstairs, where the living room is also located. The ground-floor living room faces north and includes a balcony, while the rear provides auxiliary outdoor space. Specifically, the project-related data presented in this study, including but not limited to quantities of work and transportation costs, were systematically collected and compiled by the authors.



**Figure 2** (a) The Hobsonville Point community case in New Zealand and (b) aerial view of the case project

Structural components include aerated concrete board interior walls and 240 mm fire-resistant block masonry for load-bearing walls. Windows and doors feature uPVC frames with thermally broken insulated glazing. Based on project import timelines and comparable case studies, Scheme 1 has a design-to-building cycle of 100 days (3 months for production/transport + 10 days for hoisting), whereas Schemes 2 and 3 require 240 days (8 months).

### 3.2 Calculation Assumptions and Parameters

This study focuses on quantifying the indirect benefits of prefabricated steel structures. Accordingly, all three construction schemes are presumed to meet New Zealand's Building Code minimum economic viability thresholds. Direct cost variations (e.g., cross-border transport, tariffs) are excluded from analysis.

#### 3.2.1 Building Lifespan and Social Discount Rate

Following standard structural design service life benchmarks, the building's lifespan is set at 50 years. Given the long-term benefits of prefabricated steel construction, and considering New Zealand's market conditions, economic development, and policy context, a uniform social discount rate of 8% is applied.

#### 3.2.2 Proportional Cost Deductions

These deductions are primarily derived from the standards and practices of New Zealand's construction industry. For instance, a 15% deduction is applied to design and development costs, while 3% is deducted for additional foundation expenses. The project is anticipated to be completed 140 days ahead of the conventional construction schedule. The construction-phase interest rate (5%) reflects prevailing local market conditions.

#### 3.2.3 Other Benefit Calculation Benchmarks

Financing amount: NZ\$500,000. Rental income (external leasing): 6.82 NZD/m<sup>2</sup>/month (median market rate) for a 110 m<sup>2</sup> lease area. Policy incentives: Assuming a 10-day extension of the presale approval period (to conservatively capture the potential range of policy incentives), with an associated land value benefit of NZ\$540,000. Sales prices: Steel-structured buildings: NZ\$9,218.18/m<sup>2</sup>, Concrete structures: NZ\$10,109.09/m<sup>2</sup>. Land cost: NZ\$8,000/m<sup>2</sup>. Usable area ratio difference (due to structural systems): 3.89%.

### 3.3 Cost Calculation

This section presents the detailed cost modeling for the three proposed schemes. The sum of the four cost components is summarized in Table 5. In summary, Scheme 1 demonstrates the most cost-effective solution at 3,281 NZD/m<sup>2</sup>, significantly lower than Scheme 2 (4,225 NZD/m<sup>2</sup>) and Scheme 3 (4,446 NZD/m<sup>2</sup>). This cost advantage is primarily attributable to the integrated manufacturing of prefabricated steel structures imported from China, lower domestic labor costs, and economies of scale in construction.

**Table 5** Cost comparison of the three schemes.

No.	Item	Scheme 1		Scheme 2		Scheme 3	
		Total (NZD)	Unit (NZD/m <sup>2</sup> )	Total (NZD)	Unit (NZD/m <sup>2</sup> )	Total (NZD)	Unit (NZD/m <sup>2</sup> )
1	Design Costs	28,678	260.71	76,284	693.49	80,071	727.92
2	Production Costs	145,529	1,322.99	151,452	1,376.83	167,757	1,525.06
3	Transportation Costs	21,120	192.00	2,456	22.33	3,217	29.25
4	Building Costs	165,581	1,505.29	234,554	2,132.31	238,016	2,163.78
5	Total	360,908	3,280.98	464,745	4,224.96	489,060	4,446.00

### 3.4 Benefit Calculation

#### 3.4.1 Economic Benefits Calculation

Economic benefit calculations show that the fully prefabricated steel structure imported from China (Scheme 1) achieves the highest value at 372.50 NZD/m<sup>2</sup>, followed by Scheme 2 (328.08 NZD/m<sup>2</sup>), whose lower performance is largely due to a longer project duration. Scheme 3 yields the lowest benefit. The shorter construction period of Scheme 1 allows earlier sales of residential units compared to the other schemes, generating interest income from sales capital of 34.87 NZD/m<sup>2</sup>, together with earlier rental income from tenant occupancy totaling 9.55 NZD/m<sup>2</sup>. Although area-based policy incentives were modeled, they are not applicable at the project site and are therefore excluded. Both Scheme 1 and Scheme 2, as prefabricated steel structures, qualify for early pre-sale incentives, contributing 2.49 NZD/m<sup>2</sup>.

#### 3.4.2 Environmental Benefits Calculation

Drawing on Pang, 2019, the water-saving benefit of prefabricated steel structures is quantified as 3.02 CNY/m<sup>2</sup> (0.71 NZD/m<sup>2</sup>). Wei, 2019 reports land-saving benefits of 55.6 CNY/m<sup>2</sup> (13.07 NZD/m<sup>2</sup>), while Yuan and Wang, 2021 estimate energy-saving benefits of 10.07 CNY/m<sup>2</sup> (2.37 NZD/m<sup>2</sup>). Material-saving benefits are reflected directly in construction and installation costs. Dust and noise reduction benefits during construction are taken as 6.1 CNY/m<sup>2</sup> (1.43 NZD/m<sup>2</sup>) following Zheng and Xu, 2019. Previous research (Zheng and Xu, 2019; Tavares et al., 2021) report construction-phase carbon emissions of 308.86 kg/m<sup>2</sup> for prefabricated steel structures versus 357.68 kg/m<sup>2</sup> for traditional cast-in-place structures. Using the 2023 U.S. NPUC carbon price of 71 USD per metric ton (converted to 119.08 NZD/ton), the carbon emission costs for Schemes 1 and 2 are 36.78 NZD/m<sup>2</sup>, compared to 42.59 NZD/m<sup>2</sup> for Scheme 3, yielding a carbon reduction benefit of 5.81 NZD/m<sup>2</sup> for prefabricated steel. Based on local regulations and case study drawings, construction waste generation rates are 0.13, 0.17, and 0.45 ton/m<sup>2</sup> for the three schemes, respectively. With a disposal cost of 103.49 CNY/ton (24.33 NZD/ton), the corresponding waste disposal costs are 3.16, 4.14, and 10.95 NZD/m<sup>2</sup>. Thus, the waste reduction benefits of Scheme 1 and Scheme 2 relative to Scheme 3 are 7.79 NZD/m<sup>2</sup> and 6.81 NZD/m<sup>2</sup>, respectively.

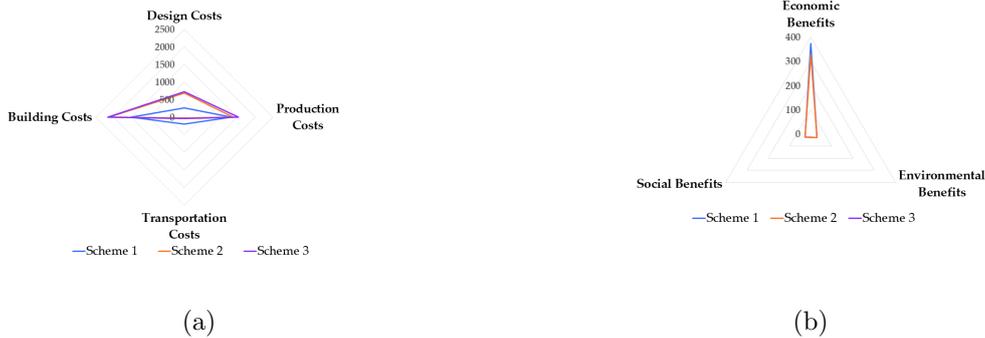
#### 3.4.3 Social Benefits Calculation

Prefabricated construction offers significant socioeconomic advantages by replacing conventional methods with advanced housing technologies. Standardized factory production improves working conditions, reduces short-term labor mobility, and enhances quality through rigorous process control, while also promoting the integration of construction industrialization with digital technology. According to Han, 2008, the social benefit of prefabricated steel structures is 107.36 CNY/m<sup>2</sup> (25.24 NZD/m<sup>2</sup>).

A comparative analysis shows that although prefabricated steel structures do not show immediate economic advantages during construction, they deliver superior integrated performance across economic, environmental, and social dimensions. The total economic, environmental, and social benefits for all three schemes are summarized in Table 6. Scheme 1 achieves the highest comprehensive benefit (428.92 NZD/m<sup>2</sup>), followed by Scheme 2 (383.52 NZD/m<sup>2</sup>), demonstrating that the fully imported prefabricated steel structure approach offers substantial advantages in construction speed, environmental sustainability, resource efficiency, quality, and social value.

**Table 6** Comparative Analysis of Benefits Across Three Schemes.

No.	Item (NZD/m <sup>2</sup> )	Scheme 1	Scheme 2	Scheme 3
1	Economic Benefits	372.50	328.08	0
2	Environmental Benefits	31.18	30.20	0
3	Social Benefits	25.24	25.24	0
4	<b>Total</b>	<b>428.92</b>	<b>383.52</b>	<b>0</b>



**Figure 3** (a) Radar chart of costs for three schemes and (b) Radar chart of benefits for three schemes

The radar chart depicting costs in Figure 3 (a) reveals that Scheme 1 exhibits the smallest enclosed area, indicating its superior cost-saving advantage. In contrast, in the benefit radar chart shown in Figure 3 (b), Scheme 1 occupies the largest area, confirming its optimal performance in terms of overall benefits.

### 3.5 Cost-Benefit Reassessment Using Grey Relational Analysis

Ten domain experts were invited to assess the importance of each indicator on a 10-point scale. The panel comprised four prefabricated steel structure specialists, two civil engineering professors, and four senior executives from New Zealand regulatory agencies. The resulting weights are presented in Table 7.

**Table 7** Synthesis of Expert Assessments and Computed Indicator Weights.

Expert	$C_d$	$C_p$	$C_t$	$C_i$	$E_C$	$E_E$	$E_S$
1	82	91	89	90	91	93	88
2	84	89	84	86	92	93	91
3	79	85	85	89	92	89	90
4	81	94	95	93	93	95	90
5	99	99	78	89	91	92	85
6	76	83	86	91	85	93	93
7	81	88	93	87	88	89	99
8	82	99	98	94	91	97	92
9	98	77	77	85	96	86	94
10	89	78	75	95	84	94	94
Mean Score $G_j$	85.1	88.3	86.0	89.9	90.3	92.1	91.6
Indicator Weights $\alpha_j$	0.137	0.142	0.138	0.144	0.145	0.148	0.147

By synthesizing the relational degree matrix with the projection weights, the resultant projection values of the three schemes are 0.346, 0.312, 0.189, respectively. The grey relational projection values quantify the similarity of each scheme to an ideal solution. A higher projection value indicates better overall alignment with evaluation criteria (cost and benefit indicators). In practical terms: Scheme 1's highest value (0.346) confirms it as the optimal choice for NZ contexts, balancing low costs with high sustainability benefits. This method moves beyond simple NPV comparisons by incorporating synergistic effects among indicators (e.g., reduced construction time may increase environmental benefits), providing a robust decision-making tool for engineers and policymakers.

#### 4. Conclusions and Recommendations

This study evaluates the economic performance of importing fully assembled prefabricated steel structures from China to New Zealand using a whole-process cost-benefit model, validated through grey relational analysis. The unit cost of the imported structures is 3,281 NZD/m<sup>2</sup>—significantly lower than local manufacturing (4,225 NZD/m<sup>2</sup>) and traditional concrete (4,446 NZD/m<sup>2</sup>), representing cost reductions of 24.6% and 35.2%, respectively. Concurrently, the comprehensive benefit of the imported solution reaches 428.92 NZD/m<sup>2</sup>, outperforming the domestic alternative by 11.8%. In conclusion, the findings demonstrate that importing prefabricated steel structures offers significant economic advantages in the New Zealand context, aligning with broader research on the benefits of prefabricated construction.

Amidst the ongoing restructuring of global industrial chains, this study identifies a dual strategic advantage for New Zealand's construction sector. First, it demonstrates that China's competitive manufacturing costs and economies of scale within transnational supply chains can offset the costs of long-distance logistics. This provides New Zealand with a viable pathway to adopt high-value industrialized building methods. Second, from a technical standpoint, a hybrid standardization system—combining Chinese technical specifications with local New Zealand certification—helps overcome technical barriers. This integration enables the smooth adoption of advanced Chinese prefabrication technologies. These findings not only affirm the economic feasibility of cross-border construction industrialization, but also offer actionable insights for modernizing New Zealand's building industry. The study presents a replicable model for international construction collaboration in the post-globalization era.

Although necessary parameters and assumptions were used in the modeling process, future research will test these findings across multiple datasets. It will also integrate Building Information Modeling with Life Cycle Assessment (BIM-LCA), and apply multi-criteria decision-making methods—such as the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)—alongside sensitivity analysis. These steps will improve the precision and robustness of the conclusions.

In summary, the long-standing China–New Zealand strategic partnership, supported by an upgraded free trade agreement, further enables the import of Chinese prefabricated building solutions. By providing quantitative evidence and a strategic framework, this study offers key decision-making support and data to help New Zealand leverage the cost and technological benefits of Chinese prefabricated steel structures. Ultimately, this supports the transition toward a greener, more efficient, and sustainable construction industry.

#### Author Contributions

Kang Li: Concept, Design, Methodology, software Writing-original draft. Ting Jing: Implementation, Review, Funding sourcing.

#### Conflict of Interest

The authors declare no conflicts of interest.

## Supplementary Materials

This manuscript has no associated supplementary materials.

## Declaration of AI

The authors declare that no generative AI technologies were used in the creation of this manuscript.

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