Holistic Considerations for Low-Rise Building Design

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ABSTRACT

The cost of building structure considering initial cost and long-term sustainability are evaluated in terms of 6 parameters: (i) initial direct construction cost; (ii) initial construction time; (iii) short-term sustainability (embodied carbon); (iv) Long-term direct cost; (v) Long-term construction time; and (vi) Long-term sustainability as per the "Mana Matrix". Software used included: BIM software; BRANZ LCAQuick (for lifecycle assessment considering carbon emissions); and spreadsheets to perform the convolution integrals associated with earthquake losses and compile the data in a form suitable for the Mana Matrix. Time and cost parameters were estimated considering the capacity to source materials and labour given the time constraints.

Two residential building structures were selected as case studies to demonstrate the application of the Mana Matrix in accommodating client preferences from three perspectives. These perspectives include those of property developers who prioritize: (a) both cost and time parameters rather than sustainability, (b) sustainably sourced material, and (c) long-term structural resilience. It is shown that the preferred structure changes depending on the client preferences. Through this study, it becomes apparent that the Mana Matrix serves as a valuable tool for decision-making, allowing stakeholders to tailor structural designs to meet specific client requirements and preferences.

1 INTRODUCTION

In response to growing consumer demands, the construction sector has emerged as a significant contributor to New Zealand's economy, ranking as the country's fifth largest industry (around 18 billion NZD) (MBIE 2022). With over 10% of the national workforce employed in construction, there is a clear imperative for innovation to ensure the industry's sustainability and further economic growth. Decisions made regarding construction can be simplified to relate to the initial direct cost, the construction time, short term sustainability which can be measured related to equivalent carbon used, and long-term sustainability. Long-term sustainability, which also to cost, time and equivalent carbon, of buildings is related to:

(a) gradual effects over its life. This includes heating, ventilation, and air-conditioning (HVAC), and deterioration which required regular maintenance. These effects are not directly related to the structural system. For similar design of building non-skeletal elements (NSEs), these factors are likely to be similar for similar buildings, so these effects are not further considered in this study concentrating on the structural system.

(b) sudden impacting effects. Probably the most significant sudden event affecting New Zealand buildings is earthquake. The impact of earthquakes on the long-term sustainability depends on the building resilience. A low resilience may require a rebuild which results in substantial cost (demolition and re-build), and associated equivalent carbon credits.

When good structural systems are used, the level of resilience is generally increased with greater frame stiffness and strength, which implies greater member sizes. Greater members sizes result in more cost and more equivalent carbon usage initially, but lower effects later. Wen and Kang (2001) showed that optimisation may be performed to determine the most appropriate strength for design. However, the over a structural strength range of about 300%, the long-term cost associated with different strengths does not change much. Also, there is huge uncertainty associated not only with the input variables, but also with the assumptions made to evaluate the loss. Therefore, these differences in initial strength are not so significant on the total long-term sustainability (MacRae, 2023).

Direct cost, construction time, and carbon emissions are key parameters utilized to evaluate each structure, empowering clients to customize the design according to their preferences. The Mana Matrix described in this study, which enables stakeholders to assess various structural configurations within the defined parameters. These configurations can influence the total initial cost of each structure, ranging from the procurement of sustainable materials to enhancing earthquake resilience.

The interaction between long-term and short-term sustainability indicators is dynamic, and organizations need to find a balance between the two to ensure sustainable outcomes in the short term while also achieving long-term strategic goals.

The implementation of modern computer methods (MCM), including artificial intelligence (AI), holds promise as tools for driving innovation within the construction sector. With the development of MCM, design automation can facilitate streamlined structural modifications across the design process. Moreover, the adoption of "press-of-a-button" technology stands to revolutionize construction practices, offering potential cost savings in both time and materials, all while promoting sustainable and culturally sensitive design solutions. The successful integration of Construction 4.0 into the New Zealand construction industry hinges upon prioritizing stakeholder usability and ensuring that all involved parties are equipped to leverage these advancements effectively.

This paper seeks to address this need by finding answers to the following questions:

- What parameters influence the most appropriate structure for a certain situation?
- How can we quantify appropriate cost parameters to develop an evaluation matrix?
- How could Mana Matrix be beneficial in the future structural design?

2 QUANTIFICATION METHOD

2.1 Initial Parameters (IP)

Many building structure designs are controlled by seismic effects in New Zealand, this could be simple to use single degree of freedom method and equivalent static method. Every building must be safe. For many normal buildings, sizes may be designed by the equivalent static procedure. Here:

i) the design strength, F_{des}, of many normal ductile buildings is governed by the return period factor for the serviceability limit state (SLS), R_s (= 0.25) times the ultimate limit state (ULS) shaking associated with an annual probability of exceedance of 1/500, according to NZS 1170.5 (2004) and Equation 1. It is not controlled by the lateral force reduction factor, R, but it is equivalent to a lateral force reduction factor of $1/R_s = 1/0.25 = 4.0$.

$$F_{des} = R_s \times \text{ULS} \tag{1}$$

ii) a low estimate of the actual nominal strength, F_{nom}, may be 1.25 times F_{des} as given in Equation 2 due to material, member and system overstrength.

$$F_{nom} = 1.25\, F_{des} = 1.25\, R_s \times \text{ULS} \tag{2}$$

This strength (F_{nom}) is related to the initial cost ($C_{initial}$) of the structure, which represents the initial, or short-term, cost of the structure. This cost/loss or negative effect may be reflected by three parameters:

(1) Initial Direct Cost

The Initial parameter of direct cost, denoted as IP(DC), involves consideration of various aspects in the construction process. The expenses related to obtaining materials are assessed. Material and labour costs may be estimated using data from Rawlinson’s New Zealand Construction Handbook after considering inflation rates. The monetary cost ($) may be based on the volume of material, or the floor area within the structure, using traditional or computer methods. Some of the modern methods use BIM.

(2) Initial Construction Time Loss

The duration of the initial construction period (in units of weeks) for a specific building, denoted as IP(CT), might be evaluated by professional engineers. This depends on material availability and delivery time (which may be considerable especially international import is required), and the availability of fabricators/erectors for construction. Modern computer methods may be used to interrogate the web and other online databases to obtain some of this information. The IP(CT) may be characterised by a normalized monetary value ($) using rental expense of the building and/or interest loss during construction.

(3) Initial Loss of Sustainability

A parameter reflecting the loss due to lack of sustainability (IP(LS)) may be represented by the equivalent carbon emission considering the initial cost of structural material, which could be found through quantity take-offs conducted on the provided BIM, which were then used in conjunction with BRANZ LCA Quick (LCAQ): Life cycle assessment tool to calculate the total carbon emissions (CO_2 *eq*) from the materials in each element. It is convenient to use the same units of loss for sustainability and financial requirements. This is difficult to do, but in this work, everything is represented by a monetary value for simplicity.

These structural elements are split into different categories to streamline the import process into LCAQ. These categories are currently but not limited to doors, walls, windows, roofs, and floors. Moreover, the skeletal part of building, i.e. structural framing, structural foundation and structural columns, would provide a key addition to the total volume of CO_2 *eq*.

This information can guide the client's decision-making process. If the client prioritizes a low-carbon building, these values might prompt adjustments to the building design to achieve a reduced embodied carbon footprint.

2.2 Long-term Parameters (LP)

The long-term cost of a structure considering seismic resilience could be described by loss estimation methods (e.g. MacRae (2006), Bradley et al., (2007), and Yeow et al. (2017)). When considering earthquake effects, often damage parameters such as peak drift or acceleration are used. However, these methods are too complex for structural design applications, so a simpler method is used here. It is based on the following assumptions:

i) Due to other factors, which are not able to be easily computed, damage will not occur until the strength is 10% greater than F_{nom}. The force associated with the onset of damage, F_{dam}, which could be expressed as below.

$$F_{dam} = 1.1\, F_{nom} = 1.375\, F_{des} \tag{3}$$

It is assumed that as the shaking level increases to 3.0 times the level associated with F_{dam}/R_s, denoted as $F_{replace}$, according to Equation 4, and the total cost of repairs is equal to that of a new structure, $C_{initial}$. It is noted that shaking intensities of 3.0 F_{dam}/R_s or greater are extremely rare indicating that most modern structures designed properly in good locations are not likely to require replacement in a major event.

$$F_{replace} = 3.0\, F_{dam} / R_s \tag{4}$$

ii) For levels of shaking demand ranging from F_{dam} to $F_{replace}$, the cost of repair is assumed to increase linearly from $0 to the cost of replacement of the structure. It does not mean that at collapse occurs at this shaking level (as was seen from the behaviour of houses in the Christchurch earthquakes), but it means that the costs associated with repair make replacement as attractive an option. Assuming the replacement cost is approximate equivalent to that of constructing a new structure, $C_{initial}$, the relationship curve between repair cost and shaking level is shown in Figure 1.

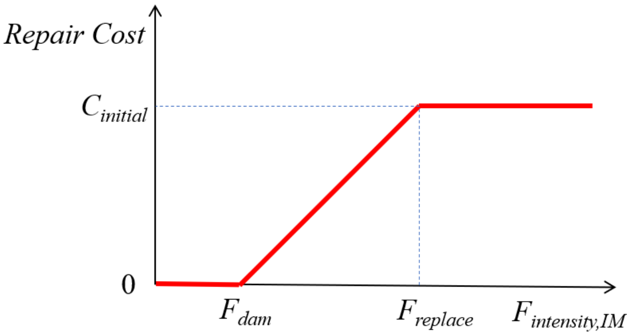


Figure 1. Simplified relationship between repair cost and shaking level

iii) For a structure with a certain damage threshold, F_{dam}, subject to given shaking intensity, IM_i, $F_{intensity,IMi}$, the cost ratio, $R_{cost,IMi}$, given as the repair cost divided by the initial cost, is computed for a given intensity measure (IM) in Eq. (5).

$$R_{\text{cost,IM}} = \begin{cases} 0 & (F_{intensity,IM} \leq F_{dam}) \\ \frac{F_{replace} - F_{intensity,IM}}{F_{replace} - F_{dam}} & (F_{dam} < F_{intensity,IM} \leq F_{replace}) \\ 1 & (F_{intensity,IM} > F_{replace}) \end{cases} \tag{5}$$

i) For simplicity, in this study, the annual rate of at least one exceedance of a particular event in a year, λ, is given from the Poisson distribution according to the annual probability of exceedance (APE) as follows. This is found from a hazard curve, such as can be extracted from Table 3.5 of NZS1170.5 which relates the return period factor to the annual probability of exceedance, APE.

$$\lambda = -\ln(1 - APE) \approx APE \tag{6}$$

ii) Within the life of a structure, which is estimated as 60 years, the rate is simply λ_{60} = 60 years $\times \lambda$ = 60 λ per 60 years. This λ_{60} is the mean number of occurrences of shaking exceeding a particular shaking intensity, IM_i, over the life of the structure. The mean number of occurrences of shaking at a particular intensity over the life of the structure, $N_{Occur,IM}$, is approximated as the mean number of occurrences of shaking exceeding IM_i-$\Delta IM/2$, $N_{Exceeding,IMi-\Delta IM/2}$, minus the mean number of occurrences exceeding IM_i+$\Delta IM/2$, $N_{Exceeding,IMi+\Delta IM/2}$. That is $N_{Occur,IM}=N_{Exceeding,IMi-\Delta IM/2} - N_{Exceeding,IMi+\Delta IM/2}$, where ΔIM is the intensity increment between the different IM_i considered.

iii) The expected cost for each intensity, IM_i, is computed as $N_{Occur,IMi} \times R_{cost,IMi}$, and the total damage as a proportion of the building cost ($R_{cost,total}$) is found by summing these for all shaking IMs ranging from SLS level to the extremely shaking level (ESL) with an APE of less than 1/10,000 the hazard is ignored following the recommendation of *Porter* (2015). This simple process is known as a convolution integral and it may be implemented easily in a spreadsheet. This can be done for cost, time and equivalent carbon.

$$R_{cost,total} = \sum_{IM=SLS}^{ESL} N_{Occur,i} \times R_{cost,IMi,} \tag{7}$$

iv) The additional cost for the building considering seismic hazard is obtained by multiplying the ratio $R_{cost,total}$ and initial cost ($C_{initial}$) considering the discount rate dr. The present value of long-term cost, C_{long}, is calculated as:

$$C_{long} = \left[1 + \frac{R_{cost,total}}{(1+dr)^{60}}\right] \times C_{initial} \tag{8}$$

Following the quantification method mentioned in short-term consideration, long-term parameters considering the post-earthquake repair construction and downtime interruption may be obtained and transferred to normalized values. These monetary values, including i) direct cost, LP(DC), ii) long-term construction time, LP(CT), and iii) long-term lack of sustainability, LP(LS). The long-term cost, C_{long}, is larger than the initial loss, $C_{initial}$.

3 MANA MATRIX

3.1 Development

The initial Mana matrix was developed and was shared with the HERA Construction 4.0 team which are dealing with the design of large commercial or industrial structures using structural steel. It was noted at the time, that the Maori term “Mana” has a meaning corresponding to concepts such as prestige, authority, control, power, influence, which is associated with effective decision making, and that the meaning should be changed after consultation with Maori. This was presented to the HERA circular design group in Oct 2022, and was widely disseminated within that group. In June 2023, the group within the HERA project responsible for Maori aspects of the work indicated that probably other Maori should be consulted about an appropriate name as the term “Mana” may be regarded as tokenism. The authors also proposed discussed the term “Mauri” as another option the HERA group several people in November 2022, are still open to other names. However, as there has been no Maori feedback directly suggesting other names, the term “Mana” remains at least in the short term. The matrix has evolved with thinking, and a second version was used in an undergraduate student project in 2023 (Holland and Gray, 2023), before this January 2024 version.

3.2 Concept

The example of the Mana Matrix is presented in Table 1, which encompasses six parameters reflecting direct cost, construction time, and sustainability (carbon emissions) across both initial and long-term perspectives. Normalized values (NV) using units of dollars, are obtained for a particular building.

In addition to the short and long term parameters above, other factors (OF) can be considered with consider less easily quantifiable values, such as those which promote well-being, or incorporate architectural details of special significance.

A weighting system (WS) comprising six parameters is employed, ensuring that the sum of these factors always equals 1.0. The specific values assigned to each parameter within the weighting system may vary based on the particular considerations. These values are high if the stakeholders prioritise avoiding a quantity, such as lack of sustainability (LS). For example, a high NV for direct cost (DC), means that the high direct cost should be avoided, as cost is a priority concern of the stakeholder. For instance, contractors involved in buy-and-sell transactions might assign higher values to initial parameters, while long-term holding owners may prioritize long-term considerations.

To determine the score for a given structure, one simply multiplies the WS and NV values for each parameter and then aggregates them. This straightforward process facilitates decision-making. By focusing on key parameters using this method, it becomes feasible to develop software and establish linkages with BIM software and BRANZ LCAQuick tool, thereby realising the automatic generation of resilient structural designs using the rapid "one - button run" feature. Then, six parameters and the rating score might be changed by employing various structural designs with differing levels of strength F_{des} in Eq. 1 (which also increases the stiffness). Normalized Value (NV) can be obtained by comparing parameter values to an average or standard value. For instance, if the initial cost of a particular design equals the average initial direct cost of all designs, the NV would equal 1.0. This ensures that values for different parameters are standardized and comparable. Consequently, making comparisons among these structural designs using Mana Matrix rating scores would highly support decision-making processes. This dream scenario imagines a future where engineering decisions are no longer dependent directly on engineers at all, and where the client, likely tenant, architect, and other stakeholder groups with various perspectives, including those of indigenous communities like NZ Maori, may be considered.

Table 1. Mana Matrix Example

Parameters	**Initial Parameters**			**Long-term Parameters**			**Other Factors**	**Total Score**
	IP(DC)	**IP(CT)**	**IP(LS)**	**LP(DC)**	**LP(CT)**	**LP(LS)**		
Normalized Value, NV	0.9	1	1	0.8	1.1	1	1	—
Weighting System, WS	0.3	0.2	0.1	0.2	0.1	0.05	0.05	1.0
Score (WS×NV)	1.2	0.2	0.1	1.2	0.2	0.1	0.05	**2.07**

4 CASE STUDY

4.1 Client types

Three scenarios have been utilized to calibrate the matrix, demonstrating its functionality and illustrating how variations in client priorities impact the values within the Mana matrix.

i) Client A is a prospective property developer whose priority is profit maximization, WS values for sustainability and long-term parameters might be zero. They have high concern and WS in the IP(DC), IP(CT), but nothing on the items related to sustainability.

ii) Client B is more environmentally conscious and seeks to minimise the impact of their structure on the environment. This entails a high IP(LS), and LP(LS), but lower emphasis on cost and time.

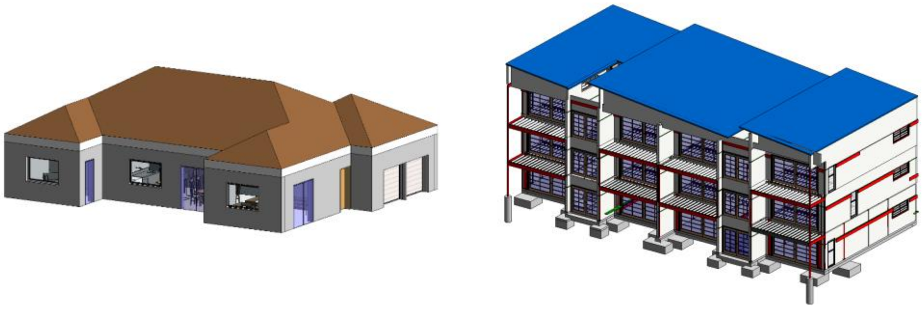
iii) Client C needs a stronger building, so that it can operate soon after a major event, but they do not care about sustainability as measured by equivalent carbon.

4.2 Building Information

(1) Prototype

In order to show how the system works, two building types are put up as case study to show how different ratings systems can result in different ratings for the same building, or how different buildings may be preferred according to the same rating system. Two residential buildings were selected, and the cost of material and carbon emission quantification are carried out by Holland and Gray (2023), Building #1 is a single storey house, the BIM model (Fig.2a) provided by Dr G. Loporcaro. Building #2 is a triple storey residential design concept (Fig.2b) provided by Design Engineering.

The initial direct costs of both cases were obtained through BIM Revit software by Holland and Gray (2023). The direct costs of Building #1 and #2 are approximately 370 k NZD (total floor area is 170 m^2, \$2210/m^2) and 1720 k NZD (total floor area is 1050 m^2, \$1633/m^2), respectively. Initial carbon emission quantities for two buildings using BRANZ LCAQuick tool are around 86 Tons and 114 Tons CO_2 *eq*, respectively. Initial construction time of the building#1 and 2# are assumed to be 80 weeks and 120 weeks, respectively, then the monetary values for two buildings might be 64 k NZD and 300 k NZD, respectively.



(a)Building #1. *(b) Building #2.*

Figure 2. Illustration of case study buildings

(2) Parameters

Based on the existing cost data of prototype buildings, three structural designs for each building are compared in this study, including:

a) Prototype structures, assuming they are designed at importance level 2 to meet the basic requirements and perspectives of property developers.

b) Environmental structures, which are constructed using sustainable material to minimize carbon emissions. Then, assuming the direct cost of the structures may increase by up to 50% by achieving 50% carbon emission reduction;

c) Resilient structures, which are designed at importance level 4 to minimize seismic loss. In this study, assuming the prototype structure is provided with a strength resulting in F_{dam} = 0.35, then the total earthquake loss is estimated to be 30% of the total building value (in present value terms) over the life of the structure. If F_{dam} is increased to 0.50 to ensure the importance level 4, the structure is stronger, then the estimated loss of total building value is reduced to 5%. This loss in building value due to lack of resilience may be found for different F_{des}, F_{nom} and F_{dam} using a simple spreadsheet format. However, the of the stronger structural members would be larger than the prototype ones, so that 30% additional direct cost and carbon emission is considered in this study.

Consequently, the values of parameters for each design consideration and their average values are listed in Tab.2.

Table 2. Values of Parameters

Building NO.	**Design NO.**	**Initial Parameters**			**Long-term Parameters**		
		IP(DC) (k NZD)	**IP(CT) (Weeks)**	**IP(LS) (Tonnes)**	**LP(DC) (k NZD)**	**LP(CT) (Weeks)**	**LP(LS) (Tonnes)**
Building#1	**Building#1*a***	370.00	80.00	86.00	481.00	104.00	111.80
	Building#1*b*	555.00	80.00	43.00	721.50	104.00	55.90
	Building#1*c*	462.50	80.00	107.50	485.63	84.00	112.88
	Average	462.50	80.00	78.83	562.71	97.33	93.53
Building#2	**Building#2*a***	1720	120	114	2236.00	156.00	148.20
	Building#2*b*	2580.00	120.00	57.00	3354.00	156.00	74.10
	Building#2*c*	2150.00	120.00	142.50	2257.50	126.00	149.63
	Average	2150.00	120.00	104.50	2615.83	146.00	123.98

4.3 Matrix Score

For both Building #1 and Building #2, the Normalized Values (NVs) can be derived from the values in Tab.2 compared to the corresponding average value. Additionally, Weighting System (WS) for various stakeholder groups, outlined in Section 4.1, are considered. Other Factors (OF) are not included in this study.

The Mana Matrix for building #1 and #2 are provided in Tabs. 3 and 4, respectively, where the “Total Score” column indicates the relative loss for each stakeholder group. The design with the lowest total score is deemed the most sustainable according to the clients’ WS. The scoring process for different building cases yields stable results that align with the clients’ preferences.

It may be seen that for the variations in Building #1, as shown in Table 3, that Client A prefers Building #1a, Client B prefers Building #1b, and Client C prefers Building #1c. Similar trends were found for the variations of Building #2.

Using modern computing systems that the design of one building configuration and layout may be optimised for a particular set of weightings at the push of a button. The procedure allows the relative variation in the different parameters for different weighting systems to be obtained in order that the best decision to be made for a particular structure, and so that the result be explained in a way that key stakeholders holders can easily understand and communicate.

Table 3. Mana Matrix for Building #1

Type	**Parameters**	**Initial Parameters**			**Long-term Parameters**				**Total Score**
		IP(DC)	**IP(CT)**	**IP(LS)**	**LP(DC)**	**LP(CT)**	**LP(LS)**		
NV (1k NZD)	**Building#1*a***	0.80	1.00	1.09	0.85	1.07	1.20	0.80	-
	Building#1*b*	1.20	1.00	0.55	1.28	1.07	0.60	1.20	-
	Building#1*c*	1.00	1.00	1.36	0.86	0.86	1.21	1.00	-
Weighting system and score of Client A	**WS$_A$**	0.80	0.20	0.00	0.00	0.00	0.00	0.80	-
	Building #1a Score	0.64	0.20	0.00	0.00	0.00	0.00	0.64	**0.84**
	Building #1b Score	0.96	0.20	0.00	0.00	0.00	0.00	0.96	1.16
	Building #1c Score	0.80	0.20	0.00	0.00	0.00	0.00	0.80	1.00
Weighting system and score of Client B	**WS$_B$**	0.10	0.10	0.50	0.00	0.00	0.30	0.10	
	Building #1a Score	0.08	0.10	0.55	0.00	0.00	0.36	0.08	1.08
	Building #1b Score	0.12	0.10	0.27	0.00	0.00	0.18	0.12	**0.67**
	Building #1c Score	0.10	0.10	0.68	0.00	0.00	0.36	0.10	1.24
Weighting system and score	**WS$_C$**	0.10	0.10	0.00	0.40	0.40	0.00	0.10	
	Building #1a Score	0.08	0.10	0.00	0.34	0.43	0.00	0.08	0.95
	Building #1b Score	0.12	0.10	0.00	0.51	0.43	0.00	0.12	1.16

of Client C	**Building #1c Score**	0.10	0.10	0.00	0.35	0.35	0.00	0.10	**0.89**

Table 4. Mana Matrix for Building #2

Type	**Parameters**	**Initial Parameters**			**Long-term Parameters**				**Total Score**
		IP(DC)	**IP(CT)**	**IP(LS)**	**LP(DC)**	**LP(CT)**	**LP(LS)**		
NV (1k NZD)	**Building#1*a***	0.80	1.00	1.09	0.85	1.07	1.20	0.80	-
	Building#1*b*	1.20	1.00	0.55	1.28	1.07	0.60	1.20	-
	Building#1*c*	1.00	1.00	1.36	0.86	0.86	1.21	1.00	-
Weighting system and score of Client A	**WS$_A$**	0.80	0.20	0.00	0.00	0.00	0.00	0.80	-
	Building #1a Score	0.64	0.20	0.00	0.00	0.00	0.00	0.64	**0.84**
	Building #1b Score	0.96	0.20	0.00	0.00	0.00	0.00	0.96	1.16
	Building #1c Score	0.80	0.20	0.00	0.00	0.00	0.00	0.80	1.00
Weighting system and score of Client B	**WS$_B$**	0.10	0.10	0.50	0.00	0.00	0.30	0.10	**-**
	Building #1a Score	0.08	0.10	0.55	0.00	0.00	0.36	0.08	1.08
	Building #1b Score	0.12	0.10	0.27	0.00	0.00	0.18	0.12	**0.67**
	Building #1c Score	0.10	0.10	0.68	0.00	0.00	0.36	0.10	1.24
Weighting system and score of Client C	**WS$_C$**	0.10	0.10	0.00	0.40	0.40	0.00	0.10	-
	Building #1a Score	0.08	0.10	0.00	0.34	0.43	0.00	0.08	0.95
	Building #1b Score	0.12	0.10	0.00	0.51	0.43	0.00	0.12	1.16
	Building #1c Score	0.10	0.10	0.00	0.35	0.35	0.00	0.10	**0.89**

5 CONCLUSIONS

This paper describes a new procedure for holistic structural design of structures in seismic zones. It is shown that :

1. Initial parameters (IPs), and long-term parameters (LPs), of direct cost (DC), construction time (CT), and lack of sustainability (LS) were identified as being important in deciding on an appropriate structure together with weighting systems (WS) for the parameters.
2. Methods of quantifying the DC, CT, and LS parameters above are described using the Mana matrix. Furthermore, long term effect (e.g. related to maintenance and resilience) on these parameters over the building life are described. The long term resilience to earthquake is quantified by a very simple convolution integral approach and implemented in a spreadsheet. The WSs are subjective, determined by the client group, and depend on the building purpose as well as the value systems of the group members. The parameter values, together with the WSs, are combined simply to obtain one total loss number associated with that building.
3. In an example, two different residential buildings, each with different variations in properties, and client groups with three different weighting systems are considered and evaluated using the Mana matrix. It is shown that the total loss number associated with a particular building variation depends on the WSs used. Modern computing systems can be used to optimised the design for a particular building shape and set of weightings at the push of a button in order that the best structural design/construction decision be made. The Mana matrix approach provides a good suitable approach to that decision makers can easily understand and communicate the result to stakeholders.

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