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Emerging Technologies: The cost of designing in timber.

A comparative energy and cost based study of structural systems comprised of timber, concrete and steel.

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Preface

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Acknowledgments

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This work is made possible by the valued efforts of the partnering researchers from the research group at Studio of Pacific Architecture.

Acknowledgements to Jackson Prattley-Jones for the calculation of operational costs, embodied energy and embodied CO^2 in section 7.2 of this report.

Notes

This research does not intend to substitute or compete with the work of a Quantity Surveyor, rather to provide a bespoke methodology to allow a viable cost comparison with the resources available.

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1.0 Introduction

This research aims to support the efficacy of engineered timber structures at a commercial scale by evidencing the minimal difference in total building capital cost, compared to concrete and steel alternatives. The purpose of this research was derived from the lack of evidence available to prove to clients, developers, leasees and others that comparatively, an engineered timber building *can* to be of similar expense to concrete and steel alternatives. Carbon sequestration and a significantly lower embodied energy are key benefits of constructing in timber (Andrew Buchanen, 2013) which have not been sufficiently encouraging to see an increased demand for engineered timber at the commercial scale. It is acknowledged that a variety of factors influence the limited use of timber, including limited local suppliers, lack of professional expertise and non-established industry workflows; issues that result in the increase in, or, *expected* increase in capital cost compared to common practice alternatives, concrete and steel. By evidencing the minimal difference in total building capital cost comparative to concrete and steel, particularly in relation to other benefits of timber, this research reinforces the efficacy of engineered timber construction at the commercial scale in New Zealand.

The costed concrete and steel alternative schemes were preliminary designs of the structural systems required to compose the *equivalent* design of the case study, with respect to minor changes due to the differing structural capacity of each system (ie: beam depths). The methodology of this process is explained in detail in section 4 of this report.

The majority of this research involved defining the methodology for cost comparison and the preliminary structural resolution of the concrete and steel alternatives before they could be costed. All final costs and conclusive results are heavily dependent on the methodology of these processes, therefore explained in detail throughout this report. This research concludes promising findings and opens various areas for further research which could increase the efficacy of designing in engineered timber at a commercial scale in New Zealand.

1.1 Case Study Building

This research was based on the available costing data of one 12 storey engineered timber office building proposed for Wellingtons CBD in 2018. The building had a typical floor area of 310m^2. The main structure is composed of LVL and glulam beams and columns, CLT floors and a concrete core.

Studio of Pacific Architecture (SPA) allowed access to all required information to carry out the cost analysis of this case study. Therefore, discussion of the case study refers to a consented commercial office building, structurally and architecturally resolved to the standard of the New Zealand Building Code (NZBC) as of mid-2018.

2.0 Phase 1: Defining the methodology of costing the timber case study with QV cost builder

Costing data of the timber case study is extracted from confidential sub trade bids to tender. This data provided the total costs of each engineered timber type; CLT, LVL and glulam. The costs per unit of each timber element were derived as a division of these totals by their unit quantity. The confidential tender evaluation (mid 2018) provides the total contract price of the project including each individual tenderer. These costs were the basis of all calculations and were used to establish the costing methodology through comparison to the costing database, QV Cost Builder.

To ensure applicability and understanding of the implications of this research beyond this case study, the capital costs for all three schemes are calculated per floor. The original costing data from the case study included bespoke floors and elements which were removed from the total building cost due to their likelihood of skewing total costs per floor and tendency to differ extensively across projects. These included the bespoke floors included the ground floor, plant room and the roof. The remaining total building cost was then divided by 11 (remaining number of floors) to attain the typical cost per floor. The total building costs discussed at the end of this report are derived as the cost per typical floor multiplied by the total number of floors (11).

2.1 Defining elements to cost: Criteria for Inclusion.

This research compares the capital cost of main structural elements used across all three schemes. *Main structural elements* are defined as all primary members of the structural systems resisting lateral and gravity loads which are vital to the buildings structural integrity. For example, any vertical element of the façade system (ie: windows) will inherently help to resist gravity load, but if removed, columns and beams as part of the facade will suffice on their own. Any *non-structural* elements (i.e.: the façade windows) are not included in the cost comparison across the three schemes due to limited ability to accurately quantify and justify them as structurally imperative elements of the concrete and steel alternative schemes.

The biggest assumption of this research is that the costing of all elements defined as *non-structural* (referred to as "other costs"), are extracted from the timber case study and applied consistently to the steel and concrete schemes, despite the potential differences across each differing structural system. The implications of this are discussed in section 6 of this report.

2.2 Costing database: QV Cost Builder.

To generate an accurate comparative capital cost analysis between timber, concrete and steel, consistency was mandatory. To ensure consistency, all costs were derived from the same database; QV Cost Builder (version Q3, effective from 15 October 2019). Before costing the alternative steel and concrete schemes, the QV Cost Builder was used to cost the timber case study, generating its translated cost to be used for comparison.

The QV Cost Builder is a comprehensive reference to New Zealand building costs. The *Detailed Rates* section provided all costing used in this research. The detailed breakdown of individual elements allowed for accurate calculation of total cost per scheme, and provided a comprehensive baseline of inclusions and/or exclusions among comparative rates.

Table 1: QV Cost Builder: Definition of *Detailed Rates*

Rates	Included	Excluded
Material supply*	✓	
Delivery to site*	✓	
Fixings and consumables – nails/screws/glue/etc	✓	
Labour to install*	✓	

Allowance for small tools and hand plant	✓	
Overheads and profit	✓	
Local industry labour agreements		✓
Preliminaries and General*		✓
GST		✓

*Material supply** average trade discounts applied.

*Delivery to site** and allowance for waste.

*Labour to install** time multiplied by cost, values also provided.

*Preliminaries and General** such as site establishment, supervision, large plant, scaffolding, notices and fees, insurances, etc.

Table 2: Rounding of figures as defined by QV Cost Builder (2019)

Cost (NZD$)	Rounded to:
0 - 50	nearest 10 cents
50 – 750	nearest whole dollar
751 – 3000	rounded to nearest $10
3001 – 10,000	rounded to nearest $100
10,001 +	rounded to nearest $1,000

2.3 QV Cost Builder Disclaimers

QV Cost Builder states: "Rates can differ appreciably, due to the nature and specific requirements of each particular contract. Therefore, it is not recommended that they be used for tendering or quotations" (QV Cost Builder, 2019).

2.4 Limitations and assumptions of *QV Cost Builder* to cost timber case study

- QV Cost Builder states: "The Detailed Rates section gives indicative rates for reasonable quantities of work, and would apply to projects in the $1,000,000 to $5,000,000 range, with average site conditions" (ref). Confidential information suggested the total cost of the case study project to exceed $5,000,000. This limitation was waivered on the basis that all three comparative schemes fall under the same total cost by a minimum of 95%, all exceeding the recommended price for use of these costs. Due to the comparative nature of this research, this consistently applied limitation affects results uniformly, allowing it to be ignored.

- The most significant limitation of the QV Cost Builder is its occasional complete lack of specific building elements and/or varying dimensions among elements. The lack of variety in engineered timber elements and dimensions is significant. The timber case study structure is composed of CLT floors, LVL columns and beams and few glulam beams. QV Cost Builder is limited to a variety of dimensions of glulam beams, posts, flooring and LVL portal frames while no costing of CLT elements are provided.

- The available dimensions of LVL portal frames do not represent a similar structural capacity to the combined use of LVL columns and beams of the case study. The portal frames listed on QV Cost Builder are also limited to 12m – 20m spans, while in actuality, the most commonly occurring beam spans a maximum of 8m. These inaccuracies suggest the use of LVL as the correct engineered timber type, composed as an incorrect system, cannot be costed as a representation of the case study.

- The structural capacity of glulam columns and beams of accurate dimension were a more suitable representation of the structural system of the case study, despite the difference in engineered timber type. It was assumed that it is more accurate to prioritise the composition of the whole structural system (correctly sized column/beam instead of oversized portal frame) over the engineered timber type, in regards to structural cost

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- The cost difference in engineered timber types due to differing methods of manufacturing and timber treatment is considered irrelevant to this assumption, defined by the defined acceptable cost variation less than 30% (*see section 3.7*) resulting from the final sensitivity analysis (*see section 3.6*).

- There were limited variety among dimensions of glulam members which often do not corresponding to the dimension of LVL members used in the case study. To cost LVL columns and floor beams (deepest structural members), beams of the nearest half depth are costed twice (denoted on spreadsheet as “X2”) to ensure an equivalent cost for a similar sized members, on the basis of this costing data and consistent methodology. This methodology is tested for accuracy in the sensitivity analysis.

- Considering all floors of the case study are composed of CLT, the complete absence of CLT was another major limitation to the QV Cost Builder. Glulam flooring of limited depth is the only engineered timber flooring available on the database. The accuracy of costing glulam flooring to represent the CLT used in the case study was concluded insufficient (exceeding 15%), thereby requiring a substitute. This is elaborated in the following section(s).

3.0 Sensitivity Analysis

The sensitivity analysis tests the accuracy of the QV Cost Builder’s equivalent cost of each structural element comparative to its original unit value of the timber case study.

All per unit rates of the case study are derived from the total costs of each engineered timber type; CLT, Glulam and LVL.

The results of this analysis show which elements can be costed accurately using QV Cost Builder and which elements cannot. An acceptable margin of error (MOE) was defined to inform this. Where QV Cost Builder is not sufficiently accurate, current (*Dec 2019 – Feb 2020*) industry quotes were attained.

3.1 Limitations and Assumptions of Sensitivity Analysis

- To carry out a comparative sensitivity analysis, the case study costing data should define the per unit rates of each costed element. As a limitation, the only accessible costing data of the timber case study were the total costs of each engineered timber type; CLT, LVL and glulam. The cost per unit were derived as a division of these overall totals by their unit quantity. This unit cost therefore includes any bespoke members/circumstance which may have skewed the true unit cost. This was specifically relevant to the unit cost of glulam which included 48 *curved* perimeter beams (varying from 4.7 – 7.5m), requiring bespoke manufacturing. The total cost of glulam was therefore increased and the lineal metre unit price of all glulam elements was skewed. The sensitivity analysis defines the glulam members as outliers in the costing data.
- Elements classed as outliers in the case study costing data are replaced by current industry costs to retain accuracy. Common NZ suppliers, Place Makers, Bunnings and Mitre 10, were surveyed over the phone or via email to attain quotes. Where relevant, suppliers were contacted in both Wellington and Auckland to account for discrepancies across New Zealand, increasing applicability of this research.
- All bespoke members/circumstance within the design were substituted by traditional alternatives (specified where relevant), resulting in broader applicability beyond the case study used.
- There were discrepancies in the inclusions and exclusions of costs obtained through QV Cost Builder and the original case study costing data. These were evaluated and redefined.

Table 3: Comparison of cost incl. / excl. of case study costing and QV cost builder.

Cost Inclusions / Exclusions	Case study costing data	QV Cost Builder
Material supply	Y	Y
Labour to install	N	Y
Delivery to site	Y	Y
Protection to site	Y	Y
Sanding	N	Y
Fixings and consumables – nails/screws/glue/etc	Y	Y/N**
Preliminaries and general	N	N
GST	N	N

** <u>Case study incl. fixings</u>: ALL connection hardware (brackets and fixings)

<u>QV Cost Builder incl. fixings</u>: Bolts and/or connection rings, plates (not all fixings defined)

- Key discrepancies include the cost of **labour and sanding** in the QV Cost Builder database. These costs are attained and added to the case study data, ensuring consistency of inclusions and exclusions among comparative costs.
- QV Cost Builder's co-efficient of labour rates and time are used to add the same cost of labour to the case study data at $38.95 per hour (QV, 2019).
- The included rate of sanding timber members is not quantified by QV Cost Builder. This rate was obtained through a quote by TimberLab (NZ structural timber industry supplier) (appendix 1.1).

After these additions to the case study costing data, total costs of all structural elements represent the same inclusions as QV Cost Builder rates. These updated costs were used to conduct the initial sensitivity analysis.

3.2 Literature Review: Defining the margin of error.

A systematic literature review was conducted to define an appropriate margin of error (MOE) regarding discrepancy in costs between the unit rates derived from the original case study data and the rates provided by QV Cost Builder. The most commonly occurring related research topics concerned property valuation methodologies, where buildings were costed despite the slightly different context.

Key objectives:

1. **Defining an appropriate margin of error for the variance in cost to define the sensitivity analysis between original costing data and QV cost builder.**

Although not all findings specifically related to capital costs of alternative structural schemes, all relevant sources concerned costing among the construction industry, primarily about elements of buildings otherwise their composition as a total building cost.

The search engines used were Google Scholar and Victoria University of Wellington Te Waharoa and ProQuest. These commonly led to the ASCE database (American Society of Civil Engineers), which provided sources from the Journal of Construction Engineering and Management.

Limited sources from New Zealand were found, however due to the universal expression of the margin of error as a percentage, international currencies and fluctuation in rates did not limit the values obtained as percentages.

Key search terms used were:

Margin of error, capital costs, construction, comparative capital costs, building costs, construction costs, cost variation, estimation, methodologies, buildings

Margin of error AND capital costs AND construction

Margin of error AND capital costs AND buildings

Capital cost AND construction AND estimation AND methodologies

Findings:

Topic	Context	**Maximum MOE %**	Reference
Property valuations	Nigeria	13.16	Ogunba Olusegun Adebayo, Iroham Chukwuemeka Osmond, **2010**.
Variance of total construction cost	n/a	14.59	Skitmore & Ng, **2002**.
Construction cost estimation principles	n/a	n/a	Carr Robert I, **1989**.

Property valuations	UK and Australia	**15**	Crosby, Lavers, & Murdock, **1997**.

Table 4: MOE extracted from literature review.

Conclusion of findings:

QV Cost Builder can be confirmed as an accurate costing database for this comparative cost research if the MOE of all timber elements of the case study are kept below the defined maximum of 15% when compared with QV Cost Builder rates. If this is achieved, QV Cost Builder be trusted to accurately cost concrete and steel schemes comparatively.

3.3 Initial sensitivity analysis

The MOE represents the variance between original cost of the case study and QV Cost Builder as a percentage less than the original cost.

Case study data					**QVCB**				**% MOE**
item	*unit*	*D*	*W*	**cost/ unit**		*depth*	*width*	**cost/unit**	
LVL Columns	m	0.4	0.3	**661.1**	Glulam beam X2	0.405	0.135	**521.7765**	21.0745*
LVL Floor Beam	m	0.6	0.3	**985.65**	Glulam beam X2	0.54	0.135	**707.702**	28.19946*
LVL Floor Beam	m	0.3	0.3	**498.83**	Glulam beam X2	0.315	0.135	**413.956**	17.01461*
LVL Perimeter Beam	m	0.4	0.09	**213.93**	Glulam beam	0.405	0.09	**152.072**	28.91507*
Spandrel Support Blades	m	0.4	0.05	**114.57**	Glulam beam	0.405	0.042	**89.7045**	21.70333*
LVL Roof Rafters	m	0.2	0.06	**76.88**	Glulam Beam	0.19	0.065	**72.431**	5.786941
Glulam Perimeter Beam	m	0.4	0.09	**610.95**	Glulam beam	0.405	0.09	**152.072**	75.10893**
CURVED Glulam Perimeter Beam	m	0.4	0.09	**610.95**	Glulam beam	0.405	0.09	**152.072**	75.10893**
CLT floor panels	m2	3	0.145	**475.17**	Glulam Flooring System	3	0.135	**648.0915**	-36.3915**

Table 5: *Initial sensitivity analysis*

*OUTLIER – MOE range 15-30%

**OUTLIER – MOE range 30+%

Discussion of results

- The initial sensitivity analysis resulted in a MOE of 5 of the 9 items costed to represent outliers exceeding the MOE range of 15-30% and 3 of the 9 exceeding 30%. These 3 elements (linear and curved glulam perimeter beams and CLT floor panels) are major outliers that require substitution with current industry costs to achieve accuracy.
- Excluding these major outliers, the sensitivity analysis evidenced the highest MOE (LVL perimeter beams) at 28.9%, exceeding the defined maximum of 15%. The complete absence of LVL and CLT costs, as a major limitation of QV Cost Builder, exposed significant discrepancies.
- Costing similar dimensions of glulam is not accurate enough to represent the cost of the LVL members used in the case study. This was expected due to the differing methods of manufacturing. To acknowledge the general difference in cost between LVL and glulam engineered timber types, current industry rates were surveyed.

3.4 Cost comparison: LVL and Glulam

(Supplier A = Place Makers, Supplier B = Mitre 10, Supplier C = Bunnings)

Timber dimension and spec.	Supplier A	Supplier B	Supplier C	**MOE Lvl/Glulam**	Reference/quotes obtained *(see appendix 2)*
$ / 1m X 400X300 H3.3 PL8 visual beam. Excl. GST					
LVL	4299.6 (6m) 1m @ **716.60** (ProLam)	-	-	**+ 18%**	Phone
Glulam	588.67 (ProLam)	764.62 (Techlam)	-		Email
$ / 1m X 300X300 H3.3 PL8 visual beam. Excl. GST					
LVL	-	-	-		
Glulam	2815.10 (6m) 1m @ **469.20** (Prowood)	**594.68**	-		Email
$ / 1m X 100X100					

H3.3 PL8 visual beam. Excl. GST					
LVL	-	-	-		
Glulam	177.78 (6m) 1m @ **29.50**	**47.30**	-		Email
Average					

Table 6: *Surveyed costs: LVL vs. Glulam*

Limitations

- Supplier C provided no quotes after multiple requests.
- Supplier A could not obtain quotes for the cost of one lineal metre, therefore had assumed 6m lengths. It is likely that the cost for 1m will differ from 1/6 of this cost obtained.
- Only one supplier could provide quotes for LVL, at one dimension.

From the attainable data, LVL was surveyed as more expensive than Glulam by 18%.

This results of this survey assume a further increase in the MOE of 15% to 33% (addition of 18%) retains an acceptable MOE for all LVL members. All results fall within this acceptable range.

Note: The most commonly used dimensions of timber in the case study project were selected for this comparison.

3.5 Substitution of Outliers

1. **Glulam beams:**

The unit cost of the 400X90 glulam perimeter beams was skewed by the inclusion of bespoke curved members, significantly exceeding the MOE of 15% at 70%, defining it as an outlier. The lack of costing data of individual elements disallows the bespoke members to be removed as outliers from the total cost of glulam, as it is not clear what proportion of the total cost they occupy. An average rate derived from various quotes from NZ's main timber suppliers, provides the current industry cost to substitute this outlier.

Although the case study includes various bespoke circumstances, the output of this research aims to be applicable across a wide range of commercial scale timber construction, therefore seeks to represent a standardised model. All bespoke elements of the case study are replaced with standardised elements in relation to the preliminary role of the QV Cost Builder. Therefore, the curved glulam perimeter beams are costed as linear beams, allowing a consistent comparison of non-bespoke circumstance across timber, concrete and steel schemes.

$ / 1m x 400X90 (405X88) Glulam, H3.3 PL8 visual beam. Excl. GST	Wellington	Auckland	*Average*
Place Makers	160	181	170.5
Mitre 10	212.64	199.25	205.95

Bunnings	156.20*	171.17	163.7
Average	176.28	183.8	**180**

Table 7: Survey of NZ Glulam suppliers: 400X90 Glulam. Quotes obtained over the phone, see appendix 2.

The average per unit cost of $180.00 for 400X90 glulam perimeter beams was used as a substitute in for the second attempt sensitivity analysis.

2. **CLT flooring:**

The MOE of -36% defines the cost of Glulam flooring from Rawlinson's as an outlier. This is likely due to the lack of any CLT pricing within Rawlinson's as a major limitation.

To substitute this outlier, NZ manufacturers of CLT were surveyed to obtain viable quotes. Suppliers were commonly hesitant to provide CLT quotes.

CLT Billet 145mm depth (5layer)	$ / m2	No. m2 per m3
XLAM	228	7.1
Red Stag Timber	No quote provided	N/a

Table 8: *CLT Flooring industry quotes*

3.6 Inclusions/exclusions of surveyed quotes

There are discrepancies in the inclusions and exclusions of costs obtained through QV Cost Builder, and the various surveyed industry quotes.

Specific Industry Quotes **Cost Incl. / Excl.**	XLAM CLT Flooring	Glulam beams	Case study data (adapted to QV inclusions)	QV Cost Builder
Material supply	Y	Y	Y	Y
Labour	N	Y	Y	Y
Delivery to site	N	Y	Y	Y
Protection to site	N	Y	Y	Y
Sanding (timber only)	N/A	N	Y	Y
Fixings	N	Y	Y	Y
GST	N	N	N	N
Prelims/general	N	N	N	N

Table 9: *Incl / Excl. of industry quotes.*

Key discrepancies include lacking cost of sanding in the surveyed glulam quote and the cost of labour, site delivery/protection and fixings for the surveyed CLT quote. These costs were attained through manufacturer specification *(appendix 1.2)* and added, ensuring consistency of inclusions and exclusions among comparative costs.

3.7 Additional costs to industry quotes of QV Cost Builder inclusions:

1. **Glulam beams**

Glulam + Additional Costs	$/m
Glulam beam 400X90	180
Sanding	11.60
Total	**191.60**

Table 10: *Cost additions to glulam beams.*

2. **XLAM CLT Flooring**

CLT Raw Timber + Additional Costs	$/M2
Raw timber	228
Delivery to site (Incl. Protective coating / wrappings)	75
Fixings	154
Labour	89.58
Total	**542.40**

Table 11: *Cost additions to CLT flooring.*

(Appendix 1.1, 1.2)

3.8 Sensitivity analysis: Second Attempt with Substitution of major outliers

Table 12: Sensitivity analysis B.

Case study data					QV Cost Builder / Quotes gathered				% MOE
item	unit	depth	width	**cost/unit**		depth	width	**cost/unit**	
LVL Columns	m	0.4	0.3	**661.1**	Glulam beam X2	0.405	0.135	**521.7765**	21.1
LVL Floor Beam	m	0.6	0.3	**985.65**	Glulam beam X2	0.54	0.135	**707.702**	28.2
LVL Floor Beam	m	0.3	0.3	**498.83**	Glulam beam X2	0.315	0.135	**413.956**	17
LVL Perimeter Beam	m	0.4	0.09	**213.93**	Glulam beam	0.405	0.09	**152.072**	28.9
Spandrel Support Blades	m	0.4	0.05	**114.57**	Glulam beam	0.405	0.042	**89.7045**	21.7
LVL Roof Rafters	m	0.2	0.06	**76.88**	Glulam Beam	0.19	0.065	**72.431**	5.8
Glulam Perimeter Beam	m	0.4	0.09	**610.95**	Glulam beam	0.405	0.09	**191.60**	68.6 *n/a
CURVED Glulam Perimeter Beam	m	0.4	0.09	**610.95**	Glulam beam	0.405	0.09	**191.60**	68.6 *n/a
CLT floor panels	m2	0.145	/	**475.17**	CLT floor panel (XLAM)	0.14	/	**542.40**	-14.1

*n/a = MOE ignored due to outlier circumstance, see *section 3.4.1.*

3.9 Conclusion of costing workflow

- The sensitivity analysis ensures that the use of QV Cost Builder will result in accurate cost calculations under the scope of this research methodology. Sufficiently similar or exact elements are defined by a maximum MOE of 15% (30% for LVL members).
- Where the sufficiently similar or exact elements are not available (ie: CLT flooring), surveyed current industry prices provide accurate substitution. These industry prices were analysed and compared to QV Cost Builder in terms of their inclusions and exclusions to ensure consistency across all sources/methods of costing data.
- Bespoke elements were replaced with standardised alternatives to increase wider applicability of the findings (ie: curved perimeter beams replaced with linear perimeter beams).

See section 6 of this report for a discussion of the total costs calculated via this workflow.

4.0 Phase 2: Resolving alternative schemes: Steel and concrete.

Concrete and steel systems supporting the same design as the timber case study do not exist as available resources. In order to compare the capital cost of timber to concrete and steel structures, a major phase of this research was the resolution of alternative structural schemes. Without reference to a structural engineer, a preliminary structural design software (RESIST) was used to devise the most efficient alternative schemes based on the design of the case study.

Conforming to the same floor plan and load capacity, the size and arrangement of structural elements differs when the case study building is constructed in steel or concrete instead of timber. The methodology for establishing *equivalent* alternative steel and concrete schemes was informed by a literature review of similar studies.

4.1 Literature Review 2: Defining methodology for resolving alternative steel and concrete schemes

A systematic literature review was conducted at early phases of this project for general enquiry around methodologies among similar research topics. The most commonly occurring related research topic concerned cost comparisons among different costs associated with buildings (ie: capital cost, time, energy cost, operational cost) however only *one* search result provided capital cost comparisons between differing structural material systems of similar buildings, and *none* compared the same building. The literature review reinforced this research gap.

Key objectives:

The two specific methodologies being reviewed were:

1. **The inclusion and/or exclusion of costs among general capital cost comparison.**
2. **How (if) alternative structural schemes of the "same design" were established.**

The objective findings of this review primarily concern the methodologies stated above. Various search results applied at a scale outside that of a 12 storey commercial office building located outside New Zealand. These results still managed to suggest relevant methodologies as the objectives were not dependent on site context. Key findings of these methodologies were evaluated and adapted where necessary.

The search engines used were Google Scholar, Victoria University Library Te Waharoa and ProQuest. These larger search engines became directories for more discrete yet relevant engines such as THEIJES (The International Journal of Engineering and Science).

Relevant search terms used were:

capital cost, cost, construction, architecture, timber, concrete, steel, comparative cost, comparative capital cost, engineered timber, commercial, high rise, structural materials

Successful search combinations were:

Capital cost AND construction AND timber concrete steel

Comparative cost AND timber AND commercial AND construction

Comparative cost AND structural materials AND high rise AND construction

Applicable key findings relating to main objectives:

1. **General cost comparison**

- Building cost comparison can be calculated as an average cost per floor (Cazemier, 2017) to become easily adapted to variance in number of floors if used comparatively outside of this research.
- Costing of bespoke elements should be ignored and replaced by traditional alternatives (Smith et al., 2009).

2. **Establishing of alternative structural schemes of the "same design"**

- Alternative structural schemes do not need to follow the same quantity of structural members. Instead of only altering material and dimension of structural members, their configuration as a whole system can be altered to maximise efficiency as long as the required structural capacity met (Cazemier, 2017).
- *AutoDesk Robot* is suggested as a computer software that can be used to resolve structural systems (Ogunba Olusegun Adebayo et al., 2010). Training for appropriate use of this software would shadow time better spent on further research into this research, although previously understood softwares can be used in replacement of *AutoDesk Robot*. This suggests the use of RESIST.
- The resizing and configuring of suitable substructure should be adapted to each structural system due to its vital role in load resisting in relation to the total weight of the building (Ogunba Olusegun Adebayo, et al., 2010
- Bespoke circumstance was replaced by traditional methods of construction to increase applicability outside of this research (Smith et al., 2009).
- It is expected that concrete structures will have more similar grid configurations to timber than steel (Smith et al., 2009).
- *Steel Construction NZ* can provide a resource for deriving conceptual steel schemes for steel structures (Smith et al., 2009).

4.2 Defining "equivalent" configurations using concrete and steel

To obtain an accurate cost comparison of alternative structural schemes, various limitations were self-imposed by the nature of this *equivalent* comparative study. Configuration and sizing of structural elements were informed primarily on the basis of the existing case study, although discrepancy across the load capacity and performance of differing structural materials caused various design aspects of the original timber scheme to be altered.

It was acknowledged that the concrete and steel alternative schemes will never configure an identical architecture to the original timber scheme due to inherent differences of each material. Some of these differences include structural properties, construction methods and connections. The *equivalent* use of the differing structural systems was defined by prioritising maximum similarity to the case study among the following factors:

1. Perimeter dimensions of floor plan
2. Location and dimension of core
3. Structural grid (depth of columns and beams)
4. Floor depth (span of flooring system) and inter-storey height
5. Lack of columns disrupting the open floor plan

The approximate priority of each factor is reflected as ordered, although all factors are somewhat co-dependent. With respect to their co-dependence, the configuration of alternative concrete and steel schemes represent *equivalent* designs to the timber case study.

4.3 Preliminary structural design software: RESIST

RESIST (2016) is the preliminary design tool used to size and configure structural elements of the concrete and steel alternative schemes.

The software states:

"RESIST is an application for the simplified evaluation of the structural performance of lateral load-resisting systems in a building under seismic and wind loads. It is designed to be used in educational settings as a guide for the sizing of lateral load resisting systems for Architectural and Civil Engineering students. RESIST should not be used as a final preliminary design; a full, complete preliminary design should be carried out by a structural engineer".

4.4 Assumptions and limitations of RESIST

- RESIST only calculates structure concerned with lateral load resistance. To account for the addition of structural elements resisting gravity load, various *Rules of Thumb* were applied. These rules were extracted from *Tall: the design and construction of high-rise architecture,* published in 2019 (Marriage, 2019).
- RESIST only allows modelling of one structural system in each opposing direction. Alternative structural resolution featuring more than one system per direction was not tested and could provide a more efficient resolution in actuality.
- RESIST only models a maximum of 8 storeys, while the timber case study has 12. Due to the consistency of this limitation across both comparative alternatives, this limitation is ignored.

4.5 Timber Case Study

Structural configuration of the timber case study is represented below as a base for comparison to the alternative schemes:

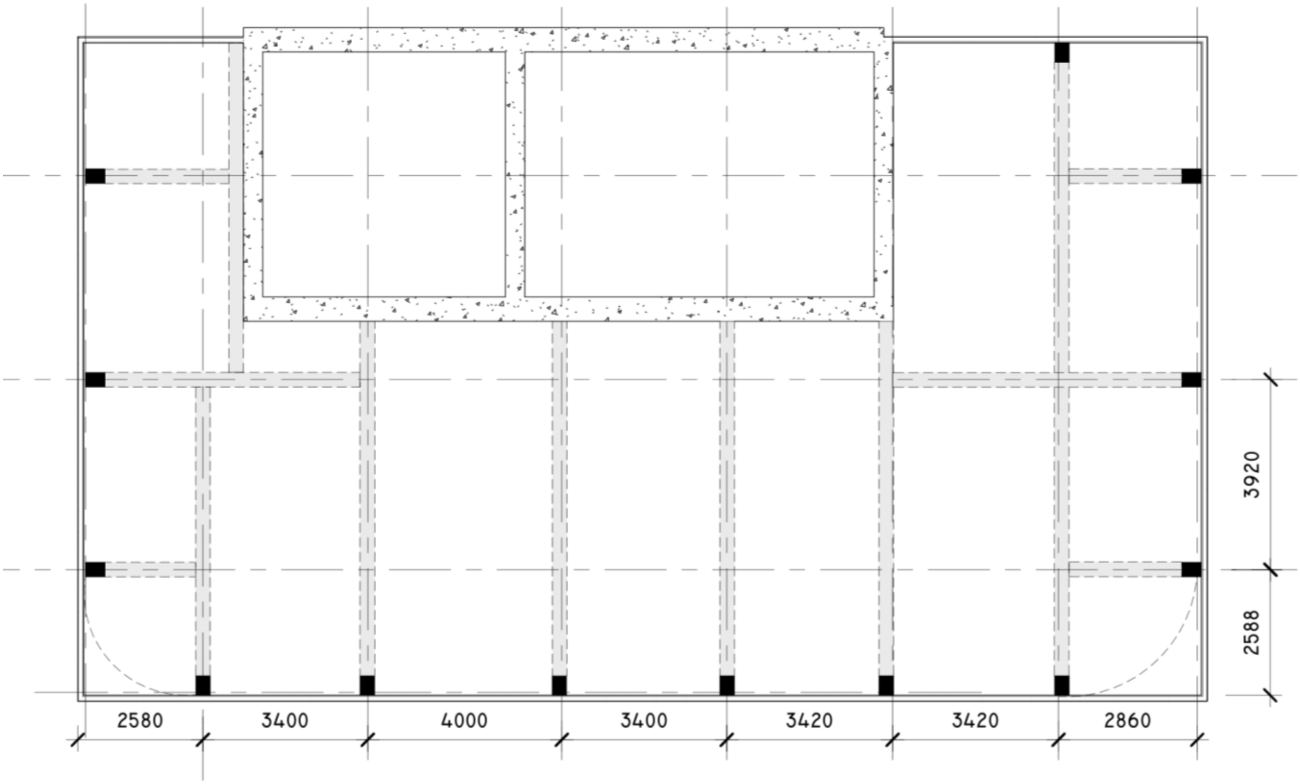

Figure 1: Timber case study, simplified structural plan. Authors own drawing.

<u>Lateral/Gravity load resisting structure</u>:

Spec: LVL Beams @ 600X300, 300X300. Glulam beams @ 300X90. LVL Columns @ 400X300. CLT floors @ 0.145 depth.

<u>Core:</u> Reinforced concrete shear wall core.

4.6 Concrete Scheme

Using RESIST, the timber case study was resolved using concrete structure as below:

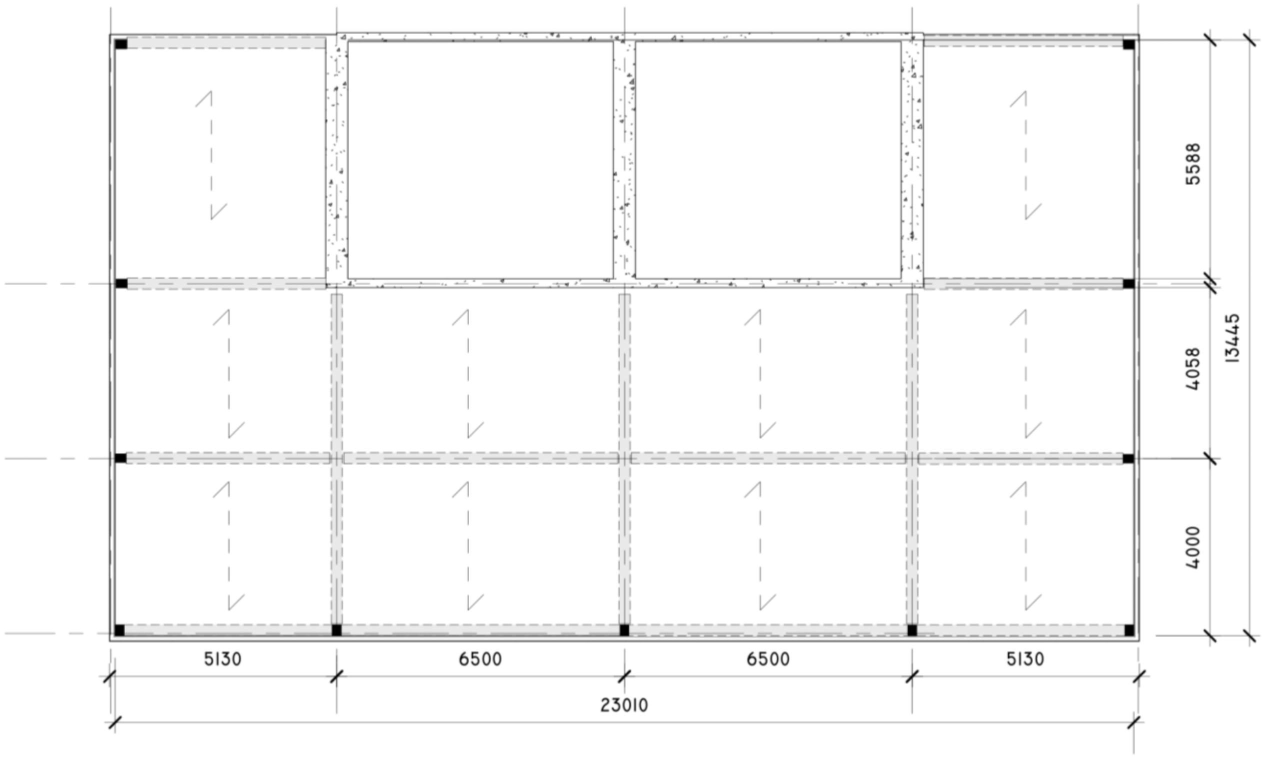

Figure 2: Concrete scheme, structural plan (NTS) resolved in RESIST. Authors own drawing.

Lateral load resisting structure: Reinforced concrete shear walls located as core walls.

Spec: 550mm deep in the Y direction (6m) and 200mm deep in the X direction (13m).

Gravity load resisting structure: Concrete columns and beams, composite steel decking and concrete flooring.

Spec: Beams @ 350X250, columns @ 250X200. TrayDec80 @ 200mm

Core: Composed by the lateral load resisting concrete shear walls.

Limitations and Assumptions

- In replacement of the CLT floors of the timber case study, composite steel decking and concrete floors were used for the concrete scheme. This flooring was assumed the most likely system to be used in the context of commercial office buildings in New Zealand.

- There is slight difference in the overall structural floor depth of 500mm compared to 685mm of the timber case study. The difference of 185mm was assumed insignificant, as a gain in vertical space is typically considered positive and not related to this research.

4.7 Steel Scheme

Using RESIST, the steel case study was resolved using concrete structure as below:

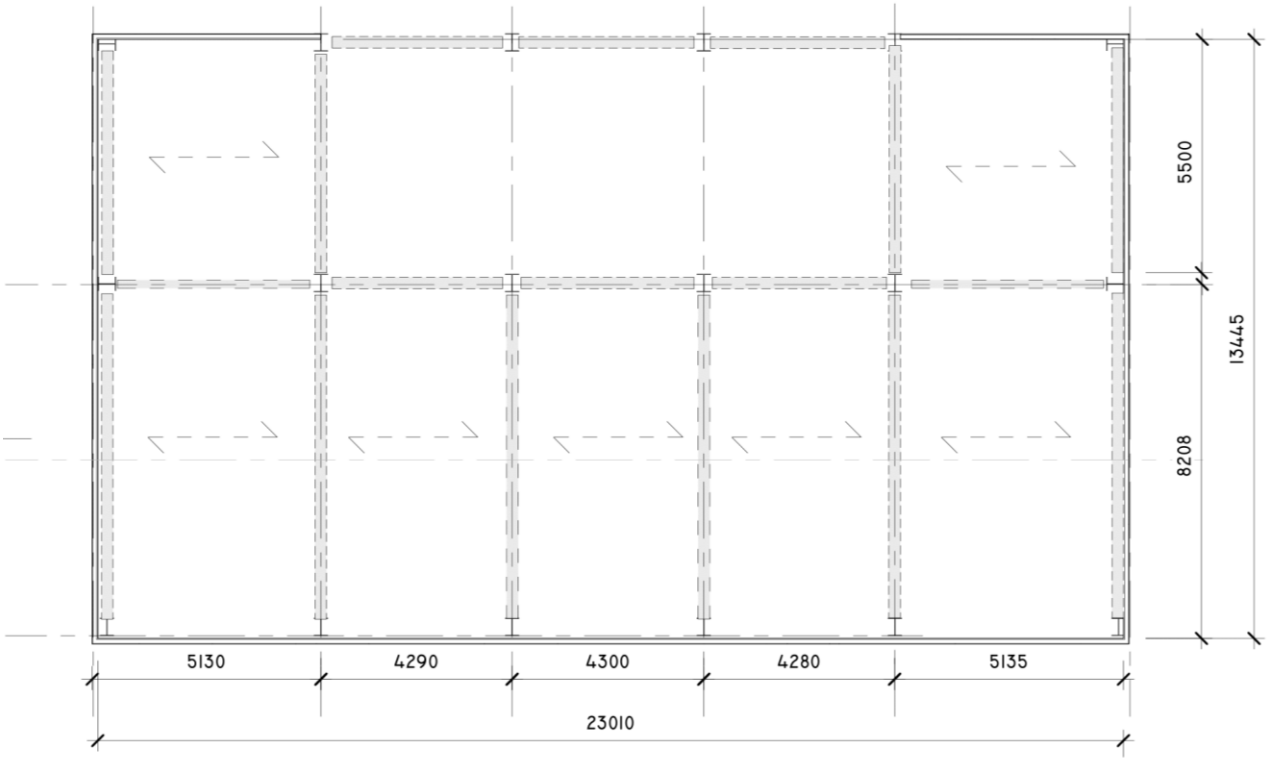

Figure 3: Steel scheme, structural plan (NTS) resolved in RESIST. Authors own drawing.

Lateral load resisting structure: Steel moment frames.

Spec: Beams @ 670X243 in the Y direction and 613X228 in the X direction. Columns @ 550X550.

Universal UB & UC dimension: 690UB253, 610UB228, 310UC (283 kg/m).

Gravity load resisting structure: Steel columns and beams (few extra required), composite steel decking and concrete flooring.

Spec: 410UB178, 310UC (96.8kg/m). TrayDec80 @ 200mm.

Core: The core zone is defined by arrangement of lateral load resisting steel moment frames. No extra structural material required to resist loads about the core.

Limitations and Assumptions

- Where columns of intersecting moment frames overlap in RESIST, it was assumed that one column at the same recommended dimension is sufficient, particularly with the addition of gravity load resisting elements outside of RESIST.
- RESIST doesn't allow unequal bay lengths within each moment frame. Where four 2 bay moment frames compose the structural system in the Y direction, the bay length was tested at both lengths (5.5m and 8.2m). RESIST suggested the same beam depth and an insignificantly larger width (3mm variation) for the 8.2m spanning bay, allowing the assumption that this beam dimension is sufficient to resist load across both bay lengths at the same dimension of 690UB253 (670X243 in RESIST).
- RESIST reccommends a 550UC as the structural column dimension of the steel moment frames. Information on the density and cost of steel columns greater than 310UC was unobainable without an engineer. It was assumed that the highest density of a 310UC (@283 kg/m) can resist the load of a 550UC at the lesser density suggested by RESIST. The 310UC is appropriate for the steel scheme as this dimesnion was also required to resist gravity load at a lower required density of 96.8kg/m.
- In replacement of the CLT floors of the timber case study, composite steel decking and concrete floors are used for the steel scheme. This was assumed the most likely flooring system to be used in the context of commercial office buildings in New Zealand.
- There is slight difference in the overall structural floor depth of 890mm compared to 685mm of the timber case study. The difference of 205mm is assumed insignificant, as it can be resolved at the cost of various factors unrelated to this research.

General Notes:

- All sturcture was positioned to replicate the open floor plan and allow similar façade treatment to the timber case study.
- *See appendix 3.1 for full RESIST reports/inputs.*
- *See appendix 3.3 for span tables and calculation of gravity load resisting elements outside of RESIST.*
- *See appendix 4 for exact directorty of QV Cost Builder values used.*

5.0 Phase 3: Costing steel and concrete schemes

QV cost builder was previously defended as an acceptable costing database. Its consistent use across all schemes ensures an accurate cost comparison. The conclusion of the sensitivity analysis (section 3.8) defined areas of exception where QV Cost Builder may not suffice;

- *Where specific elements are not available (ie: CLT flooring), surveyed current industry prices provide accurate substitution. These industry prices were analysed and compared to QV Cost Builder in terms of their inclusions and exclusions to ensure consistency across all sources/methods of costing data.*

Across the concrete and steel alternative schemes, only one element was not able to be costed (due to lack of correct depth) using QV Cost Builder; *TrayDec80 (200mm) composite flooring system*. Substitution with current industry prices is outlined below:

Inclusions/exclusions of industry price comparative with QV Cost Builder

Specific Industry Quotes Cost Incl. / Excl.	**TrayDec80 Flooring system**	QV Cost Builder
Material supply	**Y (excl. concrete slab)**	Y
Labour	**N**	Y
Delivery to site	Y	Y
Protection to site	Y	Y
Sanding (timber only)	N/a	Y
Fixings	Y	Y
GST	N	N
Prelims/general	N	N

Table 13: Cost *Incl / Excl. of TrayDec80.*

Additional costs to industry quotes

TrayDec80 + Additional Costs	$/M2
TrayDec80 Flooring system	49
Insitu poured slab. Incl. reinforcing	340
Labour	21.30
Total	**410.30**

Table 14: *Cost additions to TrayDec80.*

(Appendix 3.4.2)

These costs are attained and added to the case study data, ensuring consistency of inclusions and exclusions among comparative costs.

5.1 Assumptions and limitations of costing concrete and steel schemes

- Due to the early assumption that the cost of a typical floor should represent an equal portion of the total building cost (due to removal of bespoke floors – ground and roof), the total cost of alternative schemes are defined by costing one typical floor and multiplying it by 11 (number of occupied 'typical office floors' of the case study).

- Composite steel decking and concrete flooring system was costed as for the steel and concrete schemes based on the assumption that it is the most likely flooring system to be used in the context of commercial office buildings in New Zealand.

- All concrete elements are assumed to be precast (excluding the in-situ pouring of slab as part of the composite flooring system).

- Despite the RESIST recommendation of steel moment frames, this system is not able to be costed in QV Cost Builder. Individual steel columns and beams of the same recommended dimensions of each member of the moment frames, were costed instead. It is assumed that the required structural capacity of the moment frames was attained with the costed column and beam system.

- Where RESIST recommends a 670UB243, a 690UB254 is instead costed as the nearest dimension available on QV Cost Builder.

6.0 Comparative Total Building Costs

Definition of costs discussed

Structural costs: Main structural elements of the proposed schemes, i.e.: columns, beams, floors. This includes both lateral and gravity resisting structural elements.

Other costs: Remaining costs when structural costs were removed from total building costs of timber case study.

Total building costs: Structural costs (timber, concrete and steel schemes costed as per the documented methodology) and other costs.

(Inclusive of; demolition, piling, concrete work, reinforcing steel, structural steel, blockwork, façade, carpentry, hardware, joinery, doors, roofing, plumbing and gas, drainage, mechanical services, fire protection, lifts and escalators, electrical services, data and comms, security, suspended ceiling, tiling, floor coverings, paint and special finishes, glazing, paving, professional sums, contractors margin).

Calculation of comparative total building costs:

Comparing total building capital costs allows the most accurate representation of the differing structural systems as opposed to comparing only structural costs. Total building costs represent the costs of each structural system, scaled in relation to all other costs. To attain total building costs of each scheme, the structural costs of each comparative system (concrete, steel, timber schemes costed in terms of QV Cost Builder) were added to the “other costs” of the timber case study. The most significant assumption of this research was that the “other costs” are consistent across all schemes.

Structural system	Total building cost	% less than **total building cost** of timber scheme
Timber scheme	$ 32,825,470.59	-
Concrete scheme	$ 31,204,800.45	5.2%
Steel scheme	$ 31,369,051.66	4.6%
Timber case study	*$ 33,815,777.00*	*-2.9%*

Margin of Error (timber scheme compared to timber case study)	3%	-

Table 15: Total building costs compared.

To construct the design of the case study with an engineered timber structural system, the capital cost was calculated at 4.6% higher than the steel scheme and 5.2% higher than the concrete scheme.

Limitations of total building cost calculations

Lack of origional costing data for the concrete and steel schemes limits the ability to conduct a sensitivity analysis (comparing costs to QV Cost Builder) for the costs of these alternative structural systems. The margin of error represents the accuracy of the costing methodoloy to produce the total building costs of the timber scheme, comparitive to the origional costing data of the timber case study. At 3%, it was safely assumed that this methodology was able to produce accurate results. It is therefore assumed that repeating this methodlogy also provided accurate results for the total building costs of concrete and steel schemes under the scope of this research.

It is assumed that all "other costs" are likely to fluctuate in relation to their structural system and various other external factors relating to budget, context and structure/design schemes. Each of these factors are dependent on various stakeholders, deeming these costs as unquantifiable under the scope of this quantitative research. Without the level of professionalism and detail obtained only through collaboration with architects, engineers and quantity surveyors, discrepancies in the total building cost of the alternative concrete and steel schemes will inevitably exist.

7.0 Discussion of findings

7.1 Capital costs

It was previously acknowledged that a variety of factors impact the limited use of engineered timber at the commercial scale, including lack of local suppliers and lack of professional expertise due to non-established industry workflows. This compares to the well-established workflows resulting from long term commercial scale use of steel and concrete. One of the most notorious examples of high rise construction, the Empire State Building, showcased structural steel and initiated global interest at the commercial scale in 1931 (Willis, 1992). The Home Insurance building, said to be the world's first skyscraper (10 storeys), featured a steel frame structure in 1885 (Turak, 1985) while the first reinforced concrete skyscraper, Ingalls Building (16 storeys) was completed in 1903 (ASCE, 2020). 135 years since the Home Insurance Building marks a significant amount of time for the practice of these industrialised systems to become mastered while engineered timber has only been considered for commercial scale use in the past decade (Barber & Robert, 2014).

Alongside these non-existing engineered timber workflows, lack of research comparing capital costs across these three structural materials is counterproductive. This research concludes that total building capital costs of concrete and steel can be as low as 4.6% - 5.2% less than that of engineered timber. This minimal difference in capital cost stresses the importance of overcoming these industry limitations by establishing workflows as common practice like steel and concrete. Without 135 years of international practice, a 4.6% - 5.2% cost variation suggests promising capital cost efficacy for the future of engineered timber, particularly in relation to other costs of construction including operational and embodied energy (*section 7.2*)

The variation between the final costs of *structural timber* in the case study using the defined costing methodology compared to that of the original tender evaluation, is 28%. The variation between the *total building costs* of the timber case study using the defined costing methodology compared to that of the original tender evaluation, is 3%. The dramatic decrease in variation between these margins of error indicates the significance of acknowledging the cost of structural elements in relation to the total building cost. This is evidenced by the costs of individual tenderers of the case study, where structural timber only represents 10.6% of the total building cost, while the remaining 90.4% are claimed by "other costs". Further research identifying likely areas of "other costs" across timber, concrete and steel structural systems is worthy of investment and could further increase the efficacy of constructing with engineered timber at the commercial scale in NZ.

Future Research

This research identifies the significance of "other costs, often inherently related to the structural system and/or materiality of that system. As an additional output of this research report, a list was initiated to suggest potential capital costs related to timber, concrete and steel structural systems. Prospective clients should be informed of potential savings and/or added expenses inherent to the use of timber, concrete or steel during early phases of design. These costs are often associated with design at a detailed phase and are commonly excluded from preliminary cost estimates, despite their heavy implication at the projects close.

See initiated list in appendix.

7.2 Operational and environmental costs

Operational costs

Structural scheme	Operational Cost per year
Timber	$55,893
Concrete	$67,072 (16.7% Increase from timber)
Steel	$73,799 (24.2% Increase from timber)

Table 16: Operational costs compared. (Appendix 5)

Embodied Energy

Structural scheme	Embodied energy of structural system
Timber (CLT floors, Glulam structure)	2,867,852 MJ
Concrete (concrete floors)	8,416,191 MJ (66% increase from timber)
Steel (concrete floors)	8,860,076 MJ (67.5% increase from timber)

Table 17: Embodied energy compared. (Appendix 5)

Limitations and assumptions

- Calculations for the timber scheme assume all timber is glulam. This aligns with the final costs of the timber scheme where QV Cost Builder was also limited to only glulam.
- The metal decking element of the composite steel and concrete floor system was not included in these calculations due to the inability to produce a cubic metre quantity based on its complex section. The in-situ concrete poured over the decking was included in these calculations for both steel and concrete schemes.

Embodied CO2

Structural scheme	Total embodied CO2 (kg/m3)
Timber (CLT floors, Glulam structure)	-239,864
Concrete (concrete floors)	1,392,479
Steel (concrete floors)	1,185,362

Table 18: Embodied CO2 compared.

(Appendix 5)

These results acknowledge the carbon sequestration capacity of timber as another benefit over concrete and steel.

Figure 4: Pie graphs comparing timber, concrete and steel costs.

The results of this research compare total building capital cost to operational and environmental costs of the case study calculated outside of this report. It is relevant to discuss their relationship in order to justify the overall efficacy of designing in timber. In terms of this research, the term *efficacy* is based on the effect of capital energy use (embodied energy and CO2), building performance (operational cost) and capital cost.

Comparative capital costs determined the engineered timber scheme to be 5.2% and 4.6% higher than concrete and steel respectively. This slight increase in capital cost should be compared to the 66% and 67.5% decrease in embodied energy and 16.7% and 24.2% decrease in annual operational of the engineered timber scheme. This suggests the capital costs of the timber scheme could be paid back 16.7% faster than that of the concrete scheme and 24.2% faster than the steel scheme, based solely on the decrease in operational costs of the timber building. Although this research primarily concerns capital cost, consideration of these ongoing energy costs helps to support the slight greater expense of the timber capital cost, reinforcing the overall efficacy of designing in engineered timber at the commercial scale in NZ.

7.3 Corporate social responsibilities

As discussed, environmental and operational cost savings are a major benefit of designing in timber which are amplified at the commercial scale. Unquantifiable under the scope of this research, savings/benefits which are equally as significant as the cost savings discussed include; the utilisation of a renewable resource (Barber & Robert, 2014), increased wellbeing and productivity (Knox & Parry-Husbands, 2018) and improved indoor air quality (Blackwell, 2017) - all highly valuable benefits of an office environment. After the conscious decision to build in timber has been made, it is the social responsibility of developers, clients and/or leasees to inform the occupants of the building how it should be used to maximise these benefits. It then becomes the social responsibility of the occupants to allow these benefit of a timber structure to be maximised.

8.0 Conclusion

This comparative analysis evidences the expected slight increase in capital costs of designing at the commercial scale in engineered timber, comparative to concrete or steel. Lack of established industry workflows and limitations to the available costing data were acknowledged to impact this result.

In November 2019, New Zealand's largest private construction firm, Naylor Love released results of a recent study claiming that engineered timber structures (based on their 6 storey commercial model) are only 3-4% more expensive to construct than concrete or steel (Steeman, 2019). It is assumed that the amount of available costing data used to conduct Naylor Love's study was significantly greater and of wider range than the *one* case study used to conduct this research. Their findings of 3-4% quality assure the findings of this research at 4.6%-5.2%.

This research is primarily limited by the lack of costing data available to quality assure the steel and concrete alternative schemes. The defined methodology therefore only concerns costing the main structural elements of each scheme. The inability to quantify other costs related to concrete and steel schemes was another limitation of this lack of available data. This was resolved by the assumption that in addition to structural costs, the remaining costs composing the total building costs were consistent across all schemes. Since these other costs are often impacted by the materiality of their corresponding structural system, there is significance in further researching these *other costs*.

This research compares capital costs and briefly acknowledges environmental and operational costs, across timber, concrete and steel structural systems. Assuming that engineered timber industry workflows will become well established overtime (as was the case for concrete and steel) the 4.6%-5.2% increase in capital cost when building in timber is promising when considering the increased benefits of timber in terms of environmental and operational costs.

This research supports the efficacy of engineered timber in commercial scale construction in New Zealand.

Disclaimers:

The original tender evaluation of the cost study was resolved in mid-2018. A 2% increase in these costs acknowledges inflation (Reserve Bank, 2020). Under the scope of this research, this inflation rate has not been applied, although could be considered if this methodology was repeated.

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10.0 Appendices

Notes:

All email and phone communication recorded between Mid-Nov 2019 – Early-Feb 2020.

Appendix 1: Email communication

General format of email questions/quotes:

" Kia Ora,

I am an Architecture Masters Student at Victoria University of Wellington undertaking a Research Scholarship regarding a comparative capital cost analysis of constructing in timber, concrete and steel in NZ.

question

This research aims to support sustainability by proving the efficacy of designing and constructing in NZ timbers. I hope that you can help me to achieve this by providing the requested information.

Kind regards,

Hannah Walsh." .

1. ***TimberLab, RE: Sanding costs.***

"Hi Andrew

Just another quick question! Are you also able to supply me with an estimated rate of sanding the timber?

Many thanks!

Hannah."

"Approx $20/m2 should cover it, remembering typically for most items (columns/posts excluded) sanding is only required to 3 faces (sides and underside)

Regards

Andrew Hewitt"

2. ***XLAM, RE: CLT rates.***

"Good Morning Hannah,

Thanks for reaching out. There is a lot in your topic here. Below are some m2 rates for you to be able to use along with a New Zealand Design Guide so you can see how the spans and loads interplay. "

Panel Designation	**Panel Thickness *(mm)***	**No. m² per m³**	**CLT Rate per m²** ***(Treated Timber) (Non Visual)***	**CLT Rate per m²** ***(Treated Timber) (Visual)***	**CLT Screw Fixings** ***(Range)***

3 Layer Panels											
CL3/90	90	11.1	$	146	$	156	$	11	$	17
CL3/100	100	10	$	162	$	173	$	11	$	17
CL3/110	110	9.1	$	178	$	190	$	11	$	17
CL3/120	120	8.3	$	195	$	209	$	11	$	17
CL3/130	130	7.7	$	210	$	225	$	11	$	17
5 Layer Panels											
CL5/140	140	7.1	$	228	$	244	$	14	$	27
CL5/155	155	6.5	$	249	$	280	$	14	$	27
CL5/170	170	5.9	$	274	$	308	$	14	$	27
CL5/190	190	5.3	$	305	$	343	$	14	$	27
CL5/200	200	5	$	323	$	363	$	14	$	27
CL5/220	220	4.5	$	359	$	404	$	14	$	27

Freight Schedule of Rates per m3		
North Island (From Mercer)		
Freight Region 1 - 100km	$	33
Freight Region 2 - 150km	$	50
Freight Region 3 - 250km	$	67
Freight Region 4 - 350km	$	83
Freight Region 5 - 450km	$	100
Freight Region 6 - 600km		

<u>CLT fixing calculations:</u>

No. of fixings required per m2 based on average spacing of 250mm provided by technical data specification by Egoin (UK CLT company; no NZ manufacturers could provide an average). Average size panel (case study project) = 2.5m2. Average fixings per CLT floor panel = 27 = 11/m2(assuming 9 fixings per edge panel, 12 fixings per central panel).

(UK, 2020)

Cost of fixings provided by XLAM (see above communication) (Used $14, as lowest price from range provided)

Costed as Non-visual due to acoustic floor system topping.

Assuming 94m2 per hour – noted as very common in email comms.

Labour costed via QV Cost Builder as rate for “general labourer” @ 2.3hrs per m2.

3. Lvl / Glulam Quotes

CUSTOMER COPY

Account Address	Job Address		
CASH SALES	CASH SALES	Quote No	W-11760.1
		Date	11/02/2020
		Rep	James Vaotuua

Customer: cash CASH SALES

Account: CASH Job: BEAMS Customer Ref: Op: UV3 Page 1

Item	Description	Unit	Quantity	Price	Value
/NC	TECHLAM PREM POST 88X88 H3.2 GL8 LM	EA	1.000	47.30	47.30
/NC	TECHLAM 300X300 SANDED VISUAL GL8 LM	EA	1.000	594.68	594.68
/NC	TECHLAM 400X300 SANDED VISUAL GL8 LM	EA	1.000	764.62	764.62
/FREIGHT	FREIGHT FROM SUPPLIER	EACH	1.000	76.67	76.67

Deposit: 50% Value: 741.64

Signed: Name: Date:

Note:

GST 193.47
Incl. GST 1483.27

All prices Include GST

ALL PRICES INCLUDE G.S.T.

Customer Ref	Loc	Source	Date	Time	Salesperson	Account #
Estimate Only	293	spor	11/02/20	10:11	Louis S	CASHR

Ln.	Product No	Description	Qty	Price $	UOM	Ext. Amt
		Estimated leadtime (Despatch) 14-15 working days				
1	Techlam Premium	Techlam Premium 270x270 H3.2 6.0m	6	461.20	LM	2,767.20
2	Techlam Premium	Techlam Premium 88x88 GL10 6.0m	6	52.03	LM	312.18
3	Techlam Visual	Techlam Visual 405x290 Sanded GL10 6.0m	6	657.42	LM	3,944.53

Terms: Due Immediately

Includes GST of: 916.16

Total: 7,023.91

WELLINGTON

ALL PRICES INCLUDE G.S.T.

Customer Ref	Loc	Source	Date	Time	Salesperson	Account #
Estimate Only	293	spor	11/02/20	09:44	Louis S	CASHR

Ln.	Product No	Description	Qty	Price $	UOM	Ext. Amt
		**Production Leadtime :12 working days (excluding weekends & holidays)plus 3-5 working days for shipping into Wgtn				
1	Prowood 260x260 1@6.000m	Prowood 260x260VisualPL12/H3.2/KD/G4S 6m	1	2,815.10	EA	2,815.10
2	Prolam 88x88 Vi 1@6.000m	Prolam 88x88 VisualPL12/H3.2/KD/G4S 6.0m	1	177.78	EA	177.78
3	PROLAM 360x260 1@6.000m	PROLAM 360x260Visual/PL12/H3.2/KD/G4S 6m	1	4,299.59	EA	4,299.59

Terms: Due Immediately

Includes GST of: 951.20

Total: 7,292.47

Appendix 2: Phone communication

$ / 1m x 400X90 (405X88) Glulam, H3.3 PL8 visual beam. Excl. GST	Wellington	Auckland	*Average*
Hardware store 1	160	181	170.5
Hardware store 2	212.64	199.25	205.95
Hardware store 3	156.20*	171.17	163.7
Average	176.28	183.8	**180**

Phone call specification:

These quotes obtained over the phone all relate to an H3.3 visual beam, typically for exterior use and full exposure. Depending on the context of the project that this research is applied to, these costs could significantly decrease, for example, if these 405X88 glulam perimeter beams are designed to be encased on the interior of the façade.

Appendix Three: Sizing reference for structural elements

1. **RESIST reports/inputs**

Steel scheme

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walshhann 15:35

RESIST 4.0.0.2475

RESIST(NZ) - Preliminary Lateral Load Design Architectural Report

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RESIST is an application for the simplified evaluation of the structural performance of lateral load-resisting systems in a building under seismic and wind loads. It is designed to be used in educational settings as a guide for the sizing of lateral load resisting systems for Architectural and Civil Engineering students. RESIST should not be used as a final preliminary design; a full, complete preliminary design should be carried out by a structural engineer.

Project: **STEEL**
Modeller: **walshhann**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Steel Moment Frame

	Wind	Seismic (U)	Seismic (S)
Drift	10%	30%	49%
Shear	9%	66%	26%
Moment	13%	95%	55%

Y-Direction: Steel Moment Frame

	Wind	Seismic (U)	Seismic (S)
Drift	17%	32%	52%
Shear	12%	73%	26%
Moment	22%	96%	61%

Wind Vibrations

Irrespective of the wind deflection performance, vibrations could be excessive, but will be improved by increasing building weight. Discuss with a structural engineer. $H^{1.3}/M$ = 2.2 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Normal structures
Number of storeys	8
Total height	34.7 m
Floor plan points	(-11.62, -6.725), (11.62, -6.725), (11.62, 6.725), (-11.62, 6.725)
Floor plan properties	Area: 312.7 m^2; Perimeter length: 73.4 m; Centroid: (0, 0) m; Bound lengths: (23.25, 13.45) m
Inter-storey height	3.9 m
Floor	Weight type: medium, Dead load: 2.90 kPa, Live load: office (3.00 kPa)
Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)

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walshhann 15:35

External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: light, Weight type: light, Height: 3.5 m, Dead load: 0.40 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Steel Moment Frame (x 3) Locations: (0.4421, 1.809), (0.4421, 6.528), (0.379, -6.506)
Structure in Y direction	Steel Moment Frame (x 4) Locations: (6.971, 1.011), (-6.19, 1.137), (11.5, 1.263), (-11.24, 1.137)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	W
Terrain category	City Centre
Lee effect zone	None
Site elevation	100 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	500	25
Regional 3s gust wind speed, V_R (m/s)	51	43

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.60
Soil:	Medium soil (C)
Recurrence interval years:	500 (U) ; 25 (SLS1)
Return Period factor, R:	1.0 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Steel Moment Frame
Design method	Limit-state
Number of frames	3
Number of bays	3
Bay length	4.5m

Floor width supported by beam	4.5m
Column size	Depth: 0.5m, Width: 0.5m
Beam size	Depth: 0.613m, Width: 0.228m
Foundations	Foundation beam: centre-line distance between pads: 13.50 m, square pad width: 4.80 m, pad depth: 0.98 m To anchor the lateral resisting component against tensile uplift, provide 625 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.

Lateral Load Structure, Y Direction

Type	Steel Moment Frame
Design method	Limit-state
Number of frames	4
Number of bays	2
Bay length	5.5m
Floor width supported by beam	5m
Column size	Depth: 0.55m, Width: 0.55m
Beam size	Depth: 0.671m, Width: 0.243m
Foundations	Foundation beam: centre-line distance between pads: 11.00 m, square pad width: 5.00 m, pad depth: 1.00 m To anchor the lateral resisting component against tensile uplift, provide 650 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.

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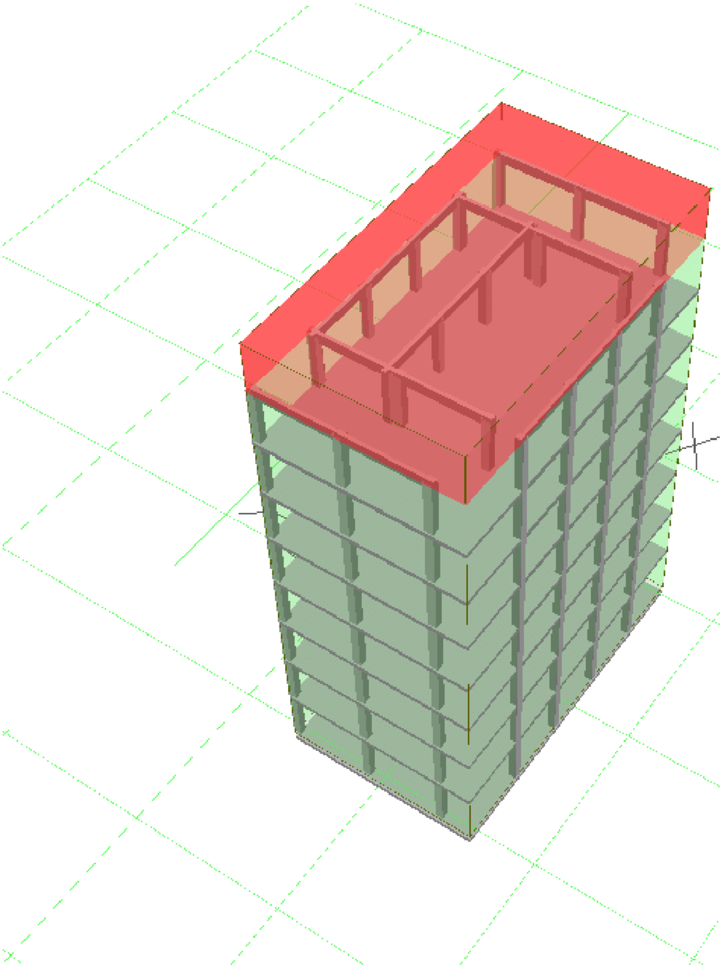

RESIST Limitations

RESIST has been designed as an education tool, primarily for Architecture students, as a means for initial sizing of lateral resisting elements for wind and earthquake loading.

RESIST may be used as a small part of the overall design process:

1. Initial preliminary design. RESIST can be used as a way of initial sizing and testing options, providing a point of discussion between architects and engineers.
2. Once a conceptual design has been formulated, the Structural Engineer will carry out another preliminary design, where ALL assumptions and initial sizes are re-evaluated for accuracy and appropriateness. RESIST cannot be used as a substitute for a complete preliminary design by a Structural Engineer.
3. Final design will follow from the structural engineer's preliminary design, and the results from RESIST should have no

RESIST(NZ) 4.0.0.2475 \\stustocoiscifs1\FAD_Users$\walshhann\Desktop Page 4 of 5
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influence on this stage of the structural design.

RESIST does not analyse or design the following:

- Floor diaphragms are not evaluated by RESIST. It is assumed that the floor diaphragms have sufficient rigidity and strength to transfer loads to all the resisting elements. They are assumed to be rigid. The floor plan editor allows non-rectangular floor diaphragms, which if highly irregular will require careful design by the Structural Engineer.
- Connections within the resisting elements and the rest of the building are not analysed or designed by RESIST. Such connections are critical to the performance of the building, and are assumed by RESIST to be have sufficient strength to ensure the expected performance of the resisting elements.
- RESIST assumes the lateral structure to be uniform for the full height of the building. In practise section sizes will reduce with height, but this requires careful design by the Structural Engineer.
- The design of Steel Eccentric Braced Frames (EBF) requires careful design to ensure they behave as expected. RESIST only carries out an initial assessment of the design of the EBF; there are many other aspects to the design of EBF that will require design by the Structural Engineer.
- RESIST uses an elastic approach for evaluating torsion effects. Generally torsion effects should be evaluated by taking into account inelastic deformations.
- RESIST does not carry out a design of gravity load support system, e.g. columns and beams, floor system.
- The lateral resisting systems provided by RESIST are only representative of the possible choices currently available. New technologies such as buckling restrained braced frames, base isolation, and other systems may be a suitable choice for a building. The Structural Engineer will provide guidance.
- Fire protection of members is not accounted for by RESIST. If required this may require an increase in the overall size of the members.
- RESIST does not analyse hybrid resisting systems where different resisting systems are used in the same direction, e.g. walls and frames.
- RESIST allows only resisting systems aligned to X and Y axes.

2. Concrete Sheme

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RESIST(NZ) - Preliminary Lateral Load Design Architectural Report

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Project: **CONCRETE**
Modeller: **walshhann**

Analysis Results

Results are percentage of max. allowable: <= 100% is OK; > 100% is Failure.
U=Ultimate Limit State, S=Serviceability Limit State (for smaller earthquakes that occur more frequently).

X-Direction: Reinforced Concrete Wall

	Wind	Seismic (U)	Seismic (S)
Drift	2%	61%	46%
Shear	2%	74%	49%
Moment	2%	56%	57%

Y-Direction: Reinforced Concrete Wall

	Wind	Seismic (U)	Seismic (S)
Drift	12%	94%	64%
Shear	3%	18%	14%
Moment	6%	30%	36%

Wind Vibrations

The building does not appear to be susceptible to wind vibrations or other serviceablility problems caused by wind. $H^{1.3}/M$ = 1.33 (should be less than 1.60; where H=building height (m) and M=Mass of building per unit height of building (tonnes/m))

Building Construction

Building Importance category	Normal structures
Number of storeys	8
Total height	35.5 m
Floor plan points	(-11.62, -6.725), (11.62, -6.725), (11.62, 6.725), (-11.62, 6.725)
Floor plan properties	Area: 312.7 m^2; Perimeter length: 73.4 m; Centroid: (0, 0) m; Bound lengths: (23.25, 13.45) m
Inter-storey height	4 m
Floor	Weight type: medium, Dead load: 2.90 kPa, Live load: office (3.00 kPa)
Interior wall	Weight type: light, Dead load: 0.30 kPa (over floor area)

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External wall	Weight type: light, Dead load: 0.33 kPa (over wall area)
Roof	Weight type: medium, Weight type: medium, Height: 3.5 m, Dead load: 0.80 kPa (over floor area), Live load: 0.25 kPa (over floor area)
Structure in X direction	Reinforced Concrete Wall (x 2) Locations: (-0.06316, 0.8531), (0.06316, 6.528)
Structure in Y direction	Reinforced Concrete Wall (x 3) Locations: (6.148, 3.651), (-6.253, 3.698), (0.0478, 3.561)

Wind and Terrain Information

Design code	AS/NZS 1170.2:2002
Wind Region	W
Terrain category	City Centre
Lee effect zone	None
Site elevation	100 m

Regional 3 sec Gust Wind Speed

The regional 3 second gust speed (V_R) depends on the wind region, building design working life, building importance, and the limit state under consideration.

Limit State	Ultimate	Serviceability (SLS1)
Recurrence interval (yrs)	500	25
Regional 3s gust wind speed, V_R (m/s)	51	43

Seismic Information

Design code:	NZS 1170.5:2004
Hazard factor, Z:	0.60
Soil:	Medium soil (C)
Recurrence interval years:	500 (U) ; 25 (SLS1)
Return Period factor, R:	1.0 (U) ; 0.25 (SLS1)

Lateral Load Structure, X Direction

Type	Reinforced Concrete Wall
Design method	Limit-state
Number of walls	2
Wall length	13.000 m
Wall thickness	250 mm
Foundations	Foundation beam: centre-line distance between pads: 10.40 m, square pad width: 6.80 m,

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walshhann 15:36

	pad depth: 1.38 m To anchor the lateral resisting component against tensile uplift, provide 850 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Penetrations in structural walls	As the wall shear stress is high, only very small penetrations for services (max. 300 mm) are allowable for the greater of one storey or a height equal to the wall length. Above this level larger penetrations are possible.
Minimum thickness	The minimum thickness to prevent wall buckling is 223 mm. The current thickness of 250 mm is sufficient.

Lateral Load Structure, Y Direction

Type	Reinforced Concrete Wall
Design method	Limit-state
Number of walls	3
Wall length	6.000 m
Wall thickness	600 mm
Foundations	Foundation beam: centre-line distance between pads: 4.80 m, square pad width: 5.70 m, pad depth: 1.15 m To anchor the lateral resisting component against tensile uplift, provide 700 mm diameter tension resisting piles. These piles will probably have bulbs or bells at their bases to provide the tension resistance.
Penetrations in structural walls	Penetrations for doors, windows and services up to 30% of the wall length at ground floor, and greater above are allowed.
Minimum thickness	The minimum thickness to prevent wall buckling is 240 mm. The current thickness of 600 mm is sufficient.

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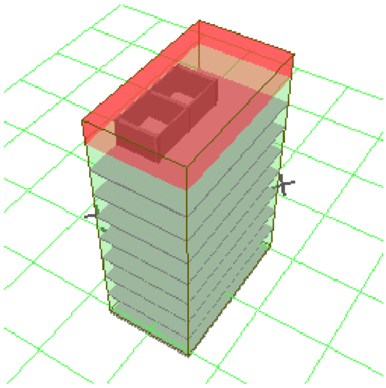

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to ensure the expected performance of the resisting elements.

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3. **“Rule of Thumb” sizing for gravity load resisting structural elements (not calculated by RESIST). Communication with Guy Marriage – Registered Architect and Author of *Tall: the design and construction of high-rise architecture* (Marriage, 2019)**

“ Hi Guy!

Hope you had a nice break!

I need a viable reference for calculating concrete and steel beam and column sizes. I am looking at the Schodek 2003 table for steel, but i cant find anything for concrete.

Also, the Schodek tables only size beams.. what are your 'rules of thumb' for concrete and steel members that I can use for the time being? I will eventually also need to reference a viable source.

Many thanks!

Hannah.”

“Morning Hannah,

BEAMS

So - basic Rules of Thumb I have used in TALL is Span/20 = beam depth (concrete, steel). (And width = approx half depth)

But Timber = Span/13 = beam depth (timber). (And width = approx a quarter of depth)

re Beams: We can use the column spacing = the span of the beam, right? So, 1/20 of the span will be a guide to the beam depth ie if a 9.0m span, then beam depth will be 450 deep. OK?

That will go for BOTH steel and concrete beams. Except, of course, that a 450 deep steel beam will then likely be a UB460 and that’s 190 wide. Refer to Table 3.2 in my book.

A concrete beam of 450 deep would be half the depth wide ie 225 wide.

All those figures are separate from the actual slab thickness, of course.

That’s what I suggested planning into the Excel spreadsheet originally, remember? So that if you changed the column spacing, the rest would update accordingly.

COLUMNS

Very tricky to give you any reliable Rules of Thumb on columns - as column size will depend on height of building and span and seismic zone etc, as well as whether the column is working as a Moment frame or just as a Gravity load only…. But….

A similar possible Rule of Thumb for Columns might be for a steel column to be two thirds the depth of the beam depth ie if beam is 450 deep, column could be 300x300. Gravity load only.

A concrete column of a similar span might be the same as the depth of the beam ie with a concrete beam depth of 450 deep, expect a concrete column of 450x450 size.

We’d need to run those past an Engineer, but they should do you as Rules for the moment. Hopefully OK ?

I've enclosed a bunch of Tables from my book to help explain, and you can reference them as a Source.

Cheers,

Guy"

NZ Span tables

3.4.1: Steel UB and UC

Dimensions and Properties

Universal Columns

Designation		DIMENSIONS: Depth of Section d	Flange Width b_f	Flange Thickness t_f	Web Thickness t_w	Radius Root r	Depth between flanges d_1	RATIOS: $\frac{d_1}{t_w}$	$\frac{(b_f - t_w)}{2t_f}$	PROPERTIES: Gross Section Area A	Profile Surface Area	About x-axis I_x	About x-axis Z_x	About x-axis S_x	About x-axis r_x	About y-axis I_y	About y-axis Z_y	About y-axis S_y	About y-axis r_y	Torsion Constant J	Warping Constant I_w
	kg/m	mm	mm	mm	mm	mm	mm			mm^2	m^2/m	$10^6 mm^4$	$10^3 mm^3$	$10^3 mm^3$	mm	$10^6 mm^4$	$10^3 mm^3$	$10^3 mm^3$	mm	$10^3 mm^4$	$10^9 mm^6$
310UC	283	365	322	44.1	26.9	16.5	277	10.3	3.35	36100	1.94	788	4320	5100	148	246	1530	2340	82.6	20500	6330
310UC	198	340	314	31.4	19.2	16.5	277	14.4	4.69	25300	1.87	509	3000	3440	142	162	1030	1580	80.1	7400	3860
310UC	137	320	309	21.7	13.8	16.5	277	20.0	6.80	17500	1.82	327	2050	2300	137	107	691	1050	78.2	2520	2380
310UC	96.8	308	305	15.4	9.91	15.2	277	28.0	9.58	12300	1.79	222	1440	1590	134	72.9	478	725	76.8	912	1560
250UC	89.5	260	256	17.3	10.5	12.7	225	21.5	7.10	11400	1.50	142	1090	1220	112	48.4	378	574	65.3	1030	713
250UC	72.9	254	254	14.2	8.64	12.7	226	26.1	8.64	9300	1.48	114	896	990	111	38.8	306	463	64.6	576	558
200UC	59.5	210	205	14.2	9.27	12.7	182	19.6	6.89	7640	1.20	61.6	587	659	89.8	20.4	199	303	51.7	486	196
200UC	52.2	206	204	12.5	8.00	12.7	181	22.6	7.84	6690	1.19	52.8	513	571	88.9	17.7	174	264	51.5	333	166
200UC	46.2	203	203	11.0	7.32	12.7	181	24.7	8.89	5930	1.18	45.9	452	501	88.0	15.3	151	230	50.9	235	141
150UC	37.2	162	154	11.5	8.13	10.2	139	17.1	6.34	4760	0.906	22.3	276	312	68.5	7.01	91.0	139	38.4	203	39.7
150UC	30.0	158	153	9.37	6.55	10.2	139	21.3	7.81	3870	0.897	17.7	224	251	67.7	5.60	73.2	112	38.0	112	30.9
150UC	23.4	152	152	6.83	6.10	10.2	138	22.7	10.7	3010	0.882	12.7	167	186	64.9	4.00	52.7	80.7	36.5	53.3	21.1
100UC	14.8	97.0	99.0	7.01	5.00	10.2	83.0	16.6	6.70	1890	0.562	3.19	65.8	74.6	41.1	1.14	23.0	35.3	24.5	35.4	2.30

Dimensions and Properties

Universal & Taper Flange Beams

Designation		DIMENSIONS: Depth of Section d	Flange Width b_f	Flange Thickness t_f	Web Thickness t_w	Radius Root r	Depth between flanges d1	RATIOS: $\frac{d_1}{t_w}$	$\frac{(b_f - t_w)}{2t_f}$	PROPERTIES: Gross Section Area A	Profile Surface Area	About x-axis I_x	About x-axis Z_x	About x-axis S_x	About x-axis r_x	About y-axis I_y	About y-axis Z_y	About y-axis Z_y	About y-axis r_y	Torsion Constant J	Warping Constant I_w
	kg/m	mm	mm	mm	mm	mm	mm			mm^2	m^2/m	106mm4	103mm3	$10^3 mm^3$	mm	$10^6 mm^4$	$10^3 mm^3$	$10^3 mm^3$	mm	$10^3 mm^4$	$10^9 mm^6$
760UB	220	776	270	28.3	17.4	16.5	719	41.3	4.46	28000	2.57	2710	6980	8050	311	93.2	690	1090	57.7	5580	13000
760UB	197	770	268	25.4	15.6	16.5	719	46.1	4.97	25100	2.55	2400	6240	7170	309	81.7	610	959	57.1	4040	11300
760UB	173	762	267	21.6	14.3	16.5	719	50.3	5.85	22000	2.54	2050	5390	6200	305	68.7	515	809	55.8	2670	9420
760UB	147	754	265	17.5	12.9	16.5	719	55.7	7.20	18800	2.51	1690	4480	5170	300	54.4	411	647	53.8	1600	7380
690UB	140	684	254	19.0	12.4	15.2	646	52.1	6.36	17900	2.33	1370	3990	4570	277	52.0	410	640	54.0	1690	5750
690UB	125	678	253	16.2	11.7	15.2	646	55.2	7.45	15900	2.32	1180	3480	3990	272	43.8	346	542	52.4	1160	4800
610UB	125	612	229	19.6	11.9	12.7	573	48.1	5.54	15900	2.09	985	3220	3670	249	39.3	343	535	49.7	1540	3450
610UB	113	607	228	17.3	11.2	12.7	572	51.1	6.27	14400	2.08	872	2870	3280	246	34.3	300	469	48.7	1120	2980
610UB	101	602	228	14.8	10.6	12.7	572	54.0	7.34	13000	2.07	759	2520	2890	242	29.3	257	402	47.6	777	2530
530UB	92.4	533	209	15.6	10.2	12.7	502	49.2	6.37	11800	1.86	552	2070	2360	217	23.8	228	355	44.9	762	1590
530UB	82.0	528	209	13.2	9.55	12.7	502	52.5	7.55	10400	1.85	475	1800	2060	213	20.1	193	301	43.9	513	1330
460UB	82.1	460	191	16.0	9.91	10.2	428	43.2	5.66	10400	1.65	370	1610	1830	188	18.6	195	303	42.2	692	918
460UB	74.6	457	190	14.5	9.09	10.2	428	47.1	6.24	9490	1.64	333	1460	1650	187	16.6	175	271	41.8	521	813
460UB	67.1	454	190	12.7	8.48	10.2	429	50.5	7.15	8550	1.63	295	1300	1470	186	14.5	153	238	41.2	371	708
410UB	59.7	406	178	12.8	7.80	10.2	380	48.8	6.65	7610	1.49	215	1060	1190	168	12.1	135	209	39.8	330	466
410UB	53.7	403	178	10.9	7.59	10.2	381	50.2	7.82	6860	1.49	187	930	1050	165	10.3	115	179	38.7	229	394
360UB	56.7	359	172	13.0	7.95	10.2	333	41.9	6.31	7210	1.37	161	896	1010	149	11.0	128	198	39.1	330	330
360UB	50.7	356	172	11.5	7.29	10.2	333	45.7	7.16	6470	1.37	142	799	898	148	9.77	114	175	38.8	236	290
360UB	44.7	352	171	9.73	6.86	10.2	333	48.5	8.43	5700	1.36	121	687	774	146	8.12	95.0	147	37.8	157	238
310UB	46.2	307	166	11.8	6.73	8.89	283	42.1	6.75	5890	1.25	99.5	648	723	130	9.01	108	166	39.1	223	196
310UB	40.4	304	165	10.2	6.10	8.89	284	46.5	7.79	5160	1.24	85.6	563	627	129	7.64	92.7	142	38.5	149	165
310UB	32.0	298	149	8.00	5.50	13.0	282	51.3	8.97	4080	1.16	63.2	424	475	124	4.42	59.3	91.8	32.9	86.5	92.9
250UB	37.3	256	146	10.9	6.40	7.62	234	36.6	6.40	4730	1.07	55.3	432	484	108	5.66	77.5	119	34.6	154	85.0
250UB	31.4	252	146	8.64	6.10	7.62	235	38.5	8.10	4000	1.06	44.6	354	397	106	4.49	61.5	94.5	33.5	87.4	66.4
250UB	25.7	248	124	8.00	5.00	12.0	232	46.4	7.44	3270	0.961	35.4	285	319	104	2.55	41.1	63.6	27.9	67.4	36.7
200UB	29.8	207	134	9.60	6.30	7.62	188	29.8	6.65	3810	0.924	29.0	280	314	87.3	3.85	57.5	88.3	31.8	102	37.6
200UB	25.4	203	133	7.82	5.84	7.62	187	32.1	8.13	3220	0.913	23.4	231	259	85.3	3.07	46.2	71.0	30.9	61.0	29.2
200UB	22.3	202	133	7.00	5.00	8.90	188	37.6	9.14	2870	0.911	21.1	208	232	85.6	2.75	41.3	63.4	30.9	45.0	26.1
200UB	18.2	198	99.0	7.00	4.50	11.0	184	40.9	6.75	2320	0.764	15.8	160	180	82.6	1.14	23.0	35.7	22.1	38.6	10.4
180UB	22.2	179	90.0	10.0	5.99	8.99	159	26.5	4.20	2820	0.691	15.3	171	195	73.6	1.22	27.1	42.3	20.8	81.8	8.71
180UB	18.1	175	90.0	8.00	5.00	8.99	159	31.8	5.31	2300	0.685	12.1	139	157	72.6	0.975	21.7	33.7	20.6	44.9	6.80
180UB	16.1	173	90.0	7.00	4.50	8.90	159	35.3	6.11	2040	0.682	10.6	123	138	72.0	0.853	19.0	29.4	20.4	31.5	5.88
150UB	18.0	155	75.0	9.50	5.99	8.00	136	22.7	3.63	2290	0.584	9.05	117	135	62.8	0.672	17.9	28.2	17.1	60.4	3.56
150UB	14.0	150	75.0	7.00	5.00	8.00	136	27.2	5.00	1780	0.576	6.66	88.8	102	61.1	0.495	13.2	20.8	16.6	28.1	2.53
125TFB	13.1	125	65.0	8.50	5.00	8.00	108	21.6	3.53	1670	0.470	4.34	69.4	80.3	50.9	0.337	10.4	17.2	14.2	40.2	1.14
100TFB	7.20	100	45.0	6.00	4.00	7.00	88.0	22.0	3.42	917	0.349	1.46	29.2	34.1	39.9	0.080	3.53	6.01	9.31	11.6	0.176

Source:
https://www.easysteel.co.nz/web/assets/ESY0200_EasysteelStructuralPropertiesBookWeb_%C5%B8_v2.pdf

3.4.2: TrayDec80

Propped spans (single/multi), one prop

Slab Depth (mm)	Construction Stage	Composite Stage – Imposed Load				
		1.5 kPa	2.0 kPa	3.0 kPa	5.0 kPa	10.0 kPa
130	–	4.7	4.6	4.3	3.9	3.3
140	–	4.9	4.8	4.5	4.1	3.5
150	–	5.1	5.0	4.7	4.3	3.7
160	–	5.3	5.2	4.9	4.6	3.9
180	–	5.8	5.6	5.4	5.0	4.4
200	–	6.2	6.1	5.8	5.4	4.8
220	–	6.6	6.5	6.2	5.9	5.2

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Source: https://traydec.co.nz/wp-content/uploads/2019/11/Tray-dec-Product-Guide.pdf

Email communication: TrayDec80 specs

"Kia Ora,

I am an Architecture Masters Student at Victoria University of Wellington undertaking a Research Scholarship regarding a comparative capital cost analysis of constructing in timber, concrete and steel in NZ.

Part of my research involves using your product: Tray-Dec 80 among calculations. I was wondering if you could provide me with a quote to increase the accuracy of my research?

Specifically, could you provide me with the square meter rate for Tray-Dec 80, 200 AND 220mm, 3kPa loading, propped span flooring system.

This research aims to support sustainability by providing cost-based incentive to construct using NZ timbers. I hope that you can help me to achieve this by providing the requested information.

Thank you very much for your time.

Hannah."

"Hi Hannah -

A lot goes into a quote that is very site specific - a simple example is that if the job is out of town we charge more for mobilization. Tray prices are also take into account installation prices which is also site specific. But to keep it simple if we are providing the material alone and the licensed building practitioner chooses to install themselves we sell Tray-dec 80 1.2mmt at $49/sq and Tray-dec 80 0.95mmt at $43/sq. The thickness of the tray are determined by the construction loads of the wet concrete and the span length. Given that the tray will be propped as you said, its safe to assume to use TD80 0.95t. You can assume the LBC will install 30sq m/ man/day. One of our 4 man crews will install roughly 150sq/day at $100/man/hr.

As so the 200mm and 220mm profiles, I think you might be referring to slab height. We don't have profiles above 80 mm but it is common to have slabs at 200mm and 220mm. If you need concrete pricing you can reference our tables online for concrete usage/sq. m. For a 200mm slab using TD80 you will use 0.16m^3 concrete per sq. m of tray. For a 220mm slab you will use 0.18m^3 concrete per sq m of tray. Hope this helps."

Appendix four: QV Cost Builder Directory

QV Cost Builder: Definition of costed elements and directory reference

Note: Costed elements not included on the following lists were costed using industry prices outside of QV Cost Builder and are discussed throughout this report.

Source: https://www.qvcostbuilder.co.nz/app.html#/home/book/page-id/048ba0da-9731-4eb0-9aa6-c63d7badfc9b

Definition of concrete elements costed

Element name	QV Cost Builder Detailed Description	QV Cost Builder directory
Precast Concrete Column 300X300	*Precast Concrete Column,* reinforcing 250kg/m3, supply, transport up to 40km, erection, propping, grouting complete	*Detailed Rates > Frame > Columns*
Precast Concrete Solid Beam 350X250	*Precast Concrete Solid Beam,* reinforcing 200kg/m3, supply, transport up to 40km, erection, propping, grouting complete	*Detailed Rates > Frame > Beams*
Insitu slab (reinforced)	Topping slab to precast floor	*Detailed Rates > Concrete Work > Reinforced Concrete*

Definition of steel elements costed

Element name	QV Cost Builder Detailed Description	QV Cost Builder directory
690UB254	*Universal Columns and Beams* Steel supply, including waste, consumables, Cartage to site, unloading, Shop fabrication, Site erection, Crane hire, plant, overheads, Margin of 5%.	*Detailed Rates > Structural Steelwork > Major Steel Work, Supply and Erect > Universal Columns and Beams*
410UB178	*As above*	*As above*
310UC	*As above*	*As above*
Insitu slab (reinforced)	Topping slab to precast floor	*Detailed Rates > Concrete Work > Reinforced Concrete*

Definition of timber elements costed

Element name	QV Cost Builder Detailed Description	QV Cost Builder directory
Glulam Beam 400X300	*Glulam Timber Beams,* H1.2 treatment, sanded	*Detailed Rates > Laminated Timber > Beams*

Glulam Beam 600X300	*As above*	*As above*
Glulam Beam 300X300	*As above*	*As above*
Glulam Beam 400X90	*As above*	*As above*

Appendix Five: Cost calculations

Full excel spreadsheets here? - See final costs spreadsheet.

Acknowledgements to Jackson Prattley-Jones for the following calculations

Embodied energy /co2 cost calculations

Timber (Glulam):

MJ/m3: 5,727 * 500.76 = 2,867,852.52 MJ

CO2/m3: -479 *500.76 = -239,864 CO2

Concrete:

MJ/m3: 11,393*738.716 = 8,416,191 MJ

CO2/m3: 1,885*738.716 = 1,392,479 CO2

Steel:

MJ/m3: 245,757*9.076 = 2,230,490.2 MJ
MJ/m3: 11,393*581.9 = 6,629,586.7 MJ
Total: 8,860,076 MJ

CO2/m3: 9,749*9.076 = 88,481
CO2/m3: 1,885*581.9 = 1,096,881.5
Total: 1,185,362 CO2

Source: https://www.wgtn.ac.nz/architecture/centres/cbpr/resources/pdfs/ee-co2_report_2003.pdf

Operational cost calculations

Timber: 331,123 kWh.yr * $0.1688 = $55,893

Concrete: 3973,47 kWh.yr * $0.1688 = $67,072 (16.7% Increase from timber)

Steel: 437,082 kWh.yr * $0.1688 = $73,799 (24.2% Increase from timber)

MBIE Source: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/electricity-cost-and-price-monitoring/

Empire State of Wood.

(Green, 2020)