University of Southern Queensland

Faculty of Health, Engineering and Sciences

Develop a framework for residential construction cost estimating in the Australian market.

A dissertation submitted by

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Abstract

Time is a valuable resource in the construction industry and it is critical to the financial success of a project that accurate cost estimates are produced. Several methods of estimating currently exist with varying degrees of accuracy and completion time. First principle estimating is the most time consuming, often taking hours to complete, however is the most accurate. The unit rate method is quick to apply although it suffers from inaccuracy. A need exists for an accurate method of cost estimating that can be quickly applied. This study solves the problem by developing a framework for cost estimating based on the residential construction sector in the Australian market, which has not been done previously.

The approach taken in this study is based on cost modelling, which is a method of statistically predicting construction costs using input variables known as cost drivers. Cost drivers are factors of statistical significance that affect the total cost of a construction project. The literature review found that previous cost modelling studies focused on a broad range of cost drivers which yield a model that is not commercially viable and inaccurate. Therefore, this study has focussed on design related cost drivers only. This will improve accuracy and the commercial viability of the framework. Previous studies used cost data from publicly available or historical sources. This data includes contractor mark-up strategies, risk contingencies, variance in construction methodology and fluctuations in unit costs between localities which skew results. This study will utilise an up-to-date cost estimating database available in the construction industry for uniform data collection. It will also focus on construction cost only rather than final project cost, this removes the influence of mark-up and contingency factors. These steps will ensure the relevance of the developed framework.

A case study using semi-structured interviews was conducted on a cost estimating company in the residential sector of the Australian construction industry. The purpose was to confirm that the first principle estimating method is currently used, it is time consuming and the most accurate method available. It also examined the validity of cost drivers found in the literature review and expanded the design related cost drivers used for the statistical analysis. In addition, the case study findings were used to calculate a first principle estimate on 170 house designs. This method was used to create the cost data samples for the statistical analysis.

A statistical analysis was conducted on the sample data using SPSS which resulted in a model that predicts the construction cost for a project. Linear regression analysis and two neural network models were tested. Models from previous studies range in accuracy from 3.98% to 19.60%, this level of accuracy is not deemed commercially viable. With a focus on design related cost drivers this study found linear regression analysis performed best and improved the accuracy of previous studies to a mean absolute percentage error (MAPE) of 1.70%. The linear regression statistical model was used to develop the framework.

The discoveries of this study benefit cost estimating professionals by offering an estimating method that is accurate, which can be applied faster than traditional first principle methods. The framework can be operated by users with little training compared to fully qualified estimators completing first principle estimates. Further development of this technique, which involves design related cost drivers only, can be applied to other sectors on the construction industry. This has the potential to lower resources for companies tendering for the procurement of work by offering an accurate method that reduces the time and skill to apply.

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Limitations of use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Table of contents

List of tables

List of figures

List of appendices

Chapter 1 – Introduction

This section will introduce the research project and detail the background for the problem along with its need to be researched. A clear definition of the problem will be detailed along with the aims and objectives this research project will achieve.

1.1 Outline of the study

The need for this project was identified through industry work experience within a Queensland based estimating company (the Company) that specialises in providing residential housing cost estimates for contractors during the concept design stage of the project. It has been recognised that accurate cost estimates from first principle methods take time and skill to perform. During periods of high-volume turnover, tight deadlines often hinder the availability of resources causing inaccuracies in cost estimates and a limit on productivity. This study will develop a framework that will reduce the time it takes for cost estimates without a significant reduction in accuracy when compared to traditional techniques like first principle estimating. This will help professionals in the industry improve productivity by providing a reliable alternative method of cost estimating.

1.2 Introduction

Often full design documentation is not available during the initial concept stage of the project. The documents available typically consist of a site plan, floor plan and elevations. This has been found to be common in residential housing construction in Australia for project and volume custom home builders with contracts entered based solely on concept plans and their initial cost estimates. A need for accurate concept estimates is critical to ensure the contractor remains profitable during execution of the contract. There are a few options used to arrive at an initial construction cost estimate in the industry, all with varying levels of accuracy and time. The most accurate method of estimating is based on a first principle build-up of costs which consist of allocating quantities and rates against a breakdown of statutory and consultant fees, materials, labour, plant and machine hire and subcontract works. This is achieved through a builder's bill of quantities (BOQ) which is an abridged and less formal version of a bill of quantities produced by a professional Quantity Surveyor.

The Company currently employs the first principle method of cost estimating and utilises software packages to improve the speed and accuracy of the process. However, these processes can only be improved up to a point as the method itself is time consuming. Depending on the complexity of the design and skill of the estimator it can take anywhere from two to four hours to extract the quantities and assign rates to build a baseline construction estimate. A baseline cost estimate will focus on the construction cost of the project only and exclude any profit margins and off-site overheads. It is common in residential construction, especially design and construct contractors, to formulate a baseline estimate on a standard level of inclusions and finishes. The baseline estimate can then have profit and overhead margins added on top to reach a proposal price for the client.

A need exists for a more efficient way to produce a baseline cost estimate without a significant loss in accuracy. The development of this framework will reduce the time it takes for a cost estimate, this will increase the turnover of estimates and lower company overheads. Whilst cost models involving statistical methods have been developed and researched for many decades, it was found that the accuracy is not commercially viable and may result in too much variance in cost to enter a contract and retain profit for the contractor. To the best of knowledge, no relevant framework or study exists with a focus on the residential housing sector in the Australian market involving cost modelling.

1.3 The problem

Much research has been performed in cost modelling construction projects. Cost modelling consists of applying a statistical analysis to a sample data set to predict an output. There has been a focus on highly complex and varied types of buildings within previous studies which often leads to variance in output accuracy detracting from the viability of the model. Many studies utilise information that span different localities, construction methodologies and completion dates for the sample data. The problem with this method is that there is no uniform comparison between the sample data sets. This can lead to inaccuracy and unreliable results from the cost model.

There can be many factors that contribute to the final price of a project in addition to the cost of construction itself. A list of possible contributing factors are detailed below:

- Market influences such as labour shortages, material supply issues, competition or local authority requirements.
- Profit markup strategy by the contractor. The profit margins contractors apply to projects will vary based on current workload and the perceived risk. This can vary greatly between projects and contractors.
- Location of the project can have variances in supply and labour rates.
- Construction methodology and type of construction materials employed.
- Level of finish and inclusions.
- Site conditions such as rock excavation or significant slope.
- Design factors such as the number of bathrooms or a complex design layout.

Previous studies have attempted to capture some or all the variable factors in the model they developed. Due to the vast amount of variance and significant ambiguity in such a method, this leads to a model that can be inaccurate. The aim of this study is to remove ambiguity through a narrow focus on design related factors or input variables (cost drivers) that will be identified through a literature review and a case study. This will formulate a model that has a relatively high level of accuracy when tested against test sample estimates.

A problem often found in cost modelling framework is the inability of the model to be periodically updated when construction costs fluctuate. Previous studies have also utilised historical data that may or may not have had up-to-date costs available when performing a statistical analysis. These models quickly become obsolete when trying to predict future construction costs if the data cannot be periodically updated and the model parameters reapplied for a revised framework. A framework that can be updated when construction costs fluctuate will be a critical component of this research project.

Time is a critical resource in construction and this study aims to reduce the time it takes to formulate a construction cost estimate. Currently a problem exists with the volume of work and the time it takes using the Company's current method of estimating. This is a common issue in the industry as time is often limited. It can take significant resources and skill to consistently output accurate estimates so a need for a more efficient method is required. A first principles estimate, no matter how well the software is set up or skill of the user, is a methodical and time-consuming process and often prone to human error. This problem can be solved with a cost modelling framework consisting of input variables which can be quicky and easily extracted from the information available during the concept design stage. This has the potential to complete a baseline cost estimate in a matter of minutes for an estimator with minimal training compared to the hours it takes for a first principle estimate to be produced.

The aim of this research project is to develop a framework that reduces the time it takes to estimate construction costs of Australian residential dwellings in comparison to traditional first principle methods through a cost modelling statistical analysis of cost drivers relating to design factors only.

1.4 Research objectives

1.4.1 Identify current cost estimating techniques

A literature review will be conducted to determine some of the current methods of cost estimating with a particular focus on residential construction, however general methods will also be reviewed to understand current practices within the industry. Research will also be conducted into any current statistical cost modelling methods, how those studies were conducted, the accuracy of the output and the tests used to determine the accuracy of the model.

A case study of the Company will be conducted to further develop an understanding of how cost estimating is currently performed in Australia, particularly the Queensland region, and to validate the findings from the literature review. Industry professionals will be observed and interviewed to ascertain how first principle estimating is currently conducted. This will determine the method this research project will use to calculate the construction costs of the sample data sets used in the statistical analysis.

1.4.2 Identify potential cost drivers

Potential cost drivers will be identified through a review of literature and semi-structured interviews conducted through a case study of the Company. The case study will serve to validate and expand the list of potential cost drivers found during the literature. These cost drivers will form the input variables for the statistical analysis required to develop the cost modelling framework.

1.4.3 Develop cost model framework

Using the estimating methods determined from the case study, concept designs will be randomly selected and construction costs calculated to form a data set. This data set will be analysed with a statistical software package using the various techniques determined through the literature review. The software systems and concept plan library available through the Company will be used to collect sample data. The data will be validated using statistical tests to analyse the output from the model. Once validated the output from the models will be compared against test samples with construction costs calculated from first principles to determine the accuracy of the cost model predictions.

The best statistical model will be selected based on certain criteria and will be used to develop the framework. The framework must allow for a cost estimate to be completed relatively quickly through the extraction of simple input variables available from concept plans. To remain relevant and reliable the framework must be able to be periodically updated when construction costs fluctuate. A methodology to update the framework will be developed.

1.5 Conclusions

Previous studies in cost modelling have had a broad focus on cost drivers which have led to models that are inaccurate and often irrelevant. No previous cost modelling studies have been identified that focus on residential construction in the Australian market. Through a review of literature and case study of a cost estimating company this research project will develop a framework with a narrow focus on design related cost drivers which will yield a more accurate and robust cost modelling framework. The resources of the Company will be utilised to gain access to up-to-date methods and construction costs when developing the framework. Test samples will be used to test the validity of the model by comparing the output against calculated first principle construction costs.

Chapter 2 – Literature review

2.1 Introduction

To develop the cost modelling framework the current method of procurement and cost estimating in the Australian market must be established. This will lead to the collection of construction cost data and cost driver identification so statistical cost modelling can be used to create a framework. A review of current literature will establish an understanding of the factors necessary to meet the research objectives and identify the research gap.

To meet the first objective of this research project a review of current literature will initially focus on current practices in the Australian residential construction industry. It will detail typical methods of procurement and cost estimating found in Australia, establish current estimating techniques and provide a basis for questions to raise during the case study of the Company using semi-structured interviews.

A review of estimating techniques that are common in the construction industry will be detailed to understand the methods available to develop the research methodology. It will also determine whether the estimating method found to be used currently in the Australian industry is common to the industry in general. To formulate a relevant cost modelling framework, the construction costs must be calculated from first principle estimating methods before they can be statistically analysed, therefore it is critical that these methods are reviewed.

Statistical cost modelling will be the main tool used to analyse the construction cost data and formulate a framework. This technique has been identified as a valid estimating method to be explored in more detail with a narrow focus of its input variables (cost drivers), models available, expected accuracies and output. The review of this technique will identify a set of preliminary cost drivers which will be validated and expanded upon during the case study interviews. The results from the literature review and case study will provide information to formulate a research methodology for the framework development.

2.2 Design and construct residential construction practices

Construction projects are delivered to completion through various contracting methods. The methods will depend heavily on the type of project, the client involved and the contractor's capabilities. Whilst many variants in delivery methods exist, the two main types are traditional or design and construct. Traditional methods involve the client commissioning the design of the project and then tendering to contractors to deliver the project (Ashworth 2002, p. 395). The contractor has no control over the design with traditional methods. Design and construct procurement means the contractor is engaged for both the design of the project and the construction, usually utilising the services of an in-house design team or external designers which are engaged by the contractor (Austroads 2014, p. 23). Design and construct delivery methods are very common in the residential construction industry in Australia (Warren-Meyers and McRae, 2017). This research project will focus on that method of delivery only.

This section will determine the typical practice for residential builders in the Australian market from information gathered through a review of current literature. It will also establish current practice in residential construction regarding standard inclusions and baseline estimating which will be used by this research project to calculate construction costs for the statistical analysis and framework development.

2.2.1 Standard inclusions, the specification and contract

Many residential builders have a library of standard plans and a specific level of inclusions. The inclusions are a detailed explanation of what types of fittings, fixtures and finishes the consumer can expect when they enter a building contract. A baseline first principle estimate is produced with this standard set of inclusions for each design and any custom designs that the contractor is working on for the consumer (Lim et al. 2016, p. 14). Standard inclusions are set out so the client knows what level of finish and construction methods are employed by the contractor. This allows the contractor to specify a standard range and level of finish for the tender proposal which often provides a point of difference for marketing their product.

Items detailed on a typical inclusion list range from assumed construction methods such as foundation type, external and internal wall and superstructure types. Internal finishes are also specified which can include floor coverings, wall linings and mouldings. Fixtures such as plumbing, appliances and electrical fittings are often from a range selected by the contractor and displayed in a display home. Prime Cost allowances for items such as carpet and tiles are included at the same rate across all baseline estimates. External inclusions such as driveways, fencing and landscaping are also included at set amounts across all baselines. The consumer has the option to vary all the inclusions and levels of finish depending on their own tastes to customise their product with adjustments made for these to the baseline estimate. Warren-Meyers and McRae (2017) found this method of procurement common in the Australian market with volume building dominated by large companies such as Metricon, Simonds and GJ Gardner. They also found that the bespoke end of the market often allows consumers more choice which is becoming common as people move toward more customised homes to suit their taste.

A specification is a detailed breakdown of inclusions and a formal proposal put forward by the contractor to the consumer. This document is based on the standard set of inclusions with any requested variations applied and detailed. It provides a contractual reference point for both the consumer and contractor and forms part of the building contract between the parties, provides a basis for accurate estimating and details the level of finish included in the proposal (Del Pico 2012, p. 14).

Standard form contracts from industry bodies are commonly used for the delivery of residential dwellings (CMG1002 Residential construction: methods, materials and management: course notes, 2018). Standard form contracts are the result of collaborative efforts and the evolutionary process to tailor the contract conditions to types of construction and to alleviate common difficulties in interpretation and implementation (Loots and Charrett 2009, p. 31). This type of contract is advantageous because they provide more certainty of contract terms and are easy for contractors to use. Industry bodies provide these standard form contracts to their members for a fee to use when contracting construction work. Procurement methods such as contract type have been featured as cost drivers during previous studies (Emsley et al. 2002, Lowe et al. 2006 and Soutis and Lowe 2011). The use of standard form contracts reduces the risk for the contractor. By using this type of contract for procurement, the contract is no longer considered a variable that may impact the cost of construction. If the standard form contract is found to be used in the residential construction industry during the case study, then it may be excluded from consideration as a cost driver.

2.2.2 Critical analysis and review of residential construction practices

Residential construction in Australia, especially volume building, can be likened to a production line due to their high turnover. Dowling (2005) found new housing construction to be economically significant with it contributing to 4% of Australia's gross domestic product and that little is known about the residential sector in general. Contractors have developed systems to estimate costs of designs through a series of standard plan ranges, set levels of inclusions and the minimisation of risk using standard form contracts. As consumers develop and become more knowledgeable, they naturally wish to customise not only their inclusions but also their designs as they are no longer simply satisfied with the standard plans on offer (Warren-Meyers and McRae 2017). A need has arisen for the ability to estimate the cost of these custom designs without negatively impacting the accuracy levels found in traditional methods of estimating, which will be detailed in next section.

A relevant study by Lim et al. (2016, p. 14) based in South East Queensland found that the most common estimating method adopted by contractors involved the production of a bill of quantities to establish a baseline cost with variances to finishes or inclusions then adjusted from that baseline. This shows that an estimate produced to standard levels of inclusion in the residential construction industry is a common method of establishing a baseline and will be used in the development of the cost modelling framework by this project.

Research into current practices in the Australian residential market show that many contractors produce baseline estimates for projects based on a standard level of inclusions using a first principle method of estimating. This baseline estimate is produced for a range of standard plan designs and can be applied to any custom designs the contractor is working on with the consumer. Consumers have the right to vary the inclusions and tailor the home to suit their needs which is then compiled into a specification produced by the contractor forming a tender proposal. The baseline first principle method of construction cost calculation will be used for the development of a suitable cost modelling framework. Various methods of estimating techniques applicable to the construction industry will be discussed in the next section to better understand the main types available along with their advantages and disadvantages.

2.3 Current cost estimating techniques available

Various methods of producing a cost estimate for construction projects exist and are common between different sectors of the industry. This section will detail some of the common methods available, their predicted accuracy and relevance to the proposed cost modelling framework. There will be a trade-off between the time and accuracy of each method employed to produce a cost estimate. The developed cost modelling framework will find a balance between the two.

The accuracy of the cost estimate typically evolves as further design details become available. It is critical that these estimates are as accurate as possible to ensure the business is achievable as the cost estimating function is an important element in the financial success of the project (Akintoye and Fitzgerald 2000, p. 162). Many studies have been conducted into the accuracy of cost estimates and the factors that contribute to the inaccuracies. Serpell (2004, p. 160) found that there are five major factors contributing to estimate accuracy including scope quality, information quality, uncertainty level, estimator performance and quality of estimating procedure.

Variance between the initial cost estimate and final cost of the construction project can vary significantly. Stoy and Schalcher (2008, p. 139) reported that a variance of up to 30% can be seen in German residential projects during the early design stages. Ashworth & Skitmore (1982, p. 24) believe this can be improved to between 13% and 18% with more detailed designs and reliable data. Research has established that a priced bill of quantities can have an accuracy level of ±10% (Ashworth 2004, p. 54). AbouRizk et al. (2002, p. 655) further validates this finding and found that accuracy favourably increases from ±50% for a strategic estimate to ±10% during the detailed design phase. This confirms that as more information becomes available, the level of estimate accuracy improves. A need has been identified for more accurate estimating methods during the early stages of project development which can be determined from the minimal design information that is available. Common methods of estimating found in the construction industry will be detailed in the following sections along with their expected accuracies.

2.3.1 The unit rate

The unit rate method of estimating is often known as an approximate estimate and involves the multiplication of a single variable with that of a unit rate (Ashworth and Skitmore 1982, p. 3). This has the advantage of being quickly applied to forecast the cost of a project by knowing only the quantity of the unit required and the rate to apply to it. Accuracy of such a method varies significantly and is a common method in residential construction in Australia due to the repeatability of project home building in general, however often needs adjusting based on design variables and historical price fluctuations (Lim et al. 2016, p. 14).

The Australian Institute of Quantity Surveyors define the gross building area (GBA) as the total enclosed and unenclosed area of the building measured from the normal outside face of any enclosing wall (AIQS 2000, p. 5). The rate used can be based on experience or a good historical library of comparable buildings which can then be adjusted for site variables or design differences (Azman et al. 2013, p. 996). Take an example of a completed house design that has a gross building area of 270 m^2 and a final construction cost of $337,500. The estimator can easily calculate a unit rate for the design.

$$Unit\ rate\ of\ Design\ A\ = \frac{\$337{,}500}{270\ m^2} = \$1{,}250\ /\ m^2 \tag{1}$$

If the new design (Design B) has some differences between the model used for comparison, there needs to be some adjustments made to this prediction value. Let us say that Design B has an additional bathroom and an additional bedroom when compared to Design A which was used to determine the applicable rate. Let us also assume that the rate obtained from Design A was from a project completed over 2 years ago. The estimator would need to first quantify the additional costs for the bathroom and bedroom and apply a cost index factor to the historic price to normalise the cost for today's rates. This then simply becomes a process of applying the adjustments accordingly.

$$Cost\ of\ Design\ B\ =\ (270m^2\ \times \$1{,}250\ /m^2)\ \times (1 + Index\ factor) + \$bath + \$bed \tag{2}$$

$$Cost\ of\ Design\ B\ =\ \$364{,}312.50 \tag{3}$$

Where;

$\$bath\ =\ \$10{,}000$

$\$bed\ =\ \$5{,}000$

$Index\ factor = 3.5\%$

This type of estimating technique lends itself as a good indicator of final cost but not as an accurate predictor. They are acceptable under certain circumstances however best left for experienced estimators and are often not accurate enough when compared to other methods (Del Pico 2012, p. 55). Ashworth (2004, p. 342) states that these types of estimates often have an accuracy of 13% which is dependent on size, method used and luck.

A variant to the unit rate method of estimating is the elemental cost estimate in which the project is broken down into major building elements and rates assigned to each of those to build up a total cost (Ashworth 2004, p. 272). The Australian Institute of Quantity Surveyors define elements in their cost management manual for components such as Preliminaries, Substructure, Superstructure, Finishes, Fittings, Services, Site Works and External Services (AIQS 2006). These elements can be further broken down into sub-elements and rates assigned to build up a total cost for construction. The accuracy of this method relies on the quality and relevance of the data used to obtain the rates. This method is quite popular in calculating construction costs with a study of UK quantity surveyors confirming 80% used this method when providing cost plans (Soutus and Lowe 2011). A similar and more detailed method is the first principle estimate which will be discussed in the following section.

2.3.2 First principle estimates

This is the traditional method of estimating adopted by many contractors and referred to as analytical estimating. It involves extracting quantities for the components required to complete the project and assigning them to labour, materials, plant hire and subcontract works which are then allocated individual unit rates to build up a total cost (Ashworth and Skitmore 1982, p. 4). Overheads and profit are often added on top of the determined construction cost to arrive at a tender price. This method of cost estimating requires considerable skill and diligence by the estimator and is also the most time consuming, however it is the most reliable and accurate method with Ashworth (2004, p. 342) claiming a typical accuracy of 10%.

The study by Lim et al. (2016, p. 14) determined that a first principle estimate using a priced bill of quantities for each standard house design to form a baseline of construction cost is common practice in the Australian residential market, the study is relevant to Queensland where this research project is basing its data collection. Del Pico (2012, p. 55) recognises that this method is labour intensive and time consuming but does yield the most accurate results when compared to other methods of estimating. The first principle estimating method will be utilised by this research project to calculate the construction costs of the sample designs used for the statistical analysis required to develop a cost model. Cost modelling will be discussed in the next section as it will be used by this research project to develop the framework.

2.3.3 Cost modelling

Cost modelling is a modern technique used to forecast construction costs which utilise numerical methods such as statistical analysis (Ashworth 2004, p. 274). A mathematical model is constructed that best fits the data available to provide an output in terms of cost (Ashworth and Skitmore 1982, p. 7). Regression analysis and neural networks are the two models that have shown the most promise and highest levels of accuracy, however both use historical data (Lowe et al. 2006 p. 750). Ashworth (2004, p. 342) determined this type of estimate provides an accuracy of between 15% - 20% depending on data quality and information available. There has been much research done into trying to develop a viable model with a high enough level of accuracy to be relevant. There have been several studies focussing on residential construction in other countries, however no focus on the Australian market has been found.

A study by Stoy and Schalcher (2007), with a focus on the German residential market, have collated similar studies dating back to 1998 identifying the data pool size, method of cost modelling and a list of cost drivers. Cost drivers are considered variables of the project that impact the construction cost of the works. Regression analysis was also used by Alshibani et al. (2018) to formulate a model for cost prediction based on Canadian low-rise residential buildings. Badawy (2019) developed a hybrid model using the output from both regression analysis and neural networks to predict the cost of residential buildings in Egypt. This shows that cost modelling is a common area of research. No information exists on models developed in the Australian residential construction sector. Current levels of accuracy are only good enough for preliminary estimates rather than detailed estimates which have an accuracy high enough to enter a building contract and maintain profitability. Cost modelling will form the basis of this research project's framework and will be further explored in section 2.4 Statistical cost modelling techniques.

2.3.4 Critical analysis of findings and research focus

The most accurate method of estimating is the traditional first principles method which is the most time consuming. One of the objectives of this research project is to produce a cost modelling framework, so it is important to determine what level of accuracy must be produced for the model to be deemed successful. Further cost modelling accuracies from previous studies will be covered in section 2.4 Statistical cost modelling techniques.

It has been determined that the first principle estimate is the most common method employed by contractors in the Queensland residential construction industry (Lim et al. 2016). A case study of a cost estimating company based in Queensland will aim to validate this finding. The data collection for this project will require a first principle estimate of sample designs to formulate the data for a statistical analysis. It is crucial to confirm that this method is currently employed in the industry. This will be validated through the case study interviews.

This section has introduced and detailed current methods of estimating and their expected levels of accuracy. Through previous research it has been determined that these methods are viable options to estimate construction costs depending on the stage of the design and level of accuracy required. An accuracy level of 50% at the strategic stage to 10% at the detailed design stage is considered typical in the industry.

First principle estimating techniques involve the extraction of quantities and assigning a rate to each item to build up a total cost. This is the most accurate method available and the most time-consuming. The unit rate method is very quick to apply and adjust however relies on the skill of the estimator and access to good quality historical data with levels of accuracy less than that of first principle estimates. Calculating construction costs using only the unit rate method, whilst fast, often yields inaccurate results due to its simplistic and one-dimensional nature. The method of first principle estimating will be used by this research project to calculate the construction costs for the sample models used for data analysis so an understanding of the procedure is important, this will be analysed during the case study.

Cost modelling is a modern technique that employees various numerical methods such as statistical analysis to predict an output cost with regression analysis and neural networks being common. The advantage of this method is that it can be performed relatively quickly given the right input variables. It can also yield relatively accurate results if the modelling is performed well with the correct input variables and quality sample data. Cost modelling will be used during the development of the framework for this research project whilst utilising construction costs obtained from first principle estimates. As cost modelling methods form the basis of the framework, the techniques currently available will be detailed in the next section.

2.4 Statistical cost modelling techniques

Cost modelling is a form of estimating that uses statistical methods to forecast construction project costs. The use of cost modelling as a cost forecasting technique and a brief introduction to the method was given in the previous section. As this technique will form the basis of the cost modelling framework for this research project, this section will provide greater detail on the method itself. It will also detail cost drivers that have been identified from previous studies which will give relevance to the choice of cost drivers statistically analysed by this study and be validated during the case study interviews. A summary of accuracies obtained through various cost modelling methods will be detailed, this will provide a target for this research project to improve upon.

2.4.1 Cost drivers

Cost drivers are statistically significant factors that have an influence on the cost of the construction project, in a cost model they are a function of the building cost (Ofori-Boadu 2015, p. 4). These form input parameters for any cost model and are typically quantitative or qualitative values. The purpose of any cost model is to determine the relationship between input variables and output variables, in this case construction cost (Dursan and Stoy 2016, p. 3). Many factors affecting the cost of a project have been identified from a broad range of categories such as market factors, site location and conditions, design details, structural parameters, project team experience, procurement method and tender period (Sayed et al. 2020, p. 3). Lim et al. (2016) categorized key factors into two categories. The categories are environmental factors such as market conditions, financial uncertainty, weather conditions and supply issues with the second category being project specific factors such as project type, duration, contract type, location, design complexity, construction method and site conditions (Lim et al. 2016, p. 7). A study by Lowe, Emsley and Harding

(2006, p. 751) determined three categories of cost drivers would be project, site and design related factors. Many factors affect the final cost of a construction project and it is impractical to adequately capture all of them in a cost model that provides a robust, reliable and accurate output. Therefore, it is best to narrow the focus of cost drivers which this research project will do by considering design related factors only.

Most studies have similar design or structural related cost drivers included in their cost models, which will be the focus of this research project. These cost drivers have an influence on the complexity of the design and therefore an impact on the cost. A review of studies involving cost modelling that contain relevant design cost drivers specific to buildings such as commercial, residential or high-rise construction have been identified and collated in Table 1. This table details the year and location of the study, type of model used and the cost drivers identified. This shows no study has been conducted in the Australian market and that linear regression features prominently as the chosen method of statistical analysis. Linear regression will be the main type of statistical method used by this research project in the development of a cost modelling framework and will be explored in the following sections along with alternative models such as neural networks.

Study	Author	Year	Location	Model	Design related cost drivers									
1	Lowe et al.	2006	U.K.	Regression	Gross internal floor area	Function	Internal walls	Wall-to-floor ratio	External walls	Floor finishes	Height			
2	Stoy and Schalcher	2007	Germany	Regression	Gross external floor area	Compactness	Area of internal divisions and internal construction/gross external floor area	Floor space/gross external floor area	Circulation area/gross external floor area	Ancillary area for services/gross external floor area	Usable floor area/gross external floor area	Area ancillary to main function/gross external floor area	Median floor height	Levels below ground
					Levels above ground	Gross external floor area/levels	Excavation volume/gross external floor area	Building base surface/gross external floor area	External wall surface/gross external floor area	Internal wall surface/gross external floor area	Ceiling area/gross external floor area	Ceiling area/gross external floor area	Facade glass/gross external floor area	(Building base surfaces + external wall surfaces + roof space) / gross external floor area
					(External wall surfaces + roof space) / gross external floor area	Ventilated gross external floor area/gross external floor area	Vented and ventilated gross external floor area/gross external floor area	Partly air conditioned gross external floor area/gross external floor area	Partly air conditioned gross external floor area/gross external floor area	Partly air conditioned gross external floor area/gross external floor area	Site area/gross external floor area	Site area covered by buildings/gross external floor area		
3	Stoy et al.	2008	Germany	Regression	Gross floor area	Compactness	Proportion of openings	Number of elevators						
4	Ofori-Badu	2015	Global	Regression	Floor area	Number of stories	Shape complexity	Height of building	Wall height per storey	Structural material				
5	Dursan and Stoy	2016	Germany	Regression & Artificial Neural Networks	Gross external floor area	Gross building volume	Average storey height	Average floor size	Number of storeys in total					
6	Alshibani et al.	2018	Canada	Regression	Number of floors	Height of floor	Type of structure	Type of envelope	Building area					
7	Juszczyk	2018	Poland	Support Vector Regression	Building footprint	Building volume	Number of storeys	Foundation type	Building and roof structure	Number of elevators	Usable area of dwelling	Number segments		

Table 1 – Design cost drivers identified by previous studies.

Forty-one cost drivers were initially identified by Lowe et al. (2006) during a study conducted in the United Kingdom, thirty-two of these related to design. The cost drivers were spread over project, site and design related factors. During the regression analysis it was found through statistical significance tests that most of these cost drivers did not impact the model and were subsequently excluded. This ended with a total of twenty cost drivers being included with seven related to design which have been detailed in Table 1. This process of reducing the number of significant cost drivers without an impact on model accuracy is crucial in developing a relevant framework and will be utilised during this research project to remove any cost drivers that are not statistically significant from further consideration.

The study by Stoy and Schalcher (2007) used regression analysis to predict the cost of residential buildings in Germany and identified a total of thirty-seven relevant cost drivers. This study has the most comprehensive use of cost drivers for residential construction and most of them centre around ratios of building elements to gross floor area. This means gross floor area becomes a function of many of the identified cost drivers. Gross floor area is the most important variable identified from this study and believed to have the greatest impact on building cost. This can also be surmised from the introduction of the unit rate method of estimating earlier in the literature review where a cost value is typically applied to the gross floor area of a building to determine a project cost.

A study by Stoy and Schalcher along with Pollalis (2008) further investigated cost drivers in the early stage estimating of residential construction. This study collated cost drivers from eight previous studies stretching back to 1998, however these include cost drivers in addition to design related factors. The study reduced the variables significantly to a total of six, with only four being related to design and the remaining two being duration of project and the region it was constructed in. Again, the overall size of the building was a prominent factor with the proportion of openings (window openings / gross floor area) and compactness (wall area / gross floor area) being common to the previous study.

A study of high-rise buildings from all over the world was found to clearly identify cost drivers, their meaning and relationship with estimating cost and accuracy (Ofori-Badu 2015). Although conducted on high-rise buildings, this study offered excellent insight into key cost drivers whilst keeping the number of input variables manageable. This is crucial in developing an easy-to-use framework and this research project will aim to include a minimal number of statistically significant cost drivers. Six cost drivers were selected with all of them relating to design factors with total floor area in common with the previous two studies. The accuracy of the output using regression analysis was approximately 9% when assessed using the mean absolute percentage error which will be discussed further in section 3.4.4 Testing of cost models.

Another German study by Dursan and Stoy (2016) used linear regression to analyse 657 buildings with a total of twenty-four cost drivers, however only five related to design factors. The cost drivers were a mixture of qualitative and quantitative variables and focused on a range of building types including residential. The cost drivers for this study were gathered through semi-structured interviews with industry practitioners. This is an excellent method to narrow down what factors drive the cost of the project, as it provides relevant input from industry professionals. Semi-structured interviews will be conducted through a case study to validate and further expand the cost drivers found during this literature review.

Low-rise residential buildings were focused on by a study conducted in Canada of 300 test samples (Alshibani et al. 2018). Six cost drivers were identified with only four being related to design. This study also used the year of construction and location as the remaining two variables which can cause significant variance in cost fluctuation and construction methodology in itself. Whilst the identification of similar cost drivers to previous studies were validated, the model had an accuracy of 90.66% which can be improved upon without the inclusion of such ambiguous cost drivers. This research project will focus on design related cost drivers with the aim of reducing ambiguity and improving model accuracy.

Several qualitative and quantitative cost drivers were used for a study on residential construction by Juszczyk (2018) in Poland. Eight of the thirteen possible cost drivers were related to design features. The issue with using qualitative variables for an analytical cost model is that they are difficult for the user to quantify without ambiguity. For example, the study used ground conditions as a qualitative variable with the options of simple, complex and complicated. This can quickly become ambiguous and difficult to interpret causing inaccurate results when the model is used by others. As a linear regression model is numeric by nature and qualitative variables can be a source of ambiguity, this research project will use quantitative cost drivers to reduce ambiguity, increase accuracy and usability of the framework.

An analysis of previous studies show there exists common cost drivers revolving around the building geometry with studies identifying factors such as floor area, wall heights, compactness and building volume. Some of these are considered functions of each other with volume being a function of wall height, external wall length and floor area. Similarly, compactness is a function of wall area and floor area so it is obvious that these cost driver components are critical when it comes to influencing the building cost. The purpose of this section was to identify common design related cost drivers to use in the development of the cost modelling framework for this project which will be validated during the case study. Whilst there are more studies that exist on cost modelling these were considered the most relevant to this research project due to their close alignment with residential construction and the project aims. No relevant study has been found to have been conducted in the Australian market which this research project will provide.

The analysis of previous relevant studies has shown that linear regression and artificial neural networks feature as the predominant form of statistical analysis for cost modelling. This research project will compare both methods and the following sections will further detail these models and provide a brief outline of how they work.

2.4.2 Statistical models available

As seen from Table 1 linear regression analysis is the most common method used when statistically analysing the data. There have been many other studies performed on different sectors of the construction industry using regression and other methods of statistical analysis during the early design stages of a project to predict cost. Table 2 collates and summarises the different types of models found during the literature review along with other relevant data such as the accuracy of each method to gain a better understanding of what has been utilised in the past and the varying levels of success for the chosen models.

Author	Year	Location	Building type	Model type	Test for accuracy	Accuracy
Badawy	2020	Egypt	Residential housing	Hybrid of regression and artificial neural network (multilayer perceptron)	Mean absolute percent error (MAPE)	10.64%
Chakraborty et al.	2020	Unknown	Multi-level highrise	Hybrid natural and light gradient boosting	Mean bias error (MBE)	9.00%
Ugar et al.	2018	Turkey	Residential multi storey housing	Artificial neural network (multilayer perceptron and classification and regression trees)	Not assessed, focus was on improving accuracy of current methods	Unknown
Juszczyk	2018	Poland	Residential and commercial buildings	Support vector regression	Mean absolute percent error (MAPE)	8.87%
Alshibani et al.	2018	Canada	Low rise residential buildings	Multiple linear regression	Average validity percentage (AVP)	90.66%
Wang et al.	2017	Taiwan	Residential reinforced concrete buildings	Artificial neural network (neurofuzzy and multifactor)	Mean absolute percent error (MAPE)	7.73%
Alshamrani	2016	USA	Educational facilities	Multiple linear regression	Average validity percentage (AVP)	94.30%
Ofori-Boadu	2015	Global	High rise buildings	Multiple linear regression	Mean absolute percent error (MAPE)	9.11%
El-Sawah and Moselhi	2014	Canada	Low rise steel buildings and timber bridges	Multiple linear regression and artificial neural network (back propagation, probalistic and generalized regression network)	Mean absolute percent error (MAPE)	16.83% to 19.35%
Gulcicek et al.	2013	Turkey	Multi-level buildings	Multiple linear regression and artificial neural network (multilayer perceptron)	Mean absolute percent error (MAPE)	5.23% (ANN)
Latief, Wibowo and Isvara	2013	Jakarta	Multi-level buildings	Hybrid (regression and adaptive neurofuzzy interface system)	Mean absolute percent error (MAPE)	3.98%
Petroutsatou et al.	2012	Greece	Road tunnel construction	Multiple linear regression and artificial neural network (multilayer forward feed and generalized regression network)	Overall percentage accuracy	90.6% (regression) and 95.35% (ANN)
Mahamid	2011	Palestine	Road construction	Multiple linear regression	Mean absolute percent error (MAPE)	13% to 31%
Yu and Skibniewski	2010	China	High rise residential buildings	Artificial neural network (Integrated neurofuzzy system)	Absolute percent error	90.01%
Zhigang and Yajing	2009	China	Multi-level buildings	Artificial neural network (Radial basis function)	Mean relative error (MRE)	6.14%
Jablonowki and MacEachern	2009	Mexico, Brazil and West Africa	Well drilling construction	Multiple linear regression	Standard error	10.89%
Stoy et al.	2008	Germany	Residential multi level buildings	Multiple linear regression	Mean absolute percent error (MAPE)	9.60%
Lowe, Emsley and Harding	2006	United Kingdom	Multi-level buildings	Multiple linear regression	Mean absolute percent error (MAPE)	19.60%
Sonmez	2004	USA	Aged care retirement facilities	Multiple linear regression and artificial neural networks (back propagation with sigmoid transfer function)	Mean absolute percent error (MAPE)	Best of 11.1% (regression)
Emsley et al.	2002	United Kingdom	Multi-level buildings	Multiple linear regression and artificial neural networks (multilayer perceptron)	Mean absolute percent error (MAPE)	19.3% (regression) and 16.6% (ANN)

Table 2 – Recent studies of construction cost prediction models and accuracy.

Table 2 shows the extent of relevant studies over the last twenty years, with a trend moving from linear regression analysis to artificial neural networks. However, regression analysis still features prominently in the studies as a valid model. Based on the evidence presented, this research project will test variants of both techniques to assess their suitability for the framework.

The mean absolute percentage error was used predominantly throughout the studies to assess the validity of the model. This test will also be utilised in this research project, this technique will be further detailed in section 3.4.4 Testing of cost models. The levels of accuracy displayed in Table 2 for previous studies can be considered highly variable with only one model achieving an accuracy under 5%. This research project will improve on this result by developing a modelling framework that focuses on design related variables only and using the baseline estimating technique found to be common in the Australian residential construction sector.

Table 2 shows that whilst many studies have been done, some with a focus on the residential sector, no cost model has been based on the Australian residential construction industry which this research project will provide.

Following on from Table 2 it has been shown that linear regression and artificial neural networks are the most common form of cost modelling used in previous studies. This research project will compare both methods as potential candidates for the framework development. A brief outline of the two methods will be provided in the following sections.

2.4.3 Linear regression analysis method

Linear regression has been used as a cost modelling technique to predict cost since the 1970's with Professor Geoffrey Trimble originally putting forward the idea (Ashworth 2004, p. 332). It is an appealing option because it provides estimates in a robust and systematic way with little information required and can be easily applied using a simple formula (Jablonoski and MacEachern 2009, p. 440). Ashworth (2004, p. 334) states that simple linear regression analysis quantifies the relationship between two variables by constructing a line of best fit derived by the sum of least squares method. This simple method includes the analysis of one input variable and one output variable. Multiple linear regression analysis is a more advanced technique which uses multiple input variables to describe the relationship between the output variable. The use of multiple linear regression will be used by this research project to develop the cost modelling framework and referred to simply as linear regression.

Linear regression has been shown to provide relatively accurate cost prediction models with the main advantage being an easily usable algebraic formula, this will allow this research project to provide a relevant framework for potential users. The major disadvantage with linear regression is that it assumes a linear relationship between the input and output variables, which is not always the case with non-linear relationships often existing between variables (Emsley et al. 2002, p. 468). This downside has been identified through previous studies and is why machine learning models such as artificial neural networks have been gaining popularity. Artificial neural networks will be used by this research study as a comparison to linear regression and the general theory will be discussed in the next section.

2.4.4 Artificial neural network method

Table 2 shows that over 60% of the modelling techniques used over the last twenty years have included some form of an artificial neural network. The success of the technique is such that it cannot be ignored and therefore it is prudent to compare of the results from artificial neural networks during this research.

It is common to first utilise linear regression to identify any statistically significant input variables, then remove any insignificant variables and use the remaining variables in the creation of the neural network. Neural networks do an excellent job at estimating non-linear relationships between variables by employing a machine learning algorithm designed to mimic the human brain (Gulcicek et al. 2013, p. 576). This is important because many of the relationships between input and output variables are generally complex and non-linear which means neural networks are best suited to predictive models (Emsley et al. 2002, p. 468). The neural network achieves this through a learning algorithm, which in its simplest form consists of an input layer, a hidden layer then an output layer as shown in Figure 1 (Zhigang and Yajing 2009, p. 32). There are many different forms of artificial neural networks that can be used as cost prediction models as seen in Table 2, however they typically follow the same layered form. This has been conceptualised in Figure 1.

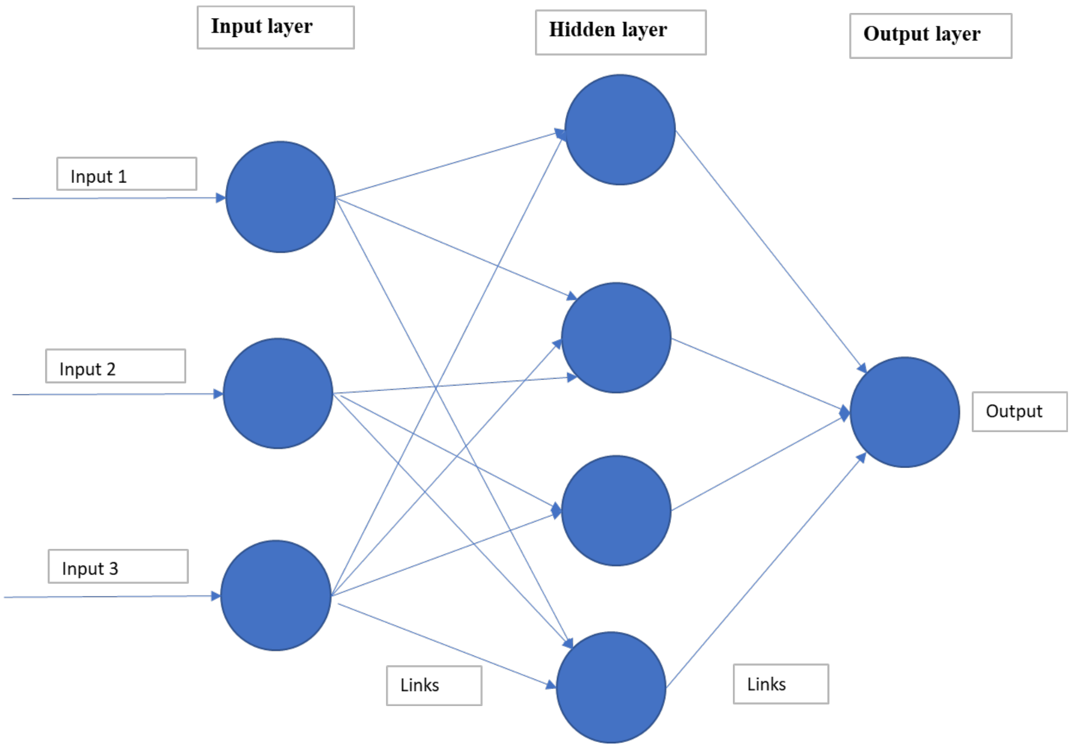


Figure 1 – Conceptual model of artificial neural network.

While artificial neural networks improve accuracy, they are also much more complicated to replicate compared to multiple linear regression analysis. To develop a relevant neural network model the output generally needs to be programmed using specialised software in comparison to linear regression which yields an algebraic equation that can simply be applied to calculate a result. This research project will select an appropriate statistical method based on factors other than accuracy and will be further detailed in the methodology chapter.

Both linear regression and neural networks produce an output from input variables. Up until this point it has been assumed that this output needs to be in the form of a lump sum of total cost, however it is unclear as to what cost this relates to. The model output options will be discussed in the next section with relevance to this research project.

2.4.5 Relevant output from the cost models

One area that needs to be explored is the output that the model provides and whether it is relevant. Many studies focus on the ability to predict the cost of the project. This project cost could range from the tender price, the final account cost for the client or the total cost to the contractor all of which could vary greatly and only be relevant to certain target audiences. It is crucial to design a predictive model that provides a relevant output without the impact of influencing factors that may not be identical across the entire data set. By focusing only on the cost of construction as an output for the statistical model this research project will remove these influencing factors and develop a more relevant and accurate model.

A study conducted by Emsley et al. (2002) recognised the difference between tender cost and final contract sum, which was a criticism of previous cost models. This cost can still be adversely skewed by market influences. Each contractor will have a different internal strategy when it comes to securing the tender and can be heavily influenced by factors such as profit margin, current work being undertaken, labour and material resources and perceived risk of the project. All these factors will adversely affect the mark-up strategy applied to the raw construction costs. There exists a gap in the current studies in that raw construction cost excluding profit and overhead contribution percentages have not been investigated, which are often added directly on top of the construction costs. Many of the models researched have not clearly specified what actual cost the model is designed to predict, however judging by the use of historical data, it can be assumed that the cost is either the final contract sum or the tender amount which are generally contained in a public record database. This research project will only be assessing the raw construction costs of the projects to gain clarity and greater accuracy. Access to these costs will be available through the Company cost estimating database. This will provide a clearer indication of the influence the cost drivers have on cost and by isolating design cost drivers this will give a more accurate baseline estimate produced by the modelling framework.

Upon further research into previous studies, it also became apparent that some models provide outputs of other relevant costs such as cost per gross floor area instead of a lump sum (Zhigang and Yajing 2009). Emsley et al. (2002) also studied the output of log of total cost, cost per m^2 and log of cost per m^2 and found that the best results were obtained through a neural network model which predicted the cost per m^2 with a mean absolute percent error (MAPE) of 16.6%. Likewise, a study using regression analysis determined total cost should be rejected as a predictor as it found that the error in project cost rises proportionally with the total cost of the project or because there is a high correlation between cost and size (Lowe et al. 2006, p. 752). As the samples this research project will be using are single storey dwellings the variance in size and cost will be relatively small, therefore the impact of this finding will be minimised. These were the only three significant studies that provide an output other than lump sum cost and therefore deemed not significant enough for this research project to explore. Validation of output from a statistical model needs to be confirmed and there exists statistical tests which can be performed, these will be discussed in the methodology section.

2.4.6 Findings from cost modelling techniques

The review of current studies into cost modelling techniques show a tendency to over complicate the input variables by trying to encompass too many cost drivers. This will lower the accuracy of any model due to the subjective nature of some of the input variables and of ambiguity from using qualitative variables. This research project aims to focus only on design related cost drivers that can be easily quantified by a user for input into the cost modelling framework. Using this technique will improve accuracy of the model and the development of a successful framework.

Multiple linear regression analysis will be used as the basis for this research project due its ease of use and historical success as a predictive model. Due to the development in recent years of artificial neural networks and their success in cost forecasting they will be utilised during this study as a comparison to linear regression. It has been found that over the past twenty years several studies have utilised these techniques with an accuracy ranging between 3.98% (Latief, Wibowo and Isvara 2013) and 19.60% (Lowe, Emsley and Harding 2006). With a focus on design related cost drivers this research project will improve these accuracies. Further improvement will be made by using the output of raw construction cost only rather than tender price or final contract sum which can often be adversely influenced by market conditions, budget over runs and contractor procurement strategies when applying profit margins during the tender stage. The output from the models will be validated using the mean absolute percentage error found during previous studies to confirm their accuracy which will be discussed in section 3.4.4 Testing of cost models.

2.5 Research gap

Baseline first principle estimates to a standard level of inclusions are common in residential housing construction in Australia. This method will remove the influence of external factors such as site conditions, contractor profit margins and variable levels of fixtures or finishes. This baseline estimate can then have profit margins applied and adjusted for variable site conditions if required which will give a more robust framework to predict costs during the concept stage of design. This method will be used by this research project in gathering the raw construction costs for the sample data used for the statistical analysis.

First principle estimates have been found to be the most accurate form of estimating but also the most time consuming which lowers productivity and increases the chance of human error. A need for an accurate cost modelling technique applicable to the Australian residential construction market has been identified as no previous studies have been performed in this area.

Previous studies have utilised historic data that is often available through public record with the data often consisting of total tender cost or final contract sum to the client. The data set is often skewed by market factors and considered an unreliable source to develop an accurate cost model. This research project aims to utilise construction costs only with up-to-date rates through access to a cost estimating company's database to produce a relevant and accurate model. Previous cost models also do not deal with the problem of how to update the model when construction unit prices fluctuate and no example of this was found. As all models developed generally rely on historic data there is a need to base a relevant framework on a system that can be periodically updated otherwise the model quickly becomes obsolete. This research project will detail a method to update the framework when construction costs fluctuate.

2.6 Summary

This literature review covered current estimating techniques in the construction industry, current practices in residential construction in Australia and a review of current methods of estimating including cost modelling. It found that cost modelling is a viable form of estimating costs of construction projects during the concept stage. Whilst many studies are available, there has been little research into residential construction and no specific focus on the Australian market.

From this analysis a gap in the current research exists. It was also discovered that many of the cost models have a focus on tender price or contract sum. This provides a misleading output due to the influence of factors that are often not captured by input variables such as contractor markup strategy or other influencing market forces such as labour or material shortages. This project will develop a more accurate model using raw construction costs and design related cost drivers with a focus on residential single storey dwellings. Data will be collected by using the baseline estimating technique which was found to be common in the Australian residential construction industry, this will provide for a uniform statistical analysis.

Chapter 3 - Research methodology

3.1 Introduction

This section will detail the methodology employed to collect and analyse the data and the steps involved in developing a cost modelling framework. The methodology for this research project will move through three distinct stages before arriving at the development of a framework. The stages will be linked successively to each other, and each stage must be completed before moving on to the next.

The first stage involves a case study of the Company using semi-structured interviews which will determine two things. The first will determine the method of estimating used by the Company which will be used to gather the sample data for a statistical analysis. The second will validate and expand the cost drivers found during the literature review which will form the input variables for the statistical analysis.

The second stage will involve data gathered through a quantitative analysis to calculate construction costs of sample concept plan designs. These sample plans will provide the raw cost data used for the statistical analysis. This data will be collected using the Company's existing cost database, software resources and estimating methods from information found during the case study.

The third stage requires a statistical analysis of the construction costs collected during stage two. The data collected will determine which cost model will move forward for inclusion in the framework. The best cost model will be selected using a weighted decision matrix and once selected will be used to develop the final framework.

The stages of methodology used to develop the cost modelling framework have been illustrated in Figure 2 and further detailed in the following sections.

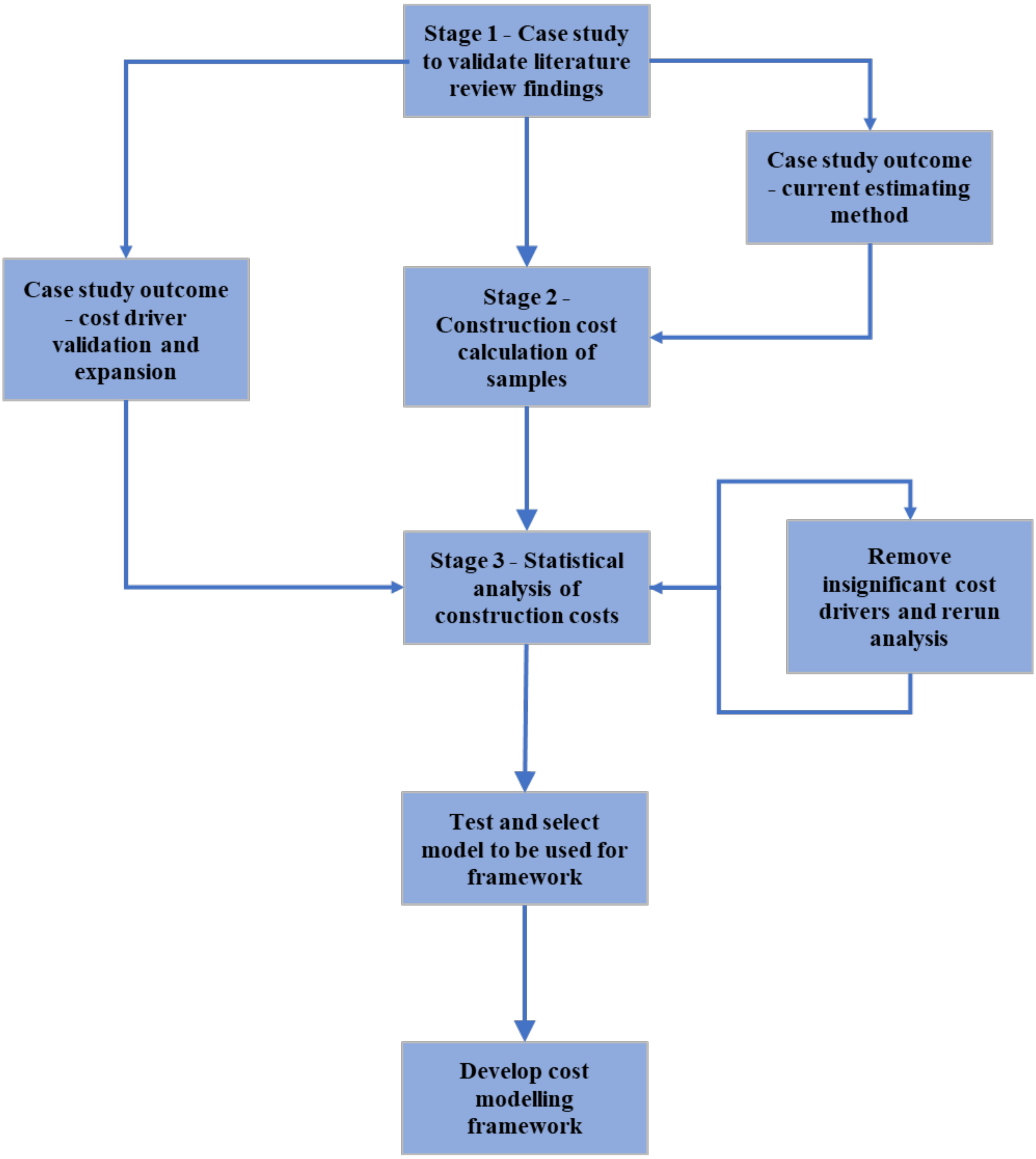


Figure 2 – Outline of stages in methodology of framework development

3.2 Case study

Two of the objectives of this research project involve the identification of current estimating techniques in the Australian residential construction industry and the identification of potential cost drivers. A review of current literature has provided the details of different types of estimating techniques common in the construction industry. Cost drivers have also been identified from a wide array of construction projects from previous cost modelling studies. To confirm the findings from the literature review a case study of the

Company will be conducted which will focus on construction cost estimating within the residential sector in the Queensland region. The Company will provide access to the resources required to perform the study. This will include a library of residential housing plans, current up-to-date cost databases, software, measuring tools and procedures to complete the data collection.

3.2.1 Case study interviews

To gather the information required for this research project interviews will be conducted with estimators at the Company. These will be conducted in the form of semi-structured interviews which are the most common form of data collection for qualitative research (DiCicco-Bloom & Crabtree 2006, p. 315). This structure will allow interviewees to add potentially valuable information on current practice and further insight (O'Keeffe et al 2016, p. 1911). The interviews will be conducted one on one with the use of open-ended questions. The interview with each candidate will not take any longer than thirty to forty minutes.

3.2.2 Interviewee selection

Three current employees of the company will be selected as interview candidates. Their time employed with the Company range from three to fifteen years. This will ensure each interviewee has relevant knowledge of the subject matter. Table 3 shows a summary of interview candidates with their experience in the industry, position in the company and time employed by the Company.

Participant	Position	Service at the Company	Time in residential construction
1	Estimator	3 years	9 years
2	Senior estimator	11 years	15 years
3	Director	15 years	26 years

Table 3 – Summary of interview candidates.

3.2.3 Interview process

The questions will be determined prior to the interview and structured around topics identified during the literature review. Questions will be open ended, which will provide the interviewee the opportunity to elaborate and provide further insight into the topics discussed. The interviewer will guide the conversations back on topic if they veer too far away from the question parameters. The interview questions will be broken into two phases. One phase will establish current practice in the Australian residential construction industry. The second phase will provide insight from industry professionals into what they perceive as design related cost drivers to verify and expand on the findings from the literature review. The findings from the literature review relating to current practice in the Australian residential industry have been summarised in Table 4.

1	There are three main methods of estimating construction costs. a) Unit rate indicator. b) First principle estimating. c) Cost modelling.
2	The level of accuracy and time taken to execute each method varies with first principle estimating being the most time consuming and accurate.
3	Full design documentation during the early stages when the contract price is set is often not available.
4	A baseline bill of quantities is often produced in residential construction for each design based on a standard level of inclusions which can be varied according to consumer taste.
5	Design and build contracts are common for residential contractors in Australia.

Table 4 – Summary of relevant findings from the literature review.

The summarised findings in Table 4 will provide a basis for the list of open-ended questions for the semi-structured interviews. The interview questions developed from the literature review findings can be found in Appendix C. The research questions will be submitted for ethical review and approval. Ethical approval for conducting these interviews has been granted and can be found in Appendix F.

A list of cost drivers found during the literature review have been identified previously in Table 1. Some items identified by the studies can be automatically removed as they are either duplicates or functions of other cost drivers. By using the baseline and standard inclusions estimating technique, some cost drivers will no longer be considered unique to each design and do not need to be included as a potential cost driver for this research. Table 5 provides a summary of cost drivers relating to design factors identified in the literature review.

Cost driver	**Unit**	**Calculation definition**
Gross internal floor area	m^2	Internal living area measured of outside face of wall
Gross external floor area	m^2	Floor area of alfresco, patios, porches etc.
Gross floor area	m^2	Total floor area of dwelling measured to outside face of wall
Compactness	ratio	Area of external walls / gross floor area
Internal walls	m	Length of internal walls
External walls	m	Length of external walls
Proportion of openings	m^2	The area of all external wall openings
Building volume	m^3	External wall length x wall height x internal floor area
Shape complexity	N/A	This will be further developed from interview data

Table 5 – Simplified cost drivers from literature review.

More data is required to be collected to form a relevant list of cost drivers for statistical analysis. A critical review of a typical floor plan for a house shows there are several features missing from the list shown in Table 5. Missing items that could potentially drive the cost of construction are the number of bedrooms, number of bathrooms and if there are any additional living areas such as separate theatre rooms, lounge rooms and rumpus rooms. As a semi-structured interview technique offers the benefit of probing to clarify and further explore data (Barriball and While 1994, p. 331), the development of additional cost driver identification will form the second phase of the semi-structured interview.

During the interview an explanation of a cost driver will be provided to the interviewee. This will be stated as "a design related factor that is believed to contribute significantly to the total cost of construction". From this statement the interviewee will be asked to name in their own words some factors they consider falling into the definition of a cost driver. These items will be recorded and further probed to seek clarification and relate them back to the cost drivers identified in Table 5. This technique will yield realistic data gathered from current industry professionals and provide a better understanding of potential cost drivers for inclusion in the data analysis. Few formal questions will be asked during this phase of the interview leaving the interviewee to develop their own answers and the interviewer to further probe interesting responses to formulate a definitive list of cost drivers to include in the cost modelling process. Interview questions for this phase of the case study can be found in Appendix D.

The data gathered from the second phase of the interview will be collated and analysed to formulate a complete list of cost drivers to be included during the data analysis.

3.2.4 Research validity and reliability

The interviewees selected are industry professionals with relevant experience and information regarding the topic. Semi-structured interviews have been shown as a valid method of qualitative data collection (DiCicco-Bloom & Crabtree 2006, p. 315). The data collected from this technique must prove to be reliable if it is to be used in this research project. It is assumed to be reliable if the responses start to yield similar or repetitive answers between the interviewees. This is known as thematic saturation and signals that no new meaningful data can be gathered about the topic (Weller et al. 2018, p. 11). When the interview responses reach this point, it will signal that the answers are reliable and can be used in this research project.

3.3 Construction cost data collection method

The method of calculating the cost of construction along with the selection and type of data to be included in the cost modelling will be detailed in this section. The resources of the Company along with their current methods of construction cost calculation will be detailed. Findings gathered from the literature review improve the accuracy of the statistical model by focusing on design features only and providing a baseline estimate for analysis, this process will also be detailed.

The first purpose of the case study is to determine the estimating technique used by the Company which will validate the findings from the literature review. The second purpose of the case study is to validate and expand the cost drivers identified during the literature review. The information gathered from the case study will be used during the collection of construction cost data which will in turn be used for analysis and development of the cost modelling framework. The following sections will outline the method of data collection used by this research project for the statistical analysis.

3.3.1 Baseline estimate method

Many previous studies complicate their models with the inclusion of many different types of cost drivers such as site conditions, environmental factors and variable levels of fixtures and finishes. It has been noted that the data used for previous studies are often gathered from historical sources and often represent total construction cost or final cost to the client which includes contractor profit margins and possible contract variations. The methodology proposed for this research project is to remove the influence these factors have on the results to ascertain a very precise and accurate baseline estimate which will form the sample data sets for the statistical analysis. It is deemed crucially important to make any assessment of construction cost without the influence of contractor profit margins as this is a variable factor which can be influenced by market conditions, contractor workloads, perceived risk of the project and previous relationships with the client.

The literature review shows a baseline estimate is common in the Australian residential construction market, especially new housing. This is because each design is relatively similar and generally consist of similar features such as garages, outdoor living areas, bathrooms, bedrooms, kitchens and laundries. These basic design components are typically present in any house found throughout Australia but can be of varying quantity and size between each design. The method of baseline estimating proposed is to keep as many of the structural elements, fittings, fixtures and general level of specification the same across all samples. A brief outline of design and inclusion assumptions for the sample data sets is provided below in Table 6.

Sample data design inclusions
Preliminaries
Statutory fees and charges
Site bins and cleans
Crane hire
Delivery fees
Structural elements
Foundations – a strip footing with masonry block base and sand filled void with a 100mm thick concrete slab
External walls – 200 series reinforced concrete masonry
Roof – pine timber trussed roof with metal roof cladding fixed to metal roof battens with plasterboard ceiling
Internal walls – pine timber stud framed walls with plasterboard ceiling.
Windows – aluminium framed glazing fitted with aluminium security screens
External doors – timber entrance doors, aluminium sliding glass doors and metal panel lift garage doors
Internal doors – hollow core internal doors in a timber frame
Finishes
External wall finish – cement render to masonry walls external wall face
Internal wall finish – plasterboard sheeting to timber framed internal walls and internal face of external masonry wall. Tiles will be included to shower and bath areas to 2.1m above floor level
Ceiling finish – plasterboard sheeting fixed to metal ceiling battens
Floor finishes – the location of select floor finishes will be consistent across all data samples. Carpet to all bedrooms. Tiles to all internal main living area, alfresco, porch and wet areas. Plain concrete to garage
Fittings
Cabinetry – all laundry units, vanities and kitchens along with any other custom cabinetry items will be included to a similar level of specification
Internal fitouts – these would include shower screens, mirrors and wardrobes and will be included at the same level of specification with only quantity varying between data sets
Services
Plumbing fixtures – these will remain the same price across all data sets, merely the quantity will vary. For example, each basin mixer used will be the same price
Appliances – an identical appliance range will be used
Airconditioning – all bedrooms and living areas will be airconditioned to the same standard
Electrical – identical fittings will be used with only the quantity varying based on design
External works
No external works such as landscaping or fencing will be included as these will be site dependant and easily adjusted after the model produces a result

Table 6 – Sample data design inclusions

By maintaining a consistent construction methodology, level of finish and fixtures across the data sets, a baseline estimate can be produced that minimises the cost influence these factors can have. This will leave a narrowly focussed data set of construction cost for the statistical analysis used for the framework development. It should be noted all labour, plant, material, labour and subcontract works will be included in the data sets based on the Company's current pricing structure which include agreed supply rates and up-to-date unit cost pricing rather than the use of outdated historical data prevalent in previous studies. This will allow the framework developed to be relevant to current industry costs.

3.3.2 Sample data set selection

The Company has a library of concept plans freely available for this research to select from. The selection will be random with variance in design complexity and overall size to ensure a realistic data set can be produced. A wide-ranging data set will provide a better statistical analysis that will more closely align with real population data. Figure 3 and Figure 4 show an example of the range of sample plans to be selected, ranging from simple to relatively complex.

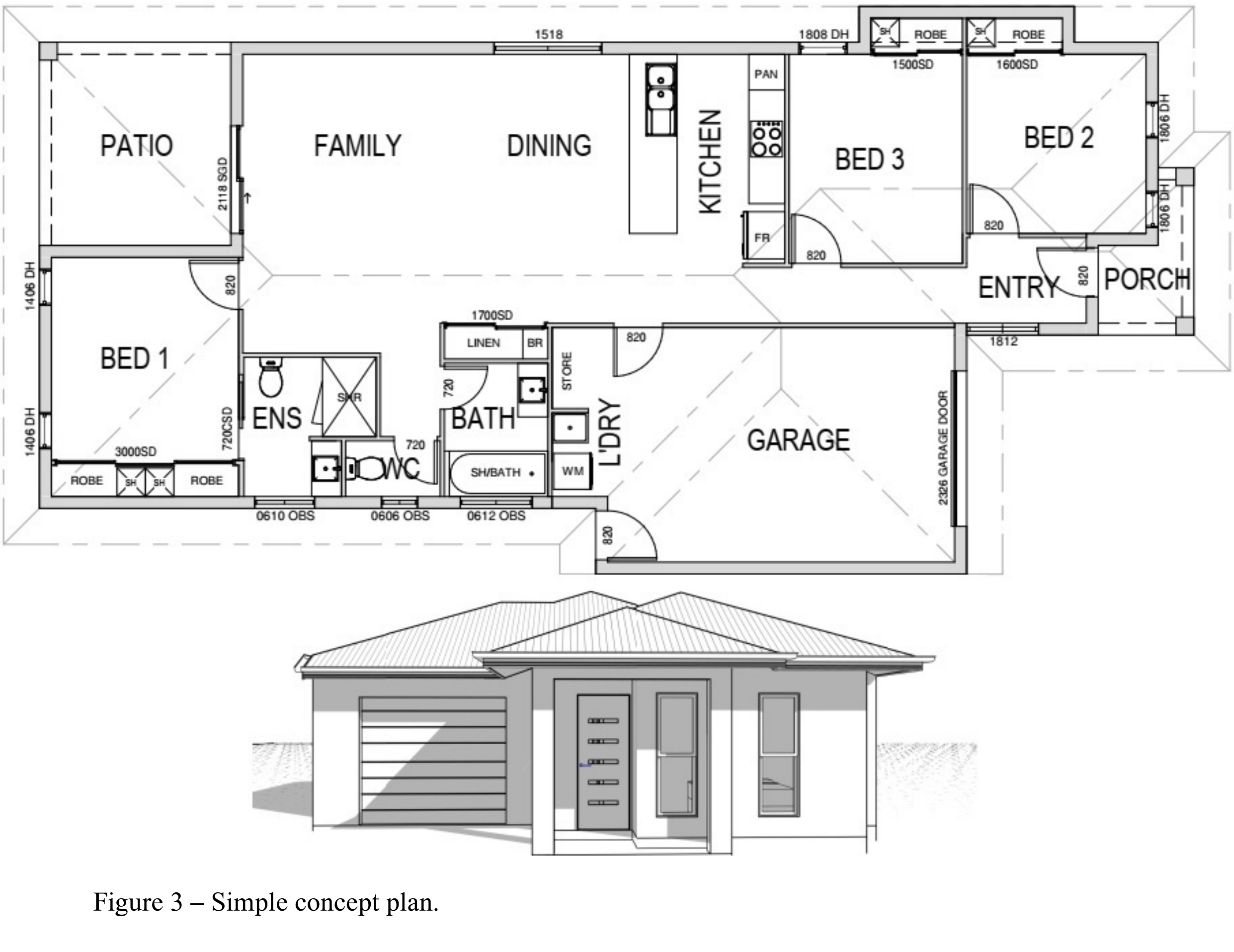


Figure 3 – Simple concept plan.

Figure 4 – Complex concept plan.

A collation of sample sizes against studies that had relatively successful cost models have been presented in Table 7. Any cost model with a variance between output and actual cost of under 10% has been included with an average sample size of 138 models. From this information it can be assumed a viable cost model can be produced from a similar quantity of sample sets, therefore 170 will be chosen for this study to ensure an adequate data spread. An additional twenty sample models will be separately selected for the testing phase of the data analysis to compare the accuracy of the output from the cost modelling framework. Twenty test samples represent over 10% of the original data set and have been selected due to time constraints when gathering the data which is approximately one hour per sample.

Author	Year	Location	Test for accuracy	Accuracy	# of samples
Juszczyk	2018	Poland	Mean absolute percent error (MAPE)	8.87%	105
Alshibani et al.	2018	Canada	Average validity percentage (AVP)	90.66%	300
Wang et al.	2017	Taiwan	Mean absolute percent error (MAPE)	7.73%	46
Alshamrani	2016	USA	Average validity percentage (AVP)	94.30%	250
Ofori-Boadu	2015	Global	Mean absolute percent error (MAPE)	9.11%	118
Gulcicek et al.	2013	Turkey	Mean absolute percent error (MAPE)	5.23%	384
Latief, Wibowo and Isvara	2013	Jakarta	Mean absolute percent error (MAPE)	3.98%	50
Petroutsatou et al.	2012	Greece	Overall percentage accuracy	90.6% (regression) and 95.35% (ANN)	33
Yu and Skibniewski	2010	China	Absolute percent error	90.01%	110
Zhigang and Yajing	2009	China	Mean relative error (MRE)	6.14%	50
Stoy et al.	2008	Germany	Mean absolute percent error (MAPE)	9.60%	75
				Average	138

Table 7 – Average sample size for successful models

3.3.3 Construction cost calculation method

Total construction costs for each sample will be gathered through the measurement of each concept design with quantities extracted and costs assigned according to the Company's current method of estimating from first principles. Each sample design will take approximately one hour to calculate using this method. This currently consists of a multi-step approach using three key software tools which measure and record quantities, then calculates the construction costs. The software that will be used is detailed below along with a brief explanation of the function the software provides.

1. **iTWO Cost X** - The Company uses iTWO Cost X developed by Rib Software International to quickly and accurately measure and record quantities (RIB Group 2021). The software provides a graphical user interface where a plan can be imported and measured on-screen using dimension groups. The dimension groups are created by the user and in this case defined as relevant building elements that need to be used during the next step of the process.

2. **Microsoft Excel** – This software provides a platform to gather and manipulate raw data then perform secondary calculations of quantities extracted from iTWO Cost X. The Company has developed an Excel measurement template which is used for each estimate. This has been developed around the measurement of building elements and features such as floor areas, walls, doors, finishes, electrical, plumbing and external features. The data is then manipulated and populates an import sheet which links directly to the cost estimating software Databuild which contains the price databases that will be used to calculate the construction costs for the statistical analysis.

3. **Databuild** - This software was developed in Australia with a focus on residential estimating (Databuild 2014). It excels at rapid estimating in which a user programs what is referred to as recipes which contain a build-up of multiple singular items that formulate the building component the recipe relates to. An example of this is a concrete slab on ground which will be measured primarily in m^2 and contain a build-up of all necessary items required to complete the component. This will include all relevant materials, labour, plant hire or subcontract works required to complete the element. Element recipes for all building components exist and quantities can be extracted to provide a first principle cost estimate build up, this will be used to finalise the total construction costs for the data set used for the statistical analysis.

A simplified explanation of the process to be used to gather the data is detailed below in Figure 5.

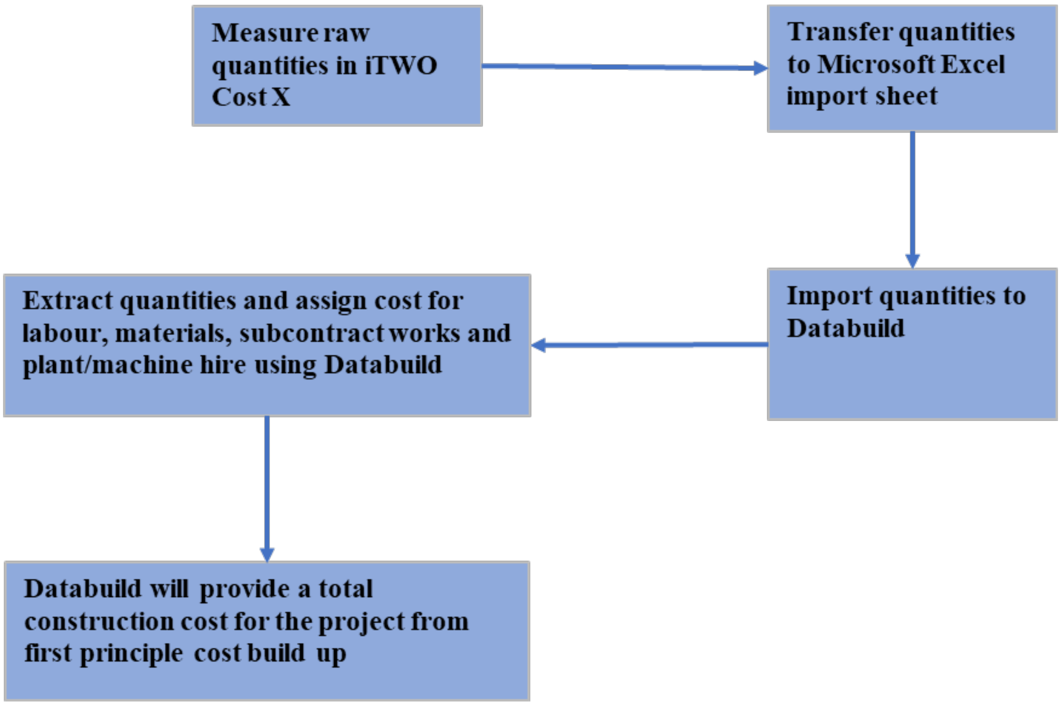


Figure 5 – Flow chart of simplified Company estimating method.

3.3.4 Collation of construction cost

Each concept design used for data analysis will have the construction cost calculated using the methods and software described in the previous section. Once complete, this data will be exported from Databuild. It will be saved in an Excel format with a sample number assigned to each data set which will be a unique identifier and contain a total cost of the construction for each 170 samples. This will form a data set which will allow the cost drivers determined from the literature review and case study to be assigned values for each sample in an Excel spreadsheet for the statistical analysis. The statistical analysis will be detailed in the next section.

3.4 Cost modelling procedure and development

With the previous sections focussing on how the construction cost data will be gathered this section will focus on how that data will be analysed to formulate a cost modelling framework. The statistical analysis will be conducted using the software Statistical Package for the Social Sciences (SPSS) by IBM as this software has an intuitive interface, can easily import data from Excel and can assess both multiple linear regression and artificial neural networks with flexible options (Arkkelin 2014, p. 3).

3.4.1 Data collation and formatting

SPSS can import data from Excel and Databuild can easily export its data to Excel. This means that the total construction costs for each sample can be exported from Databuild and manipulated in Excel to provide a data template for SPSS to utilise during the statistical analysis. The format will consist of an identification number for each sample concept design, the total construction cost excluding GST then a series of cost drivers with appropriate values populated for each sample. The regressors (cost drivers) will be identified from the literature review and the case study interviews. Table 8 illustrates the format required by SPSS for an import template when produced in Excel.

Sample #	**Target value (Y)**	**Cost Driver 1**	**Cost Driver 2**	**Cost Driver 3**	**Cost Driver 4**	**Cost Driver 5**	**……**	**Cost Driver N**
A001	$256,470.60	266.20	26.20	38.80	75.90	96.00	……	55.00
A002	$203,229.45	196.93	17.66	35.20	63.00	67.20	……	64.50
A003	$234,250.75	257.91	3.21	36.40	67.60	73.41	……	75.73
A004	$243,551.36	259.60	23.90	40.00	71.20	75.60	……	93.40
A005	$257,068.89	283.60	45.20	36.20	74.30	79.80	……	83.70
A006	$278,226.47	306.20	40.48	64.80	88.40	90.80	……	90.80
A007	$205,565.30	205.56	19.78	36.50	63.50	70.90	……	55.10

Table 8 – Example data format for SPSS import

3.4.2 Multiple linear regression analysis

Multiple linear regression analysis has already been established as a common method of statistical cost modelling during the literature review. This section will outline the procedure used to develop a regression model using SPSS. For multiple linear regression analysis to be used successfully in construction cost forecasting Morris (2020, pp. 46-59) has outlined three important concepts.

1. The data must represent the behaviour of the larger population. In this case each house design sample contains typical features found to be common between all houses such as foundations, roofing, bedrooms, living areas and bathrooms.

2. The data must typically conform to a linear model. It is expected that as a design get larger in gross floor area then the total cost of construction will increase, this shows that the data is typically linear.

3. The regressor variables (cost drivers) must not have a high degree of collinearity between them. This means the variables must not have a direct linear relationship to each other as they are meant to be independent. If there is a high degree of collinearity between variables it may adversely affect the response value (predicted output). To overcome this issue, thought will be given to the selection of cost drivers to minimise the effect and a collinearity test will be run between regressors (Alshibani et al. 2018).

The results of a multiple linear regression analysis are generally given by the following formula and best summarised by Jablonoski and MacEachern (2009).

$$y = \beta_0 + \beta x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots \beta_n x_n + e \tag{4}$$

Where;

$$y = predicted\ cost$$

$$e = random\ error\ term$$

$$\beta = input\ variable$$

$$\beta_0 = constant\ when\ variables\ equal\ zero$$

$$x = input\ variable\ coefficient$$

In order to reach an output formula, the data for n observations with k input variables is determined through the ordinary least squares method. The relationship of multiple variables is defined below.

$$y = xb + e \tag{5}$$

Where;

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \quad x = \begin{bmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nk} \end{bmatrix}, \quad b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}, \quad e = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{bmatrix}$$

The sum of the squared residual errors is then solved for vector b.

$$e'e = (y - xb)'(y - xb) \tag{6}$$

This then yields the parameter estimate for the following vector.

$$b = (x'x)^{-1}x'y \tag{7}$$

Once the output is produced it is important to remove any input variables from the model that are not significant at a 95% confidence interval, this is typically done through a t-test (Ofori-Boadu 2015). At a 95% confidence interval the P-value produced from the t-test shows that a statistically significant variable would be under 0.05.

The formatted cost data along with the populated cost drivers will be imported into SPSS for analysis. A linear regression analysis will be run using a 95% confidence interval which aims to provide a range of values that would contain the true population mean 95% of the time (Dursun and Stoy 2016, p. 9).

The next step will be to remove any regressors (cost drivers) that are not statistically significant to the model. This will improve accuracy by removing unnecessary cost drivers. A t-test will show that a cost driver is significant if the P-value is less than 0.05 for a 95% confidence internal (Alshamrani 2017, p. 320). This shows that we reject the null hypothesis and accept the alternative hypothesis which means that the cost driver significantly impacts the cost of construction.

The model validity will be confirmed using statistical checks. The regression model needs to fit the data as closely as possible; this will be determined by the statistical measure R^2. A high R^2 value close to 1 (100%) shows that the linear model is a good fit for the data (Jablonowski and MacEachern 2009, p. 448). Chatterjee and Simonoff (2012, p. 15) suggest a linear regression model makes sense if the residual errors have a constant variance, are normally distributed and no collinearity between variables exist. These checks will be done to confirm the model validity.

Once the linear regression analysis is complete and the checks are performed, SPSS will provide output coefficients for each of the remaining significant cost drivers plus a constant term. This will provide a simple algebraic formula to test the output of the model against test samples.

3.4.3 Artificial neural networks

As discussed in the literature review, artificial neural networks have been gaining attention over the last few decades and used successfully along with regression analysis as a cost modelling technique (Lowe et al. 2006, p. 750). The significant cost drivers found during the linear regression analysis will be used to form the artificial neural network input layer. This will ensure a relevant benchmark for the neural network model development and demonstrate a strong relationship to the output variable (Emsley et al. p. 469). As neural networks are inherently non-linear any collinearity between the remaining cost drivers will not cause bias in the output layer of the model (Gulcicek et al. 2013, p. 576).

The multilayer perceptron (MLP) and radial basis function (RBF) neural networks will be analysed using SPSS, these network models were used successfully on a previous study in construction cost forecasting (Zhigang and Yajing 2009). Each neural network with have a single hidden layer and use the 170 sample data sets to create the neural network. The twenty test samples will be added to the data imported to SPSS with all cost drivers populated and no quantity for construction cost. Once developed, the neural networks will provide output construction costs for each of the twenty test samples and this will be used to analyse the accuracy of each neural network model.

3.4.4 Testing of cost models

Twenty additional test sample concept plans will be randomly selected to use during the data testing for the final regression and neural network models. Twenty samples will represent over 10% of the input data set. The test samples will have their construction costs calculated using the same method of first principle estimating used to gather the 170 sample data sets. These values will then be compared to the output from each model to determine its accuracy.

There will be three cost models used for the accuracy testing and output comparison.

- A multiple linear regression model.
- A single layer multi-perceptron neural network.

- A single layer radial basis function neural network.

The Mean Absolute Percentage Error (MAPE) to assess the accuracy of the cost modelling techniques will be used. This is an easy and accurate way of expressing the errors in the models and allow for the analysis of the average errors for each forecasting model (Makridakis and Hibon 1995, p. 5). The MAPE will be used to determine which model is the most accurate at predicting construction costs for residential houses. This data will be collected, calculated and presented in Excel during the results discussion of this research project.

Table 2 collated recent predictive model studies and detailed not only the accuracy achieved but also the test used to determine the validity of the model. 60% of the studies utilised the MAPE method to test model validity. This method tests the deviation of the predicted value in comparison to the actual value as a percentage and utilises the absolute value of the variance to avoid negative results skewing the calculation (Makrisakis and Hibon 1995, p. 5). This is shown below.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - P_t}{A_t}\right| \tag{8}$$

Where;

$MAPE = mean\ absolute\ percent\ error$

$n = number\ of\ samples$

$A_t = actual\ value$

$P_t = predicted\ value$

Whilst other tests of accuracy are available, the MAPE will be utilised by this research project as it clearly shows the comparison between model prediction and actual output. It does however work best when there are no zero value variances in the output data. This is not to be expected with a model designed to predict the cost of a construction project. It would also be more relevant if there were few significant outliers to the data set which can be assessed using R^2 which determines the correlation of the data set to the regression formula (Petroutsaou et al. 2012 and Juszczyk 2018).

3.4.5 Model selection

The cost model chosen for the development of the framework will not be based solely on cost forecasting accuracy. A cost modelling framework can be chosen based on how easy it is to use, the speed in which it produces a result and a satisfactory degree of accuracy (Lowe et al. 2006, p. 750). To be a truly relevant framework, it must have the ability to be updated when construction costs fluctuate. By using a live cost database to collect data, this research project will meet that criteria.

A weighted decision matrix will be used to determine the best model to select for framework development. This will consist of the following criteria and weightings.

1. The accuracy of the model.
    - This will be determined by the lowest MAPE value.
    - A rank will be given to each model ranging from one through to three to correspond with lowest to highest performing model, 3 for the highest and 1 for the lowest.
    - This criteria will be given a weighting of 40%.
2. The ease of use and speed in which the model provides a result.
    - This will be based on whether the model output can be easily replicated using readily available software such as Excel.
    - A simple yes value (2) or no value (1) will be given.
    - This criteria will be given a weighting of 40%.
3. The ability to update the cost model.
    - This will be subjective and determined by the researcher based on how difficult it is to export cost data and run through another iteration of each statistical analysis.
    - Each model will be assigned a rating between one (worst) and ten (best).
    - The weighting for this criteria is 20%.

The total weight will be tallied and the modelling technique with the highest score will be used to develop the cost modelling framework.

3.4.6 Framework development

The cost modelling framework development will depend on the final model selected from the weighted decision matrix. Two options are available.

1. The multiple linear regression framework will be developed in iTWO Cost X and Excel. Cost X contains the ability to measure quantities on screen and live link those measurements to a workbook which functions much the same as Excel. An Excel version will also be produced as this software is more commonly available.
2. A neural network model framework will need to be run through SPSS each time a cost prediction is required or specific software will need to be programmed in order for an end user to utilise the framework model.

3.5 Summary

This section detailed the three stages the research methodology will take. Progressing through the case study to identify current estimating techniques and cost drivers will serve to validate the results from the literature review. Construction costs for the sample models will be calculated based on information obtained through the case study of the Company using their procedures and software for first principle estimating methods. This raw data will then be statistically analysed, tested and validated to determine the most appropriate statistical model to use for the development of the cost modelling framework. The different stages used during this methodology will achieve the research objectives by identifying cost estimating techniques, cost drivers and finally developing a cost model framework.

Chapter 4 – Results and discussion

4.1 Results from case study interviews

Two of the objectives for this project are to determine current estimating techniques in the Australian residential market and to identify potential cost drivers. The literature review identified some of this information however a case study of a Queensland estimating company has been conducted to validate the literature review findings and expand the cost drivers.

Part of the methodology for developing the cost modelling framework is to determine current methods of estimating and identify additional design related cost drivers through a case study. This provides a more relevant understanding of the Australian estimating methods. This section will detail the results gathered from the case study interviews and achieve two of the project objectives. The case study involved two phases. The first phase is to determine current estimating techniques in the Australian market, this will validate information discovered during the literature review. Phase two will gather additional cost drivers to the ones identified during the literature review. Summarised transcripts from each interview can be found in Appendix G with the results and analysis presented in the following sections.

4.1.1 Phase one results – establish current estimating techniques

The interviews found the initial information available for an accurate cost estimate varies according to scope and type of the project. All participants agreed that for initial estimates a concept plan only was often available. It is rare they are provided full design documentation such as detailed architectural plans, structural plans, civil plans, hydraulic or electrical plans. This was found to be common in residential construction due to the production line output of volume housing construction. Once contracted the project then has full design documentation completed, however the initial first principle cost estimate was performed on a concept plan only.

The case study interviews confirmed the time taken to produce a first principle estimate ranged from one to two hours for a simple design. It is the objective of this project to use cost modelling to cut this time down to a matter of minutes which will significantly improve productivity. It was noted that complex builds such as multi-storey dwellings or medium density residential can take one day or more, which is outside the scope of this project.

The level of accuracy for the three methods of estimating commonly found and identified during the literature review (unit rate and first principles) were validated during the case study. Each respondent agreed that the unit rate method was unreliable other than for a preliminary feasibility estimate. The accuracy of the unit rate estimate from the respondents ranged from 10% to 20%. This correlates with the findings of Ashworth (2004, p. 342) who determined a 13% accuracy using this method. A first principle estimate, depending on complexity of the project, was thought by the respondents to be between 1% and 4% of actual costs. Ashworth (2004, p. 342) determined this method to be approximately 10% accurate. The higher accuracy of the first principle method in residential construction was explained due to the relatively simple and predictable nature of housing construction compared to more complex sectors of the industry such as commercial or civil construction.

The methodology for this project's framework centres around using a baseline estimating technique of standard inclusions and design related factors. It was found to be common in residential construction to complete a first principle estimate with a baseline level of inclusions in Queensland during the literature review (Lim et al. 2016, p. 14). The case study interview responses validated this finding. The interviewees were asked how they build up the cost for a construction project, the use of a standard specification and how a consumer modifies the inclusions to suit their own tastes.

Each response agreed that a priced bill of quantities is calculated for each project to a baseline cost using a standard specification of inclusions, an example bill of quantities using this method has been provided in Appendix S. Standard specifications of inclusions are common in the Australian industry (Lim et al. 2016, p. 14) with some contractors offering different levels of finish to target certain buyer markets such as low cost or high-end. This offers a certain level of choice however it was noted in the literature review consumers often wish to customise their inclusions (Warren-Meyers and McRae, 2017). This was determined as common place by the interviewees and they cater for this by calculating the baseline estimate, adding the desired profit margins and then varying inclusions requested by the consumer. This process has been summarised below in Figure 6.

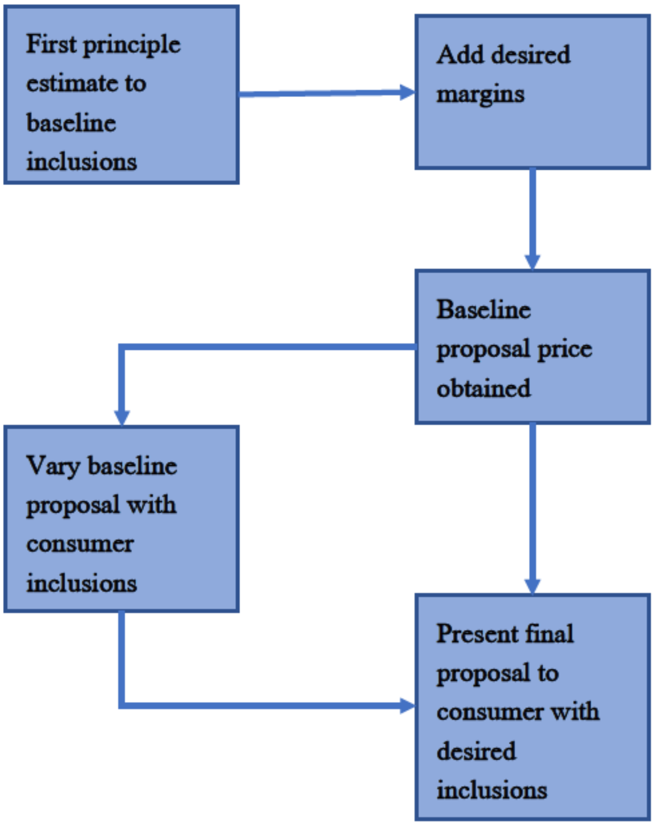


Figure 6 – Flow chart of proposal calculation build up

An example has been illustrated below in Table 9 which numerically details the process.

Description	**Cost ($)**
Baseline construction cost	$250,000
Add 10% profit margin	$25,000
Add 5% overhead contribution	$12,500
Baseline proposal price	$287,500
Vary inclusions for consumer	
Remove tiles from alfresco	-$2,500
Include stone bench tops to kitchen	$5,000
Increase carpet to premium range	$3,300
Add 10 extra lights	$1,200
Proposal price submitted to consumer	$294,500

Table 9 – Price calculation build up method

This process is important to define as this project will use the baseline estimate method discovered during the case study to collect the cost data for analysis. The literature review found that previous cost models often include too many variables which can lead to model inaccuracy. These variables are often external to the structure itself such as site conditions, contract types, environmental and risk factors. Using the baseline estimating method will remove many of the external variables, reduce the cost drivers and improve the accuracy of the framework.

The literature review found contract type was often included as a cost driver (Emsley et al. 2002, Lowe et al. 2006 and Soutis and Lowe 2011). The final interview question for this phase was to determine the type of contract used in a residential project. The results confirmed that industry body standard form contracts are typically used in residential construction with Master Builders and Housing Industry Australia being the most common. These contracts are often very similar in terms, conditions and layouts which removes the risk of differing contract terms. Due to this finding the contract type can be ignored as a cost driver.

The answers from the interviewees all garnered similar responses, meaning a saturation point was reached as detailed in the methodology. This means the data is considered reliable and can be used.

4.1.2 Phase two results – determine further relevant cost drivers

This phase of the case study determined additional cost drivers that were not discovered during the literature review. Providing tangible information from experts is critical in gathering relevant results. By first defining a cost driver for the interviewee, they were then asked to identify design related factors that they considered would contribute significantly to cost (cost drivers). The responses have been summarised in Table 10 and correlated against the results obtained from the literature review previously summarised in Table 5. Table

10 shows which cost drivers were identified during both the literature review and case study (yes) and which cost drivers were only identified during the case study interviews (no).

Cost driver identified	**Identified from literature review and case study**
Gross floor area	Yes
External areas	No
Garage areas	No
Layout complexity	Yes
Roof design	No
Number of bathrooms	No
Number of additional plumbing outlets	No
Wall height	Yes
Window openings	Yes
External wall length	Yes
Number of separate living areas	No
Number of bedrooms	No
Custom joinery / cabinetry	No

Table 10 – Summary and cross reference of cost drivers from interviews

Gross floor area was identified as the highest contributing cost driver as a positive linear relationship generally exists between the size of the building and total cost. From Table 10 it can also be seen that the interview results validated several of the cost driver findings from the literature review; this is an excellent result as these items have been deemed relevant through other studies and now validated by the case study.

The purpose of the second phase case study interviews was to determine further cost drivers that may be relevant to a cost modelling framework suited to the Australian residential construction industry. They have been identified in Table 10. The cost drivers identified in the case study have been explained in the following sections to define the cost driver measurement parameters for the framework.

4.1.2.1 External and garage areas

These two areas were identified by participant three. Clarification of this response revealed that these areas should be separated from internal living space which is often more expensive. Internal spaces are conditioned spaces which contain a higher density of costly inclusions such as electrical, air conditioning, internal partitions and windows located on external walls. In comparison an alfresco is often not enclosed by external walls and may only have a floor finish treatment with minimal electrical fittings such as lights. Similarly, a garage is generally enclosed however features no floor finishes and again minimal electrical fittings. Figure 7 shows a typical floor plan identifying external and garage areas for a reference point.

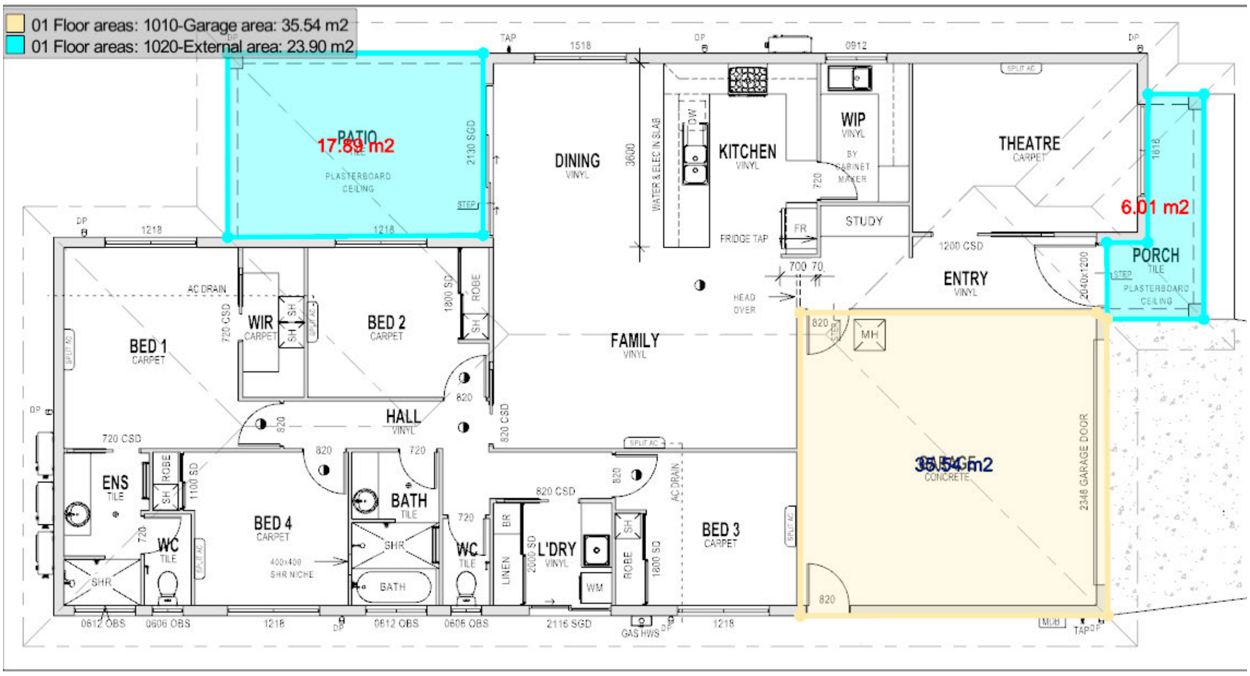


Figure 7 – External and garage area cost driver example

4.1.2.2 Roof design

A roof consists of geometric planes that combine for an attractive appeal. All three interviewees identified the roof design features as a major contributing factor to cost. Features such as hips, valleys, ridge lines, eaves, gables or parapets were common responses when probed. These items were indicated as cost drivers during the case study and will feature in the cost model development for this project. They have been identified and highlighted below to illustrate their locations.

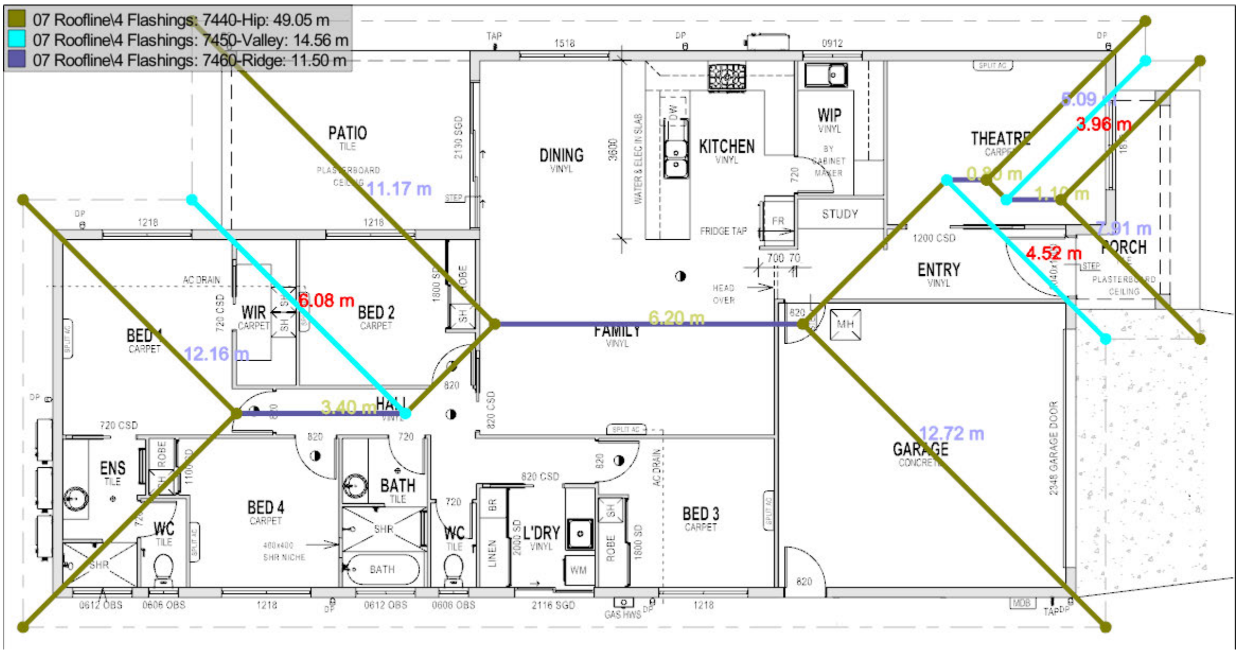


Figure 8 – Hips, valleys and ridge line cost driver example

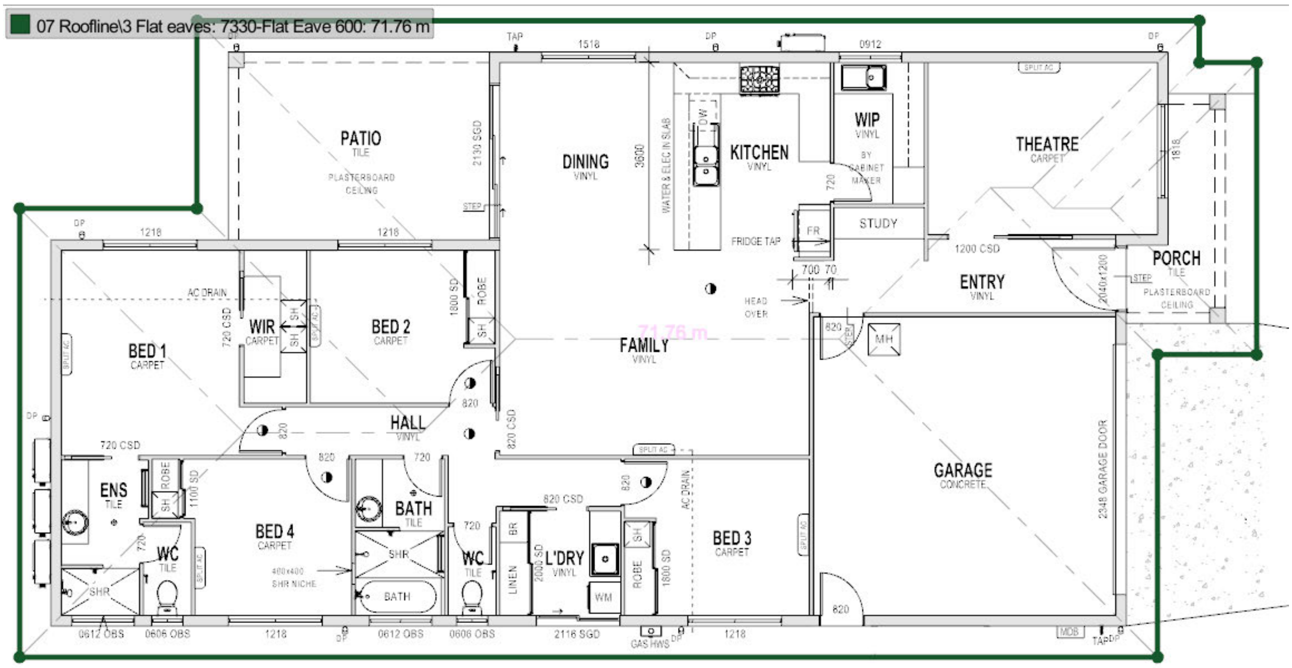


Figure 9 – Eave cost driver identification

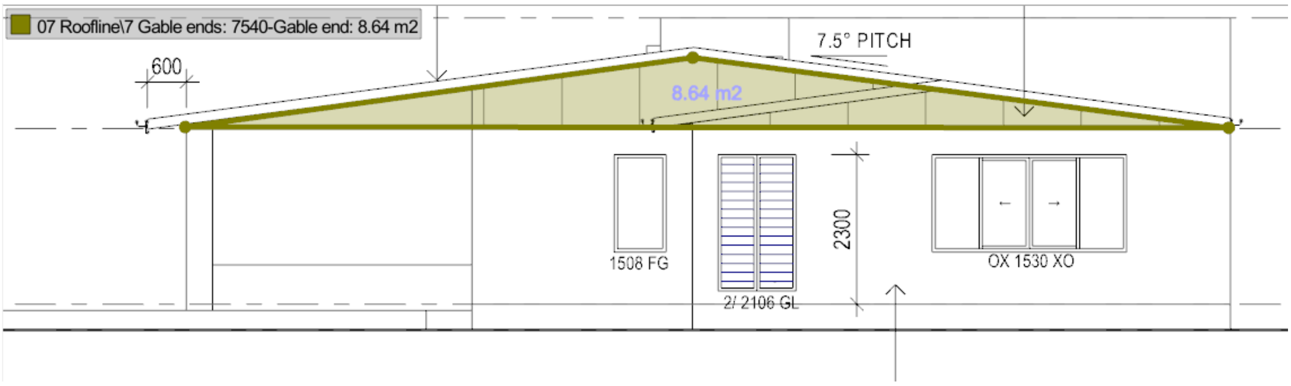


Figure 10 – Gable end cost driver identification

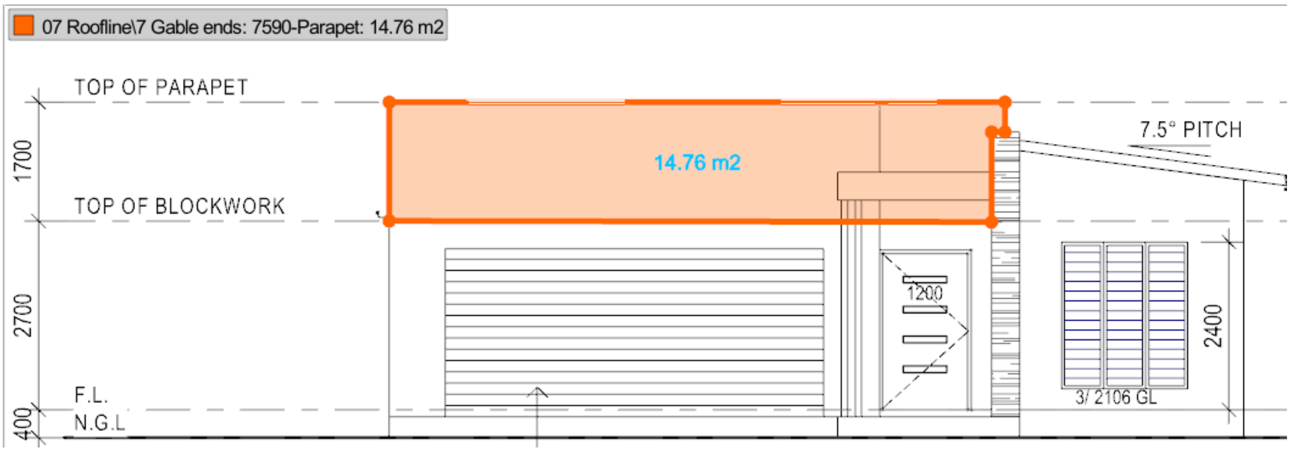


Figure 11 – Parapet cost driver identification

4.1.2.3 Number of bathrooms

Plumbing drainage and fit off requirements for a dwelling add cost. Bathrooms are often small in area however feature expensive fit out requirements such as tiling to walls and floor, custom vanity units, shower outlets, bath tubs, mirrors and shower screens. This creates a high cost per square metre of floor area. The total number of bathrooms in a dwelling was identified through the interview process as a potentially significant cost driver and must be included in the cost modelling process.

4.1.2.4 Number of living areas

The number of living areas was identified through the interview responses as being significant. It was explained by interviewees that a separate living area often requires more internal partitions to separate the area from others and requires additional electrical components such as lights, fans and air conditioning. Two figures below show different house designs that feature one and three separate living areas which will be used as a definition for the cost driver measurement.

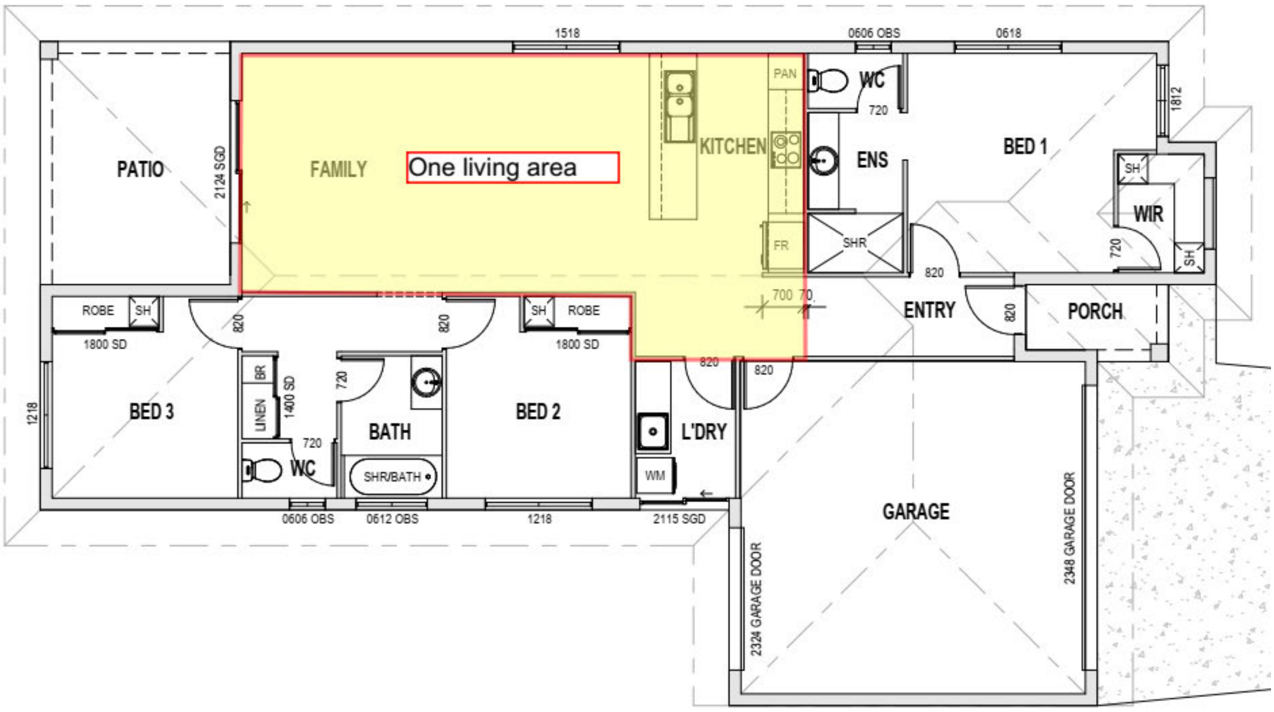


Figure 12 – Cost driver definition of one living area

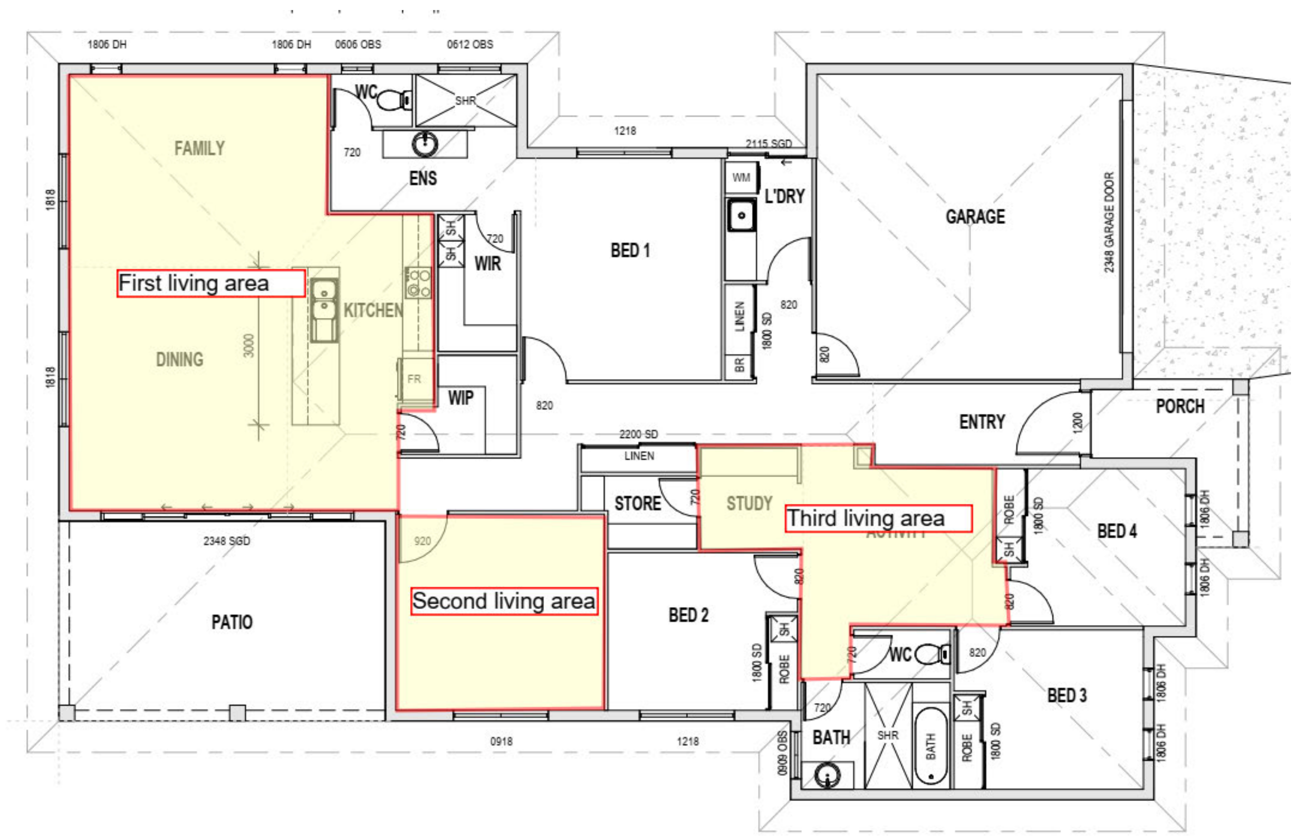


Figure 13 – Cost driver definition of three separate living areas

4.1.2.5 Number of additional plumbing outlets

This cost driver was explained by interviewees that using the Company's baseline estimate method assumes a standard number of plumbing fittings per bathroom. Any additional outlets are then considered as extras. A typical bathroom is assumed to include one shower outlet, one vanity and one bath. If a design included a double vanity or two shower outlets, then these would be identified as "extra or additional". Using this technique the framework will assume one kitchen sink, one laundry tub and a standard number of fittings per bathroom such as one shower, one bath and one vanity basin. Any extra fittings will be considered for this cost driver.

4.1.2.6 Number of bedrooms

This cost driver is similar in theory to the number of additional living areas. Each bedroom requires partitioning, air conditioning, doors, windows, robes and electrical fittings. Therefore, including the total number of bedrooms is deemed a relevant cost driver and this item was identified by at least two of the interview respondents.

4.1.3 Custom joinery or cabinetry

This cost driver relates to custom made kitchen and bathroom cabinetry which can be intricate and costly. It is possible that similar sized houses can include varying lengths of bench space and more intricate joinery. This cost is often placed into the proposal as a Prime Cost. A Prime Cost is defined as a specified item of known work which is assigned a dollar value in the proposal for the purpose of tendering (Loots and Charrett

2009, p. 216). The respondents explained they assign a lump sum value to these items for inclusion in the estimate. During the initial tendering phase an indicative sum only is used, which is calculated using lineal metres of bench space.

This finding suggests that the data may be abnormally biased toward dwellings with larger amounts of custom cabinetry independent of the size of the design. It is difficult to place a simple unit quantity against custom cabinetry for the data analysis. As one project objective is to develop a cost modelling framework which is quick and effective, measuring intricate custom cabinetry will not make this possible. This finding suggests that two discrete sets of data should be analysed when developing the framework to explore a potentially more accurate method of cost modelling. One data set will include the allowances for custom cabinetry whilst the second data set will exclude these. It is noted that this will yield an irrelevant construction cost baseline output from the framework. This can be rectified by adding the custom cabinetry component back on to the baseline cost after it has been calculated although this is not an ideal solution.

4.1.4 Cost drivers identified

Data gathered from both the case study interviews and literature review have led to a defined list of cost drivers deemed relevant to design related factors and will be used during the data analysis. These have been summarised in Table 11 with a total of 15 cost drivers identified for statistical analysis.

Cost driver description	**Unit of measure**
Gross floor area	m^2
External areas	m^2
Garage area	m^2
External walls	Lineal metre
Internal walls	Lineal metre
Eaves	Lineal metre
Compactness	Ext wall area / gross floor area
Area of external openings	m^2
No. sets of stacker SGDs	Each
Hips / valleys / ridges	Lineal metre
Gable ends	m^2
No. of bedrooms	Each
No. of living areas	Each
No. of bathrooms	Each
Additional plumbing outlets	Each

Table 11 – Final cost drivers identified for data analysis

The case study interviews have satisfied the first two objectives of this project. The first was to determine current cost estimating techniques employed in the Australian residential market. The second was to identify additional design related cost drivers to ones discovered during the literature review. The following section briefly outlines the first principle methodology used by the Company, this technique was used to collect construction cost data for statistical analysis.

4.2 Estimating methodology from case study results

First principle estimating is one of the methods identified during the literature review as the most time consuming and accurate. The case study interviews confirmed first principle estimating is common and this section will detail the method used by the Company. This method was used to collect the sample data for statistical analysis and subsequent framework development therefore important to define.

4.2.1 iTWO Cost X software

The Company uses iTWO Cost X developed by Rib Software International to quickly and accurately measure and record quantities (RIB Group 2021). The software provides a graphical user interface to import a design plan and measure quantities on screen. Dimension groups are created by the user and in this case defined as relevant building elements. They can be measured as count (each), length (lineal metres), area (square metres) or volume (cubic metres). Figure 14 and Figure 15 show a sample of the measurements taken through iTWO Cost X.

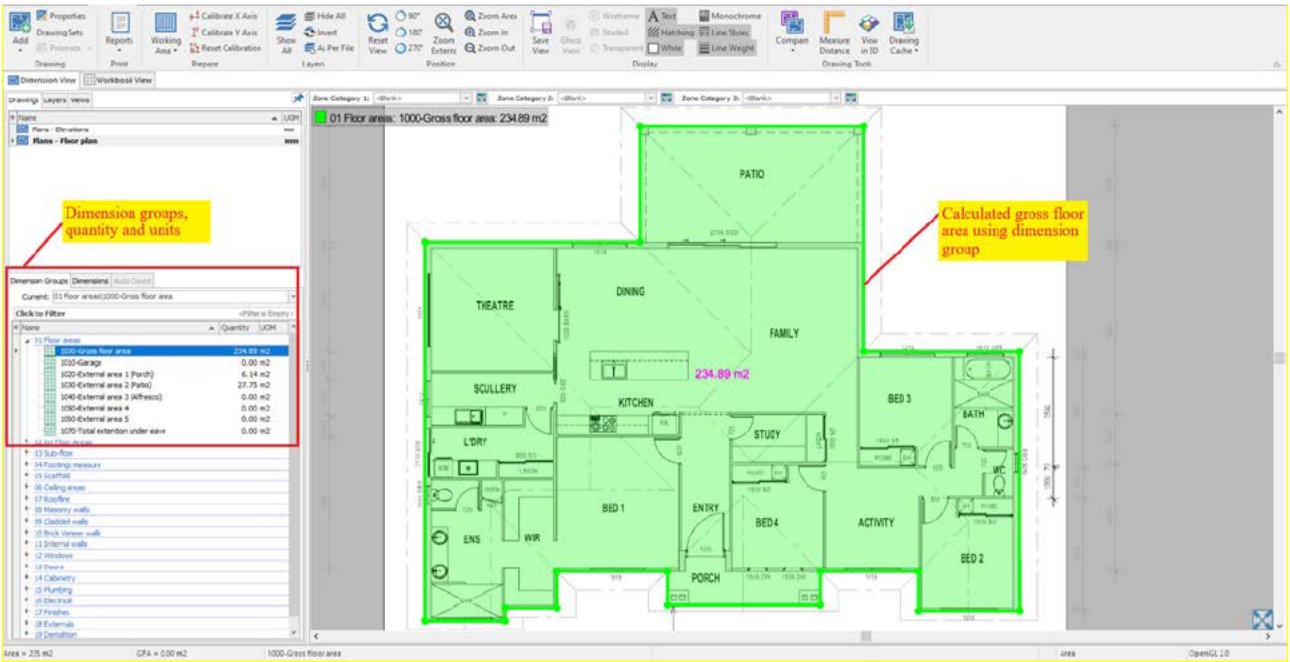


Figure 14 – iTWO Cost X measurement example (GFA)

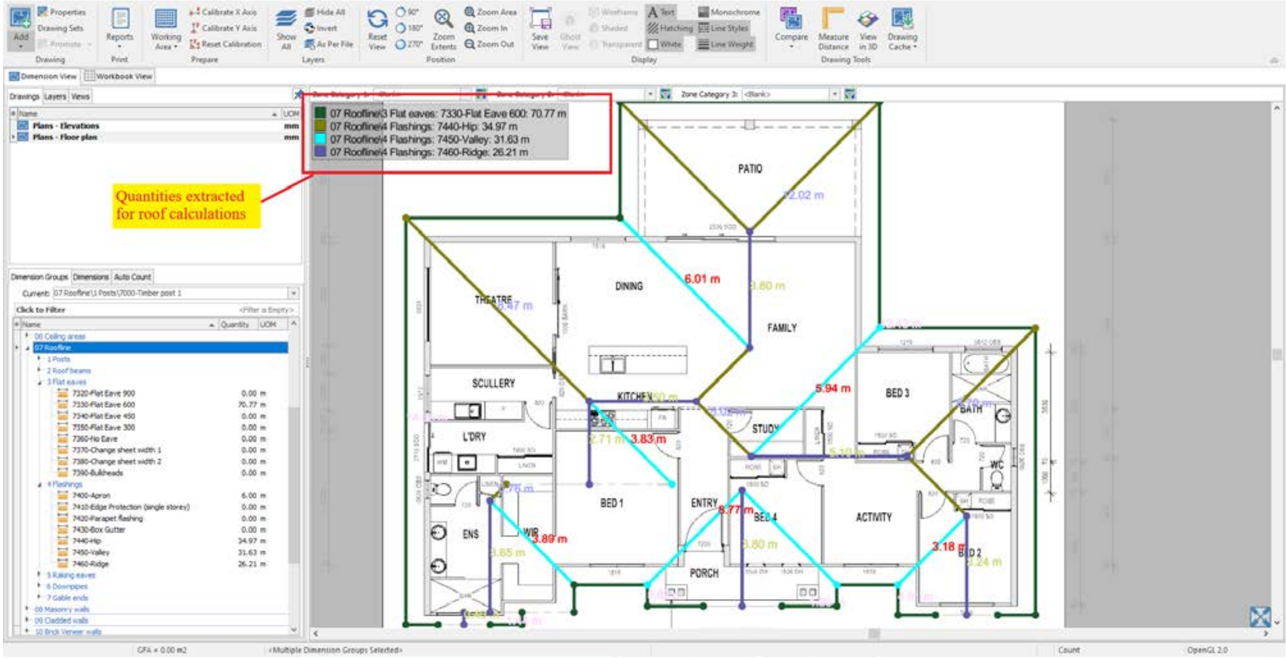


Figure 15 – iTWO Cost X measurement example (roof line)

4.2.2 Company measurement sheet using Microsoft Excel

Microsoft Excel provides an excellent platform to collect, manipulate and provide secondary calculations for raw measurement quantities. The quantities obtained through iTWO Cost X are used to populated an Excel template developed by the Company. This has been developed around the measurement of building elements and features such as floor areas, walls, doors, finishes, electrical, plumbing and external features. The data then populates an import sheet which links directly to the cost estimating software Databuild. A brief visual explanation of the Company Excel measure sheet will be provided in the following figures to detail the process involved during the data collection for this research project. The basic structure, an example of raw data along with the secondary calculations embedded and extracted using Excel and the import sheet will be shown.

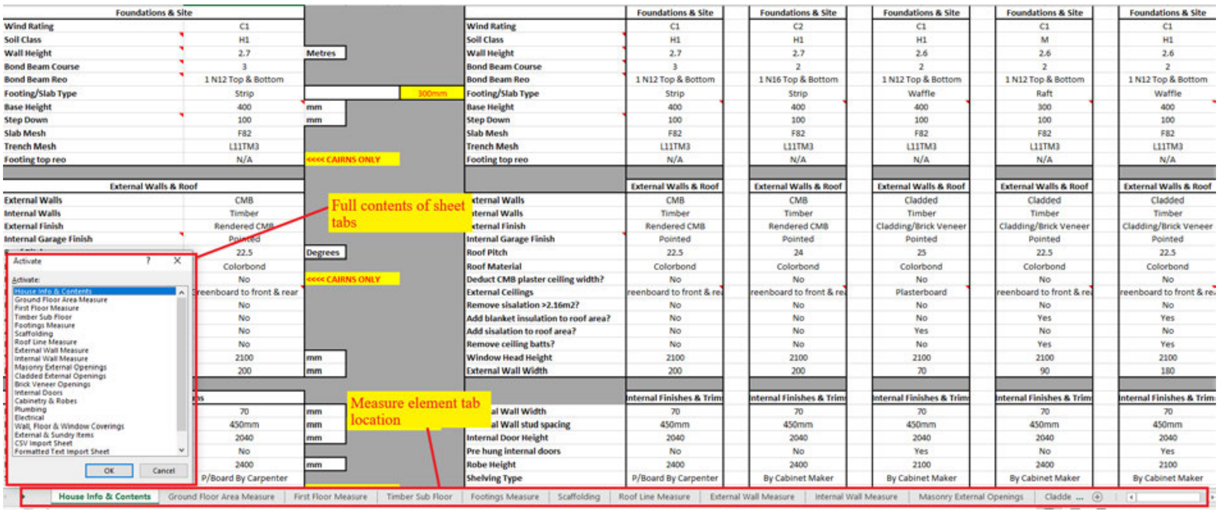


Figure 16 – Excel measure sheet basic layout example.

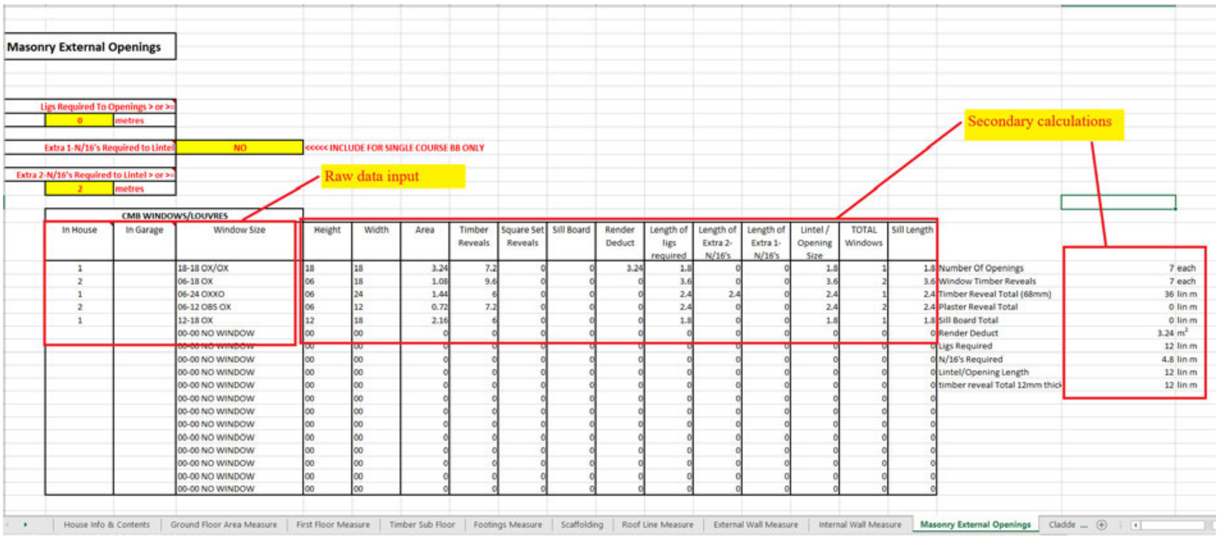


Figure 17 – Excel measure sheet example of raw data and secondary calculations.

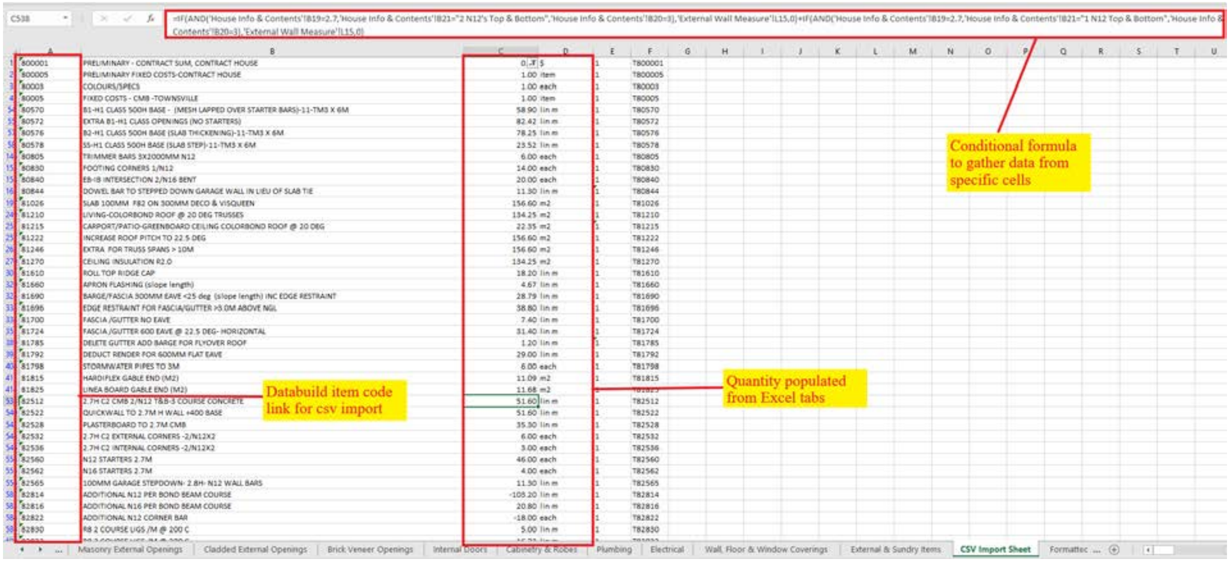


Figure 18 – Excel import sheet with link to Databuild.

4.2.3 Databuild cost estimating software

Databuild estimating software was developed in Australia with a focus on residential construction (Databuild 2014). A user programs "recipes" that represent a building element and contains multiple items to formulate that element. An example recipe is a concrete slab on ground which is measured in m^2 and contains a build-up of all necessary items required to complete the element. The recipe is programmed to include all relevant materials, labour, plant hire and subcontract works. Figure 19 shows an example of a recipe for a slab on ground programmed in the Company's version of Databuild.

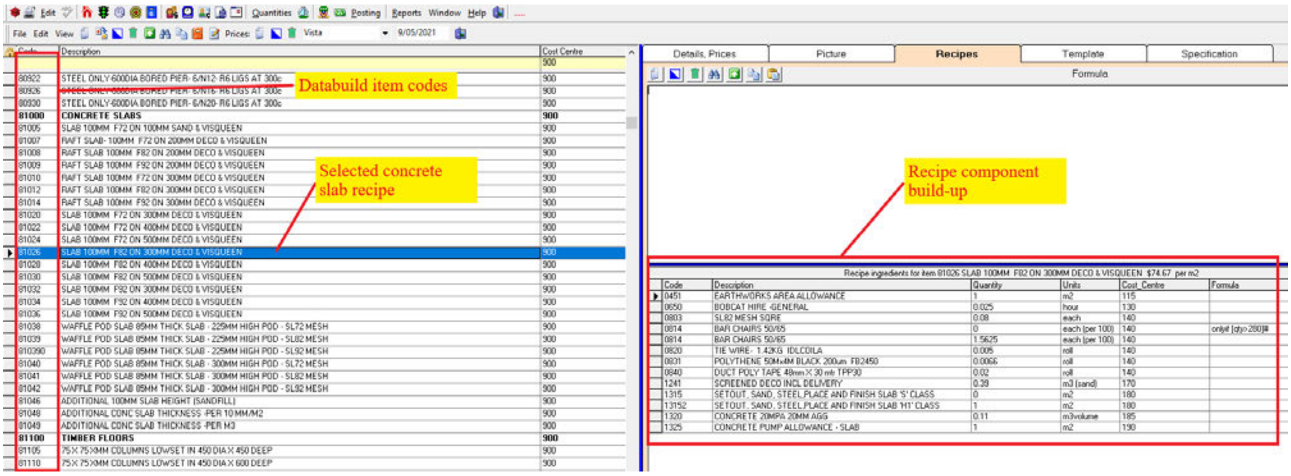


Figure 19 – Databuild recipe build example.

From the previous section Figure 18 shows the Excel import sheet and details a list of item codes running down the left-hand side of the page, these item codes directly correspond to items in Databuild as shown in Figure 19. The populated item codes from Excel are imported directly into Databuild, a list of recipes can then be compiled into the project as shown in Figure 20.

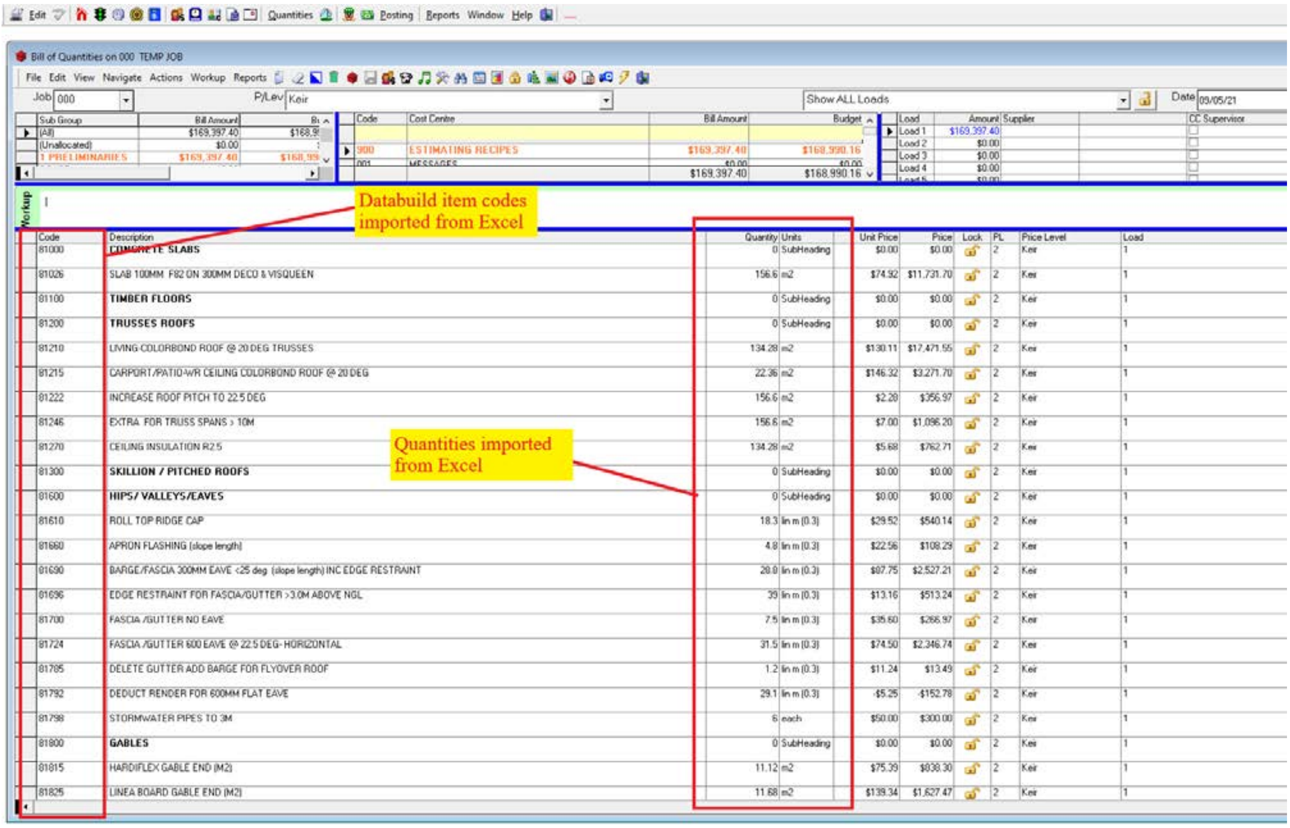


Figure 20 – Databuild recipe import from Excel measure sheet.

As shown in Figure 19 each recipe item contains the individual components required to complete the project. Databuild extracts these items from the recipes and places each item into corresponding cost centres to form a coherent and detailed first principle breakdown of the project. Figure 21 shows the quantities along with assigned unit prices from the cost catalogue contained within a bill of quantities for the project.

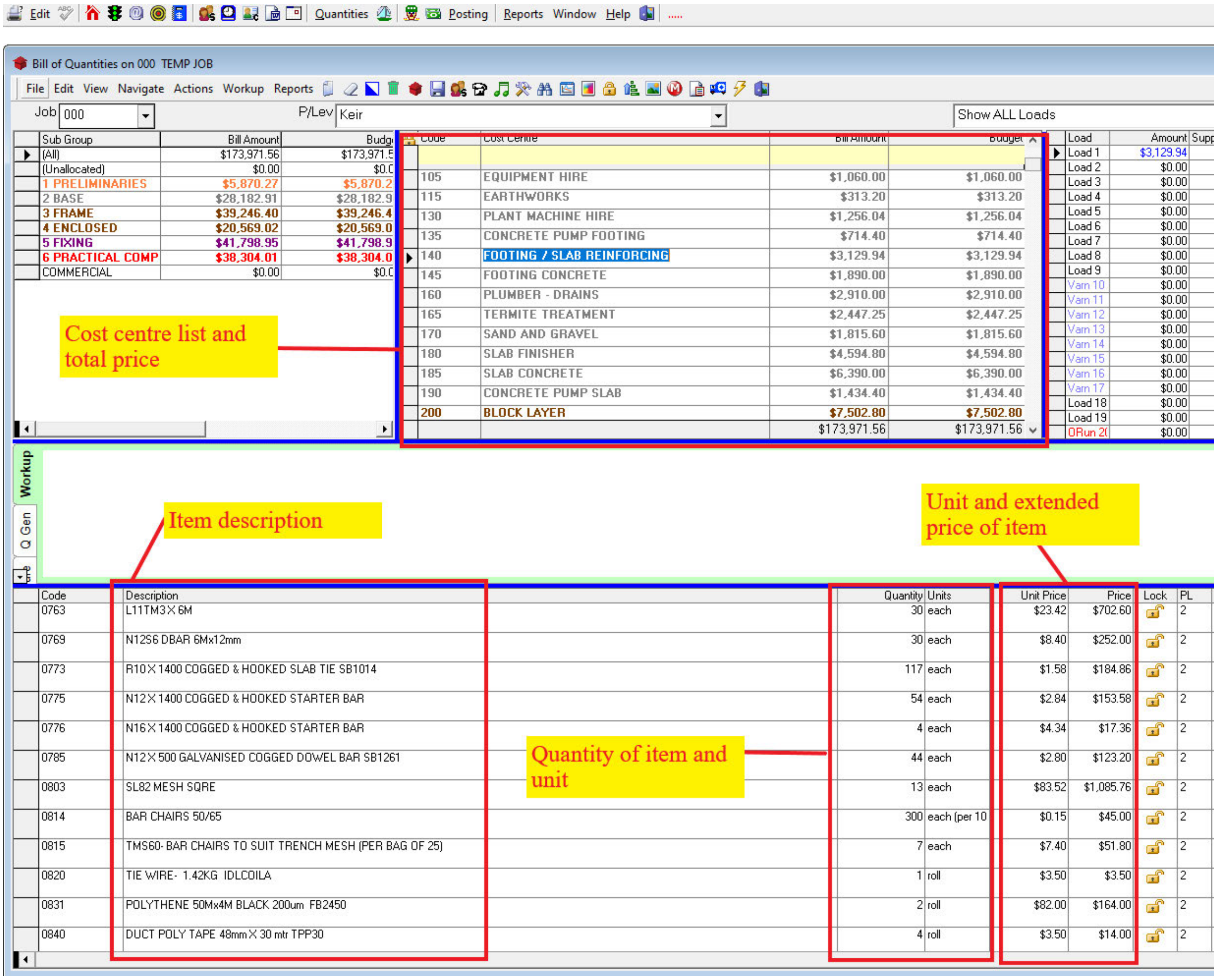


Figure 21 – Databuild output of recipe components.

The entire cost of the project can easily be totalled in Databuild. An example of a first principle estimate using this method is found in Appendix S along with a cost summary in Appendix T exported from Databuild. The cost data for each 170 sample and twenty test designs used during this research project have been created using this process. The total cost of each sample set has been exported to Excel to collate and format the data for statistical analysis in SPSS, this can be found in Appendix H.

Databuild can store costs for each unit item contained within a price catalogue. This feature will form an important part this project's cost modelling framework, it will provide functionality for a dynamic updatable data set. When prices vary Databuild can reprice all the projects instantaneous giving a revised total construction cost. This will allow the cost data to be periodically rerun through the cost modelling process to update the framework. This is a critical part of the third project objective and allows for a relevant framework to be produced which does not rely on historical data. This was considered a shortfall of previous studies during the literature review. Figure 22 shows the price catalogue for a typical item along with the unit price and the date from which the price is valid. Using this functionality means the cost model can easily be updated when unit prices alter which inevitably occur in the construction industry. This process will be detailed in section 4.5.4 Framework update example.

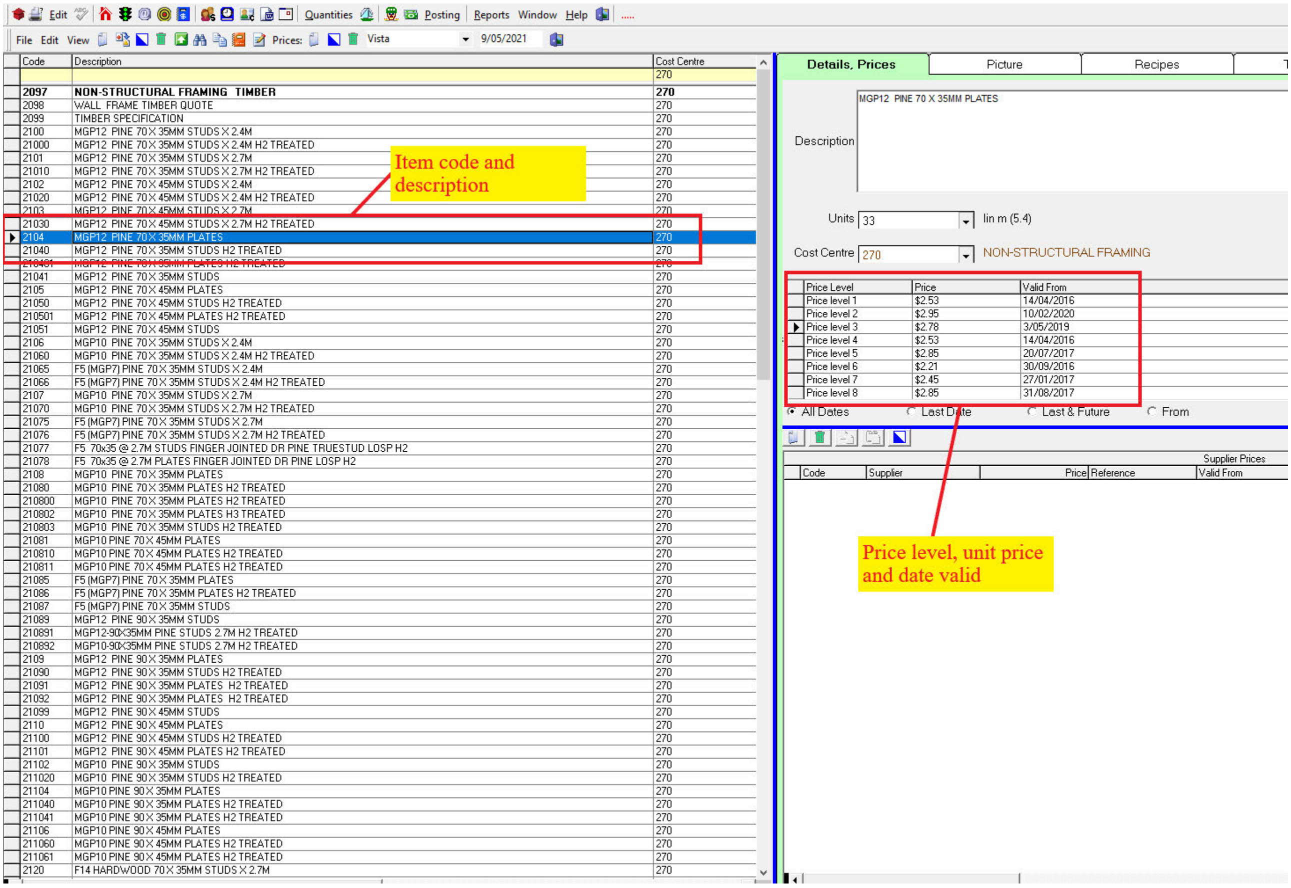


Figure 22 – Price catalogue and date valid.

4.3 Data modelling results

The methodology section explained how the framework development goes through an iterative process. Sample design construction costs were calculated using the first principle estimating method confirmed in the case study. Cost drivers identified through both the literature review and case study interviews were assigned values for each sample set. The data set then underwent a linear regression analysis to determine the statistical significance of each cost driver. Cost drivers not significant to the regression analysis were removed and the analysis run again to determine the coefficients for the linear regression equation. This lead to the testing of two neural network designs using the significant cost drivers. The results are presented and discussed in this section.

4.3.1 Data collation

Construction costs for the 170 sample designs were collated into an Excel spreadsheet. The 15 cost drivers identified for analysis were assigned values next to each sample design. This created an import template for SPSS to analyse the data. Appendix H shows the template with relevant cost driver values populated for each sample.

4.3.2 Linear regression analysis of results

The first step required a linear regression analysis to be performed in SPSS on the data set. The results identified statistically significant cost drivers. Cost drivers that were not significant were removed and the significant cost drivers remained for a second linear regression analysis. This section will discuss the results from the linear regression analysis performed on the data.

A multiple linear regression analysis was performed using a 95% confidence interval. This assumes 95% of the mean of the population will fall within this area. The dependent variable for the analysis was the total cost of construction. The independent variables were the 15 identified cost drivers. Table 12 shows the results from the first linear regression analysis.

	Unstandardized Coefficients		Standardized Coefficients		
Cost driver	B	Std. Error	Beta	t	Sig.
(Constant)	42484.836	21073.480		2.016	0.046
GFA (m2)	436.166	77.346	0.569	5.639	0.000
External areas (m2)	135.652	58.926	0.044	2.302	0.023
Garage area (m2)	-197.486	62.463	-0.041	-3.162	0.002
External walls (lin m)	566.869	278.086	0.143	2.038	0.043
Internal walls (lin m)	132.036	49.810	0.060	2.651	0.009
Eaves (lin m)	-72.345	73.220	-0.022	-0.988	0.325
Compactness (Ext wall area / GFA)	-6873.767	21883.290	-0.017	-0.314	0.754
Area of external openings (m2)	343.183	89.455	0.083	3.836	0.000
No. sets of stacker SGDs	-323.402	628.161	-0.006	-0.515	0.607
Hips / valleys / ridges (lin m)	135.596	29.424	0.097	4.608	0.000
Gable ends (m2)	468.681	72.119	0.152	6.499	0.000
No. of bedrooms (each)	-226.166	1023.109	-0.003	-0.221	0.825
No. of living areas (each)	-65.425	750.349	-0.001	-0.087	0.931
No. of bathrooms (each)	11354.954	2537.164	0.050	4.475	0.000
Additional plumbing outlets (each)	2017.203	421.354	0.081	4.787	0.000

Table 12 – First linear regression results

The results from the first linear regression were used to identify which cost driver significance. With a 95% confidence interval the P-value (shown in the sig. column) detailed in Table 12 will determine significance. Any cost driver with a $P < 0.05$ is considered significant to the model and retained. This means there is strong evidence the null hypothesis can be rejected and concludes a statistically significant relationship exists (Arkkelin 2014, p98). From these results, five cost drivers are not significant and are highlighted yellow in Table 12. These are eaves, compactness, stacker sliding glass doors, number of bedrooms and number of living areas. These are excluded from the model and the linear regression analysis run again using the same parameters. The results from the second linear regression analysis with the remaining significant cost drivers are detailed in Table 13.

	Unstandardized Coefficients		Standardized Coefficients		
Cost driver	B	Std. Error	Beta	t	Sig.
(Constant)	34911.766	5738.616		6.084	0.000
GFA (m2)	448.781	30.635	0.586	14.649	0.000
External areas (m2)	137.002	55.328	0.045	2.476	0.014
Garage area (m2)	-185.313	58.579	-0.038	-3.163	0.002
External walls (lin m)	470.019	101.773	0.118	4.618	0.000
Internal walls (lin m)	134.711	44.257	0.061	3.044	0.003
Area of external openings (m2)	328.761	83.295	0.080	3.947	0.000
Hips / valleys / ridges (lin m)	132.503	28.155	0.095	4.706	0.000
Gable ends (m2)	443.071	62.785	0.144	7.057	0.000
No. of bathrooms (each)	11000.077	2485.330	0.048	4.426	0.000
Additional plumbing outlets (each)	2015.819	408.810	0.081	4.931	0.000

Table 13 – Linear regression results with significant cost drivers

The results from the second linear regression analysis show that all remaining cost drivers are significant as all have a $P < 0.05$. It is also important to confirm the results using other tests to ensure they are reliable. Linear regression assumes that there is a linear relationship between the dependant and independent variables (Morris 2020, p. 46). To confirm the model is viable certain assumptions must be made and the data tested. Chatterjee and Simonoff (2012, p. 15) suggest a linear regression model makes sense if the residual errors have a constant variance, the errors are normally distributed and each variable is independent of one another. These tests were run on the data output with the results summarised below.

1. Residual errors must have a constant variance. A scatter plot of the residual versus the predicted values for the model can be produced. If there is no pattern and are randomly scattered around zero it means the relationship between the response and predictor variables is zero. Figure 23 confirms the residual errors have a constant variance.

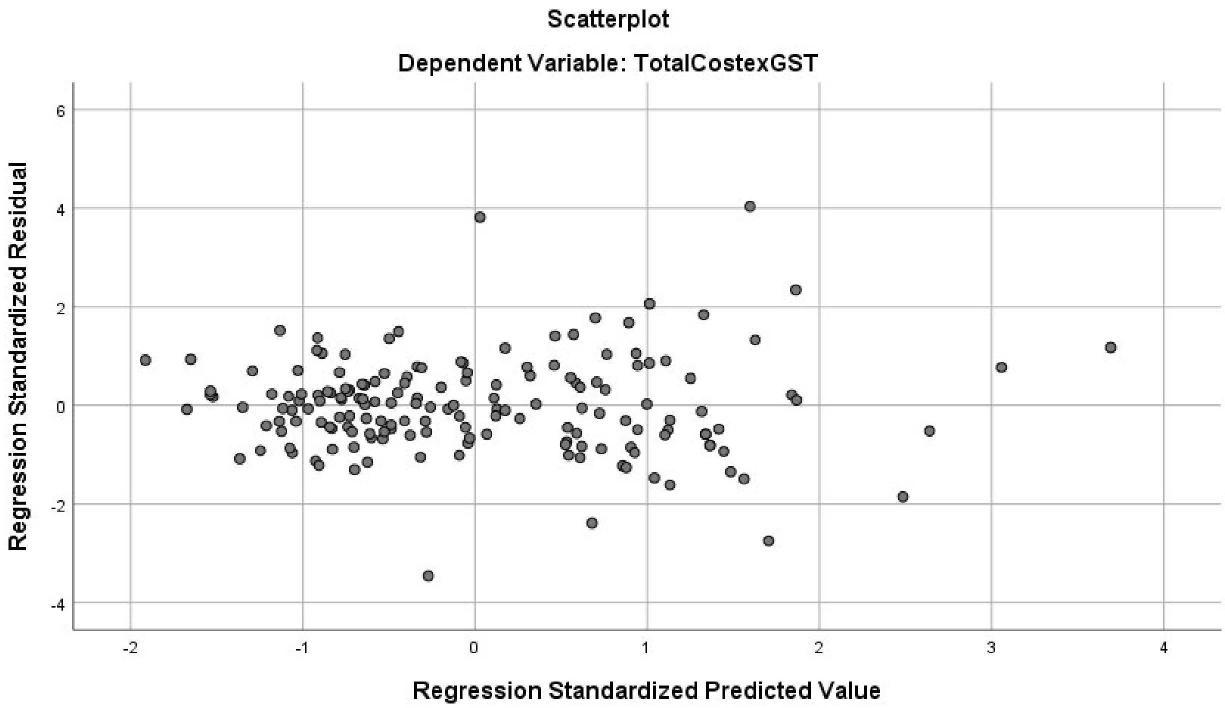


Figure 23 – Scatter plot of residual versus predicted values

2. The residual errors must be normally distributed. This is assessed through a plot of the expected versus the observed errors. If they roughly show a straight line, then normality is maintained. Figure 24 shows this relationship with the regression model holds true as a rough straight line is shown.

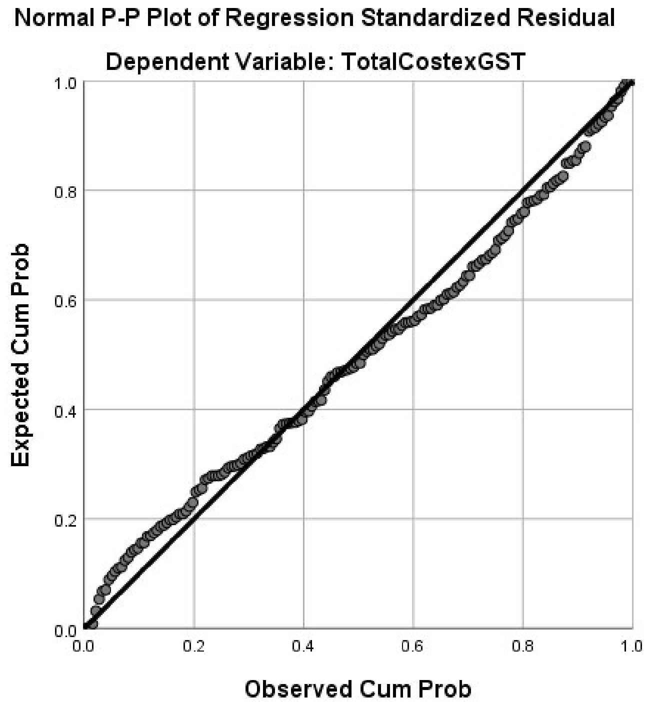


Figure 24 – Regression plot for normality of residual errors

3. Each predictor variable (cost driver) must be independent of each other. Collinearity between variables suggest the coefficients produced by the model may not be valid and the errors for these can become abnormally inflated resulting in an invalid model. A multicollinearity test is performed during the linear regression analysis. Chatterjee and Simonoff (2012, p. 29) state that the variance inflation factor (VIF) should be confirmed for each variable and that no formal cut off exists for a large VIF. They state that collinearity is not an issue if the VIF satisfies the below expression.

$$VIF < \max\left(10, \frac{1}{1-R^2_{model}}\right) \quad (9)$$

The adjusted R^2 produced by the model is 0.982. The closer that value is to 1 the better the goodness of fit for the regression model. This shows the fit of the regression model is a very good fit for the data. Since R^2_{model} is 0.982, collinearity is not an issue if the VIF of the cost driver is less than 55.56. Table 14 shows a summary of the VIF values for each cost driver. This shows that there are no collinearity issues in the model and each cost driver is independent of each other.

Cost driver	**VIF**
GFA (m2)	15.142
External areas (m2)	3.082
Garage area (m2)	1.399
External walls (lin m)	6.214
Internal walls (lin m)	3.836
Area of external openings (m2)	3.845
Hips / valleys / ridges (lin m)	3.882
Gable ends (m2)	3.947
No. of bathrooms (each)	1.129
Additional plumbing outlets (each)	2.531

Table 14 – Variance inflation factor summary for regression model

The validity of the statistical model has been confirmed and therefore can be relied upon to produce a relevant cost model. This has been done for the linear regression model using the β coefficients from the SPSS output. Table 15 shows the output from linear regression analysis with a variable being assigned to each cost driver, the cost driver name and the coefficient term.

Variable	Cost driver	β coefficient
x_0	(Constant)	34911.766
x_1	GFA (m2)	448.781
x_2	External areas (m2)	137.002
x_3	Garage area (m2)	-185.313
x_4	External walls (lin m)	470.019
x_5	Internal walls (lin m)	134.711
x_6	Area of external openings (m2)	328.761
x_7	Hips / valleys / ridges (lin m)	132.503
x_8	Gable ends (m2)	443.071
x_9	No. of bathrooms (each)	11000.077
x_{10}	Additional plumbing outlets (each)	2015.819

Table 15 – Linear regression coefficients

From this information, an algebraic formula was developed to test the data and shown in equation 10.

$$Cost\ (\$) = 34911.76 + 448.78x_1 + 137x_2 - 185.31x_3 + 470.02x_4 + 134.71x_5 + 328.76x_6 + 132.50x_7 + 443.07x_8 + 11000.08x_9 + 2015.82x_{10} \quad (10)$$

Equation 10 will be used when testing the statistical model's accuracy. The test will compare the variance between predicted and calculated costs of twenty test samples and determine the MAPE. The full SPSS output from the linear regression analysis can be found in Appendix I.

4.3.3 Critical reasoning for cost drivers failing significance test

Following on from the results of the first linear regression analysis, it was found that some cost drivers are not statistically significant. This section will provide critical reasoning why these cost drivers may not be significant to the model, a summary of these are shown in Table 16.

Cost driver	Sig.
Eaves (lin m)	0.325
Compactness (Ext wall area / GFA)	0.754
No. sets of stacker SGDs	0.607
No. of bedrooms (each)	0.825
No. of living areas (each)	0.931

Table 16 – Cost drivers removed from linear regression model

The eaves of the building were not significant even though other roof features such as hips, valleys and gable ends remain. This may be because the external walls run the perimeter of the building footprint like the eaves. The eaves could be considered a function of external walls which remained a significant cost driver. Figure 25 shows a typical plan highlighting the external walls and the eaves of the building, it can be seen both follow very similar perimeters around the building.

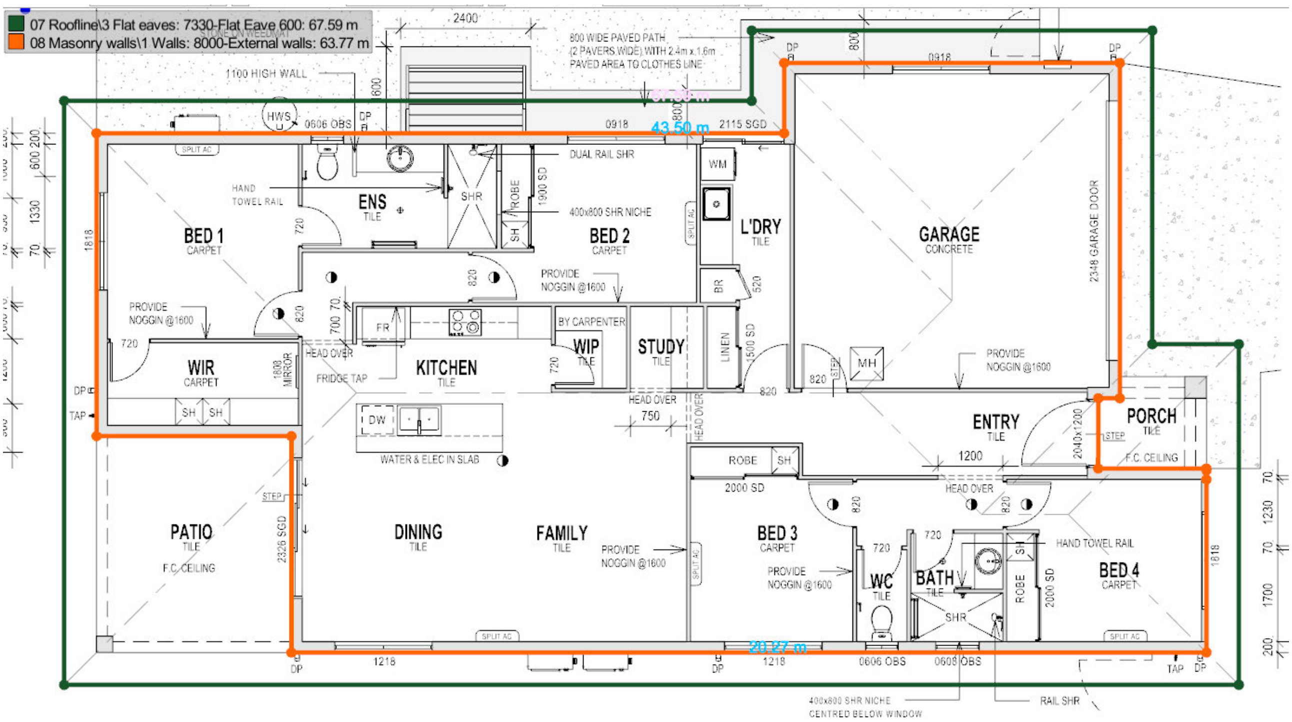


Figure 25 – Eave versus external wall perimeter layout

Compactness was discovered during the literature review as a cost driver (Stoy and Schlacher 2007 and Stoy et al. 2008). The results found it is not significant to this model. Like the eave cost driver, the compactness of a building can be considered a function of the remaining significant cost drivers. Compactness is a measure of wall area divided by gross floor area. As the external walls remain in the cost model, are all the same height and the fact the gross floor area also remains explains why compactness was not significant.

Window and sliding glass door complexity was identified during the case study interviews and the inclusion of this cost driver was based on that result. This item was likely excluded from the model as it simply is not significant enough to impact cost. External opening area remains a significant factor which is a function of window and door size.

The total number of bedrooms and living areas were also identified during the interviews. A logical analysis would suggest that these would be factors driving cost of construction. This is a puzzling result considering the additional fit out requirements for a separate room. An explanation comes from assessing the geometry of a dwelling. A separate room is made up of several components such as internal partition walls, external walls and external window/door openings. These components all remain within the cost model, so as surprising as the results are, the separation of bedrooms and living areas are a function of other remaining cost drivers within the model.

4.3.4 Linear regression model testing and results

The linear regression model has been validated and a formula derived to apply to the testing sample designs. This is a critical step in the cost modelling development and towards the next phase which tests neural network models.

Twenty test designs samples were randomly selected to test the accuracy of the linear regression model using equation 10. The cost drivers can be found in Table 15 from the previous section. Each sample had an appropriate value assigned to the cost driver. A table was produced in Excel to calculate the predicted cost of each test sample using equation 10, this can be found in Appendix L. The predicted cost was then compared to the calculated cost for each test sample. Each sample had its construction cost calculated using the first principle cost estimating method used to collect the original data sets. A comparison of predicted versus calculated costs are summarised in Table 17.

Test Sample	**Model Predicted Cost**	**Calculated Cost**	**Difference in cost (Pred vs Calc)**	**Absolute % error**	**% error**
S001	$271,294.45	$269,845.36	$1,449.08	0.54%	0.54%
S002	$233,475.42	$241,288.69	-$7,813.26	3.24%	-3.24%
S003	$257,161.76	$259,434.80	-$2,273.04	0.88%	-0.88%
S004	$269,605.37	$270,115.64	-$510.27	0.19%	-0.19%
S005	$190,189.54	$191,207.60	-$1,018.06	0.53%	-0.53%
S006	$252,880.80	$257,411.03	-$4,530.24	1.76%	-1.76%
S007	$184,771.95	$188,202.31	-$3,430.36	1.82%	-1.82%
S008	$279,777.53	$289,247.39	-$9,469.86	3.27%	-3.27%
S009	$301,716.72	$305,755.27	-$4,038.56	1.32%	-1.32%
S010	$323,620.58	$311,996.76	$11,623.82	3.73%	3.73%
S011	$254,347.21	$260,118.56	-$5,771.35	2.22%	-2.22%
S012	$203,473.55	$203,807.14	-$333.59	0.16%	-0.16%
S013	$223,225.88	$219,262.09	$3,963.78	1.81%	1.81%
S014	$280,995.88	$289,336.00	-$8,340.12	2.88%	-2.88%
S015	$217,331.26	$221,375.79	-$4,044.53	1.83%	-1.83%
S016	$227,990.94	$223,609.16	$4,381.78	1.96%	1.96%
S017	$253,980.13	$259,505.08	-$5,524.95	2.13%	-2.13%
S018	$242,171.38	$241,368.56	$802.82	0.33%	0.33%
S019	$200,694.71	$202,958.42	-$2,263.71	1.12%	-1.12%
S020	$220,577.87	$225,592.66	-$5,014.79	2.22%	-2.22%
Mean	**$244,464.15**	**$246,571.92**	**-$2,107.77**	**1.70%**	**-0.86%**
Std Dev				**1.07%**	**1.84%**

Table 17 – Linear regression model testing results summary

The results show that the costs predicted by the model has a mean absolute percentage error (MAPE) of 1.70%. Also calculated is the cost variance in dollars, standard deviation and the percentage error mean. The MAPE was determined during the methodology as the main test for model accuracy. The most accurate model discovered during the literature review was from a study in 2013 by Latief, Wibowo and Isvara (2013) which was a hybrid regression and neural fuzzy logic model based on multi-level buildings, this model had a MAPE of 3.98%. The results produced by the linear regression analysis using the baseline estimate method and cost drivers only related to design factors improved the accuracy to a MAPE of 1.70%. This proves the method sound and the validity of the statistical modelling method, this means it can be considered for the framework development.

4.3.5 Multilayer perceptron neural network analysis of results

Due to some success found during the literature review of neural networks for cost modelling, an analysis was warranted. SPSS offer two neural network options with multilayer perceptron being discussed in this section.

Using the statistically significant cost drivers a neural network was set up in SPSS. The raw input data was the same as the information used for the linear regression analysis. SPSS was setup to include the predictive output of the neural network for each test sample. As a neural network does not make assumptions of linearity, the output can be directly applied without any validity testing. Table 18 summarises the output of the multilayer perceptron neural network with the detailed output found in Appendix J.

Test Sample	Predicted Cost	Calculated Cost	Difference in cost (Pred vs Calc)	Absolute % error	% error
S001	$279,570.82	$269,845.36	$9,725.45	3.60%	3.60%
S002	$229,814.68	$241,288.69	-$11,474.01	4.76%	-4.76%
S003	$261,082.36	$259,434.80	$1,647.57	0.64%	0.64%
S004	$264,082.09	$270,115.64	-$6,033.55	2.23%	-2.23%
S005	$194,933.52	$191,207.60	$3,725.91	1.95%	1.95%
S006	$254,618.33	$257,411.03	-$2,792.70	1.08%	-1.08%
S007	$193,871.08	$188,202.31	$5,668.76	3.01%	3.01%
S008	$271,310.61	$290,642.89	-$19,332.28	6.65%	-6.65%
S009	$312,316.27	$305,755.27	$6,560.99	2.15%	2.15%
S010	$312,371.98	$311,996.76	$375.22	0.12%	0.12%
S011	$252,640.57	$260,118.56	-$7,477.98	2.87%	-2.87%
S012	$201,772.07	$203,807.14	-$2,035.07	1.00%	-1.00%
S013	$226,865.37	$219,262.09	$7,603.28	3.47%	3.47%
S014	$279,474.44	$295,506.96	-$16,032.53	5.43%	-5.43%
S015	$218,682.32	$221,375.79	-$2,693.47	1.22%	-1.22%
S016	$221,294.99	$223,649.16	-$2,354.17	1.05%	-1.05%
S017	$255,266.30	$259,505.08	-$4,238.78	1.63%	-1.63%
S018	$246,446.09	$241,368.56	$5,077.53	2.10%	2.10%
S019	$203,312.21	$202,958.42	$353.79	0.17%	0.17%
S020	$220,907.72	$225,592.66	-$4,684.94	2.08%	-2.08%
Mean	**$245,031.69**	**$246,952.24**	**-$1,920.55**	**2.36%**	**-0.64%**
Std Dev				**1.73%**	**2.91%**

Table 18 – Multilayer perceptron neural network results summary

Table 18 details the predicted cost of the neural network and the calculated costs for the test samples. The test samples are the same used for the linear regression analysis comparison, this allows for a relevant comparison between the modelling methods. The key measures of MAPE, standard deviation and percentage error have been included in Table 18. The MAPE for this method is 2.36% which is less accurate than the linear regression method, therefore a lower performing statistical model.

4.3.6 Radial basis function neural network analysis of results

The method of producing the radial basis function neural network in SPSS is the same as the multilayer perceptron with a detailed output found in Appendix K. The results have been summarised in Table 19.

Test Sample	Predicted Cost	Calculated Cost	Difference in cost (Pred vs Calc)	Absolute % error	% error
S001	$269,414.92	$269,845.36	-$430.44	0.16%	-0.16%
S002	$231,272.82	$241,288.69	-$10,015.87	4.15%	-4.15%
S003	$256,848.52	$259,434.80	-$2,586.28	1.00%	-1.00%
S004	$275,470.08	$270,115.64	$5,354.44	1.98%	1.98%
S005	$188,685.42	$191,207.60	-$2,522.18	1.32%	-1.32%
S006	$255,685.65	$257,411.03	-$1,725.38	0.67%	-0.67%
S007	$170,318.44	$188,202.31	-$17,883.88	9.50%	-9.50%
S008	$267,541.39	$290,642.89	-$23,101.50	7.95%	-7.95%
S009	$312,664.64	$305,755.27	$6,909.37	2.26%	2.26%
S010	$267,545.06	$311,996.76	-$44,451.70	14.25%	-14.25%
S011	$250,405.75	$260,118.56	-$9,712.81	3.73%	-3.73%
S012	$210,173.38	$203,807.14	$6,366.24	3.12%	3.12%
S013	$226,229.03	$219,262.09	$6,966.94	3.18%	3.18%
S014	$278,719.54	$295,506.96	-$16,787.43	5.68%	-5.68%
S015	$216,159.92	$221,375.79	-$5,215.87	2.36%	-2.36%
S016	$213,339.01	$223,649.16	-$10,310.15	4.61%	-4.61%
S017	$258,340.41	$259,505.08	-$1,164.67	0.45%	-0.45%
S018	$244,476.92	$241,368.56	$3,108.36	1.29%	1.29%
S019	$196,911.34	$202,958.42	-$6,047.08	2.98%	-2.98%
S020	$218,218.88	$225,592.66	-$7,373.78	3.27%	-3.27%
Mean	**$240,421.06**	**$246,952.24**	**-$6,531.18**	**3.70%**	**-2.51%**
Std Dev				**3.46%**	**4.44%**

Table 19 – Radial basis function neural network results summary

Table 19 summarises the results of the radial basis function neural network. This shows the radial basis function neural network has a MAPE of 3.70% which is the worst performing statistical model.

4.3.7 Critical comparison of statistical modelling methods

The three methods trialled to determine a valid cost model are linear regression analysis, multilayer perceptron and radial basis function neural networks. To better understand the results from each method and enable model selection, the results were tabulated showing predicted cost, calculated cost and the MAPE. Table 20 summarises the predicted cost values for each method and the calculated cost of the test samples.

Test Sample	Calculated Cost	Linear regression predicted value	MLP Neural network predicted value	RBF neural network predicted value
S001	$269,845.36	$271,294.45	$279,570.82	$269,414.92
S002	$241,288.69	$233,475.42	$229,814.68	$231,272.82
S003	$259,434.80	$257,161.76	$261,082.36	$256,848.52
S004	$270,115.64	$269,605.37	$264,082.09	$275,470.08
S005	$191,207.60	$190,189.54	$194,933.52	$188,685.42
S006	$257,411.03	$252,880.80	$254,618.33	$255,685.65
S007	$188,202.31	$184,771.95	$193,871.08	$170,318.44
S008	$289,247.39	$279,777.53	$271,310.61	$267,541.39
S009	$305,755.27	$301,716.72	$312,316.27	$312,664.64
S010	$311,996.76	$323,620.58	$312,371.98	$267,545.06
S011	$260,118.56	$254,347.21	$252,640.57	$250,405.75
S012	$203,807.14	$203,473.55	$201,772.07	$210,173.38
S013	$219,262.09	$223,225.88	$226,865.37	$226,229.03
S014	$289,336.00	$280,995.88	$279,474.44	$278,719.54
S015	$221,375.79	$217,331.26	$218,682.32	$216,159.92
S016	$223,609.16	$227,990.94	$221,294.99	$213,339.01
S017	$259,505.08	$253,980.13	$255,266.30	$258,340.41
S018	$241,368.56	$242,171.38	$246,446.09	$244,476.92
S019	$202,958.42	$200,694.71	$203,312.21	$196,911.34
S020	$225,592.66	$220,577.87	$220,907.72	$218,218.88
	Mean difference	**-$2,107.77**	**-$1,920.55**	**-$6,531.18**

Table 20 – Summary of predicted versus calculated cost of three cost models

As seen in Table 20 the mean difference between predicted versus actual are all negative. This shows that on average the prediction model underestimates the cost of construction in comparison to the calculated cost. Even though this result is not ideal the variance with the two top performing models is minimal when applied over the entire cost of the project as a percentage. The linear regression analysis and multilayer perceptron neural network models both have very close results, however the radial basis function is over three times higher. The percentage error for each model has been summarised in Table 21 which provides a much clearer understanding of the differences between the models.

Test Sample	Linear regression % error	MLP Neural network % error	RBF neural network % error
S001	0.54%	3.60%	-0.16%
S002	-3.24%	-4.76%	-4.15%
S003	-0.88%	0.64%	-1.00%
S004	-0.19%	-2.23%	1.98%
S005	-0.53%	1.95%	-1.32%
S006	-1.76%	-1.08%	-0.67%
S007	-1.82%	3.01%	-9.50%
S008	-3.27%	-6.65%	-7.95%
S009	-1.32%	2.15%	2.26%
S010	3.73%	0.12%	-14.25%
S011	-2.22%	-2.87%	-3.73%
S012	-0.16%	-1.00%	3.12%
S013	1.81%	3.47%	3.18%
S014	-2.88%	-5.43%	-5.68%
S015	-1.83%	-1.22%	-2.36%
S016	1.96%	-1.05%	-4.61%
S017	-2.13%	-1.63%	-0.45%
S018	0.33%	2.10%	1.29%
S019	-1.12%	0.17%	-2.98%
S020	-2.22%	-2.08%	-3.27%
Mean	**-0.86%**	**-0.64%**	**-2.51%**
Std Dev	**1.84%**	**2.91%**	**4.44%**

Table 21 – Summary of percentage error results from three cost modelling options

Table 21 shows the spread of differences between the three models. Like Table 20 the linear regression analysis and multilayer perceptron neural networks perform well with a very narrow difference between the two. Even though the multilayer perceptron model performs slightly better than the regression analysis, its standard deviation is higher. With a 95% confidence interval we expect that the population mean would lie within two standard deviations of the sample mean. An analysis of distribution can be made by assessing the spread of results shown two standard deviations above and below the mean. The percentage error has been chosen for this analysis rather the absolute percentage error so negative values are included in the distribution. The below figures show the analysis for each cost modelling method with the blue vertical lines indicating two standard deviations, the yellow lines representing one standard deviation and the red line representing the mean.

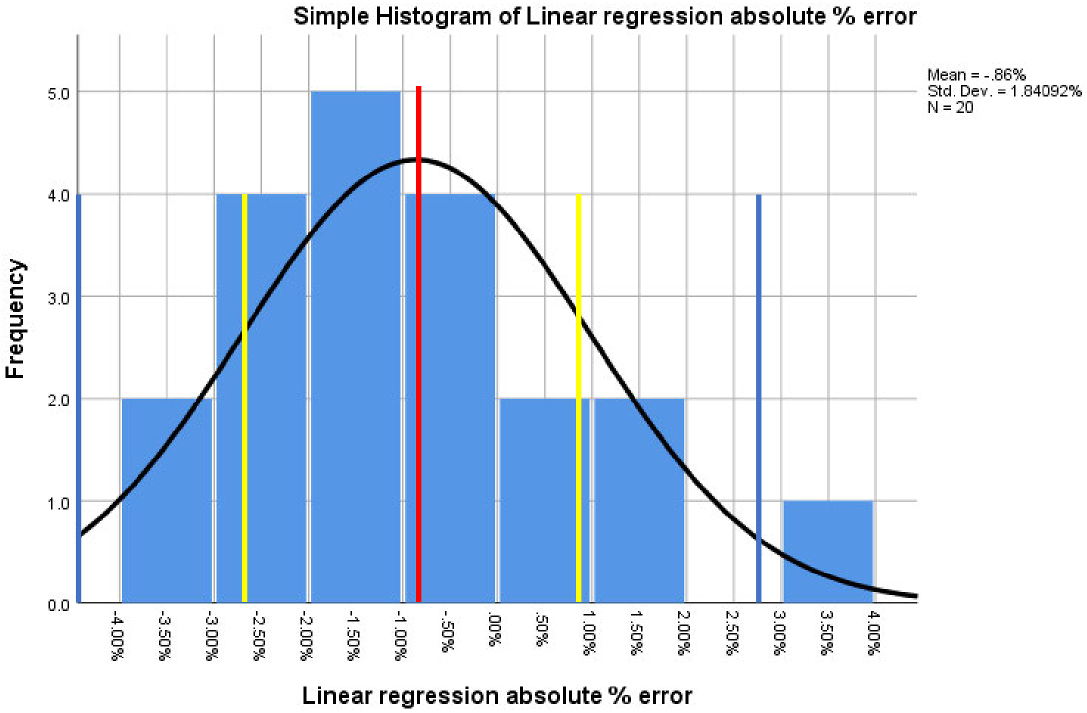


Figure 26 – Distribution of linear regression error around the mean

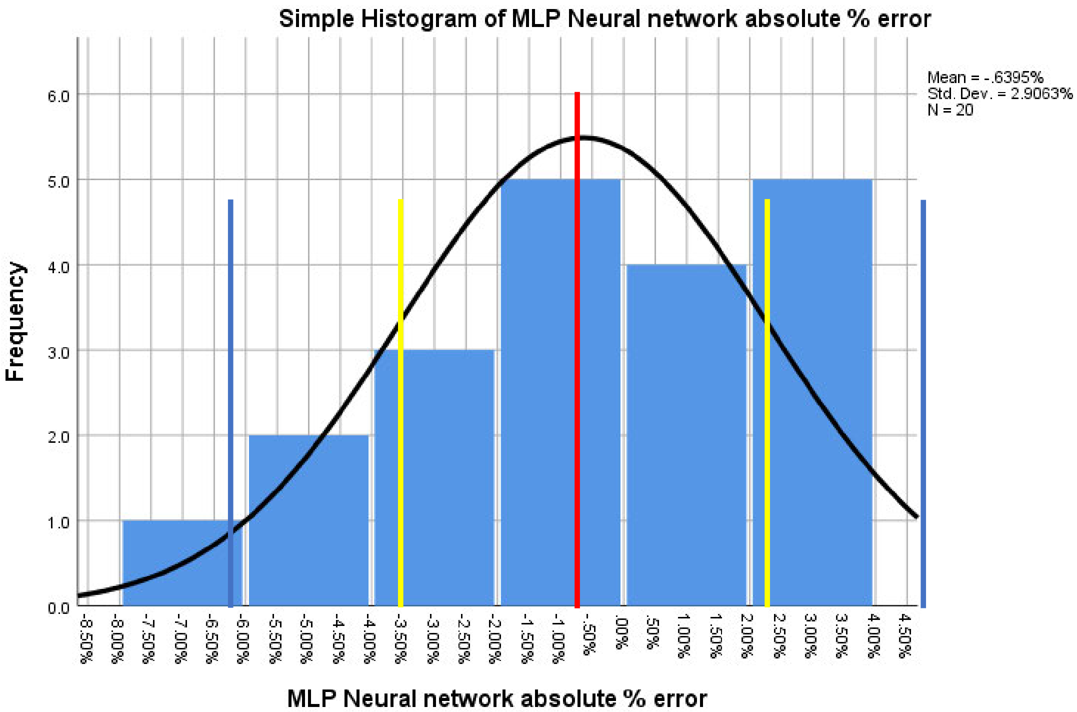


Figure 27 – Distribution of multilayer perceptron neural network error around the mean

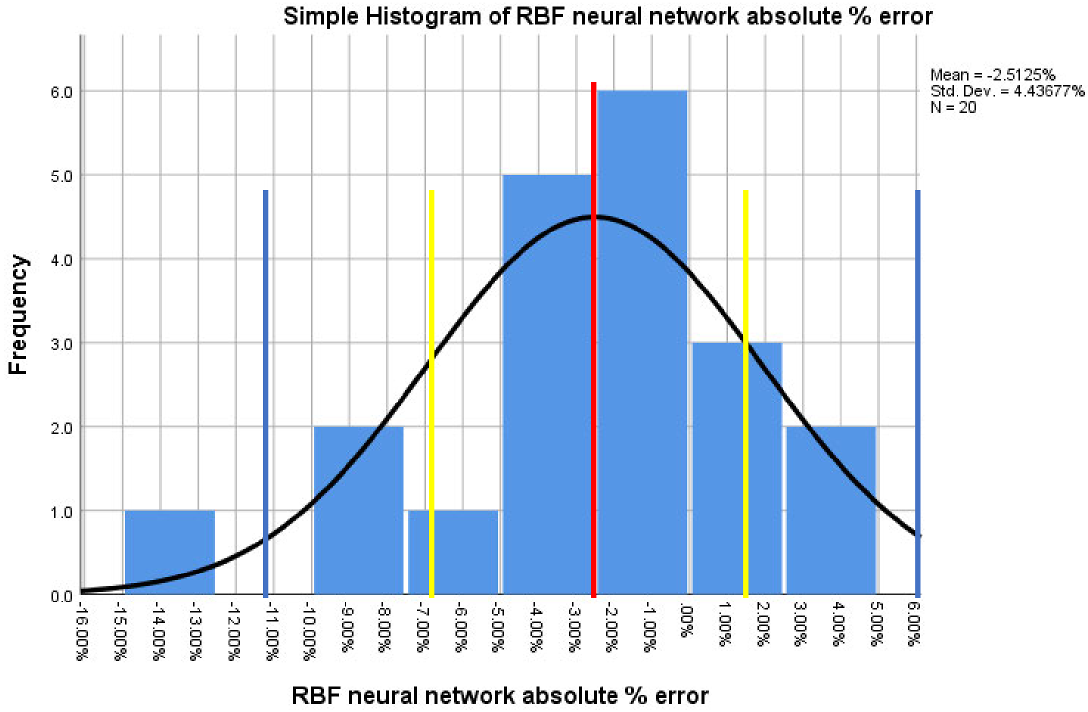


Figure 28 – Distribution of radial basis function neural network error around the mean

The above figures illustrate the spread of the results around the mean for each statistical model. The radial basis function model performs poorly with the spread of the results significantly above and below the mean. Even though most of the predictive costs are within two standard deviations, the spread of results is greater which means a less accurate and consistent model output. The multilayer perceptron, whilst showing a more favourable average percentage error does show a wider spread when compared to the linear regression model. The linear regression model shows a tighter spread meaning a greater consistency of accurate and reliable output. All models do show some skewing of the distribution with both neural networks exhibiting a negative skew and the linear regression showing a positive skew. Results within two standard deviations of the mean at a 95% confidence interval shows that there is a 5% chance the model excludes the true population mean. From this analysis the linear regression model performs better than the two neural networks.

The mean difference in predicted versus calculated values show some interesting information, however the MAPE will be used in the weighted decision matrix used to determine the best model for the framework development. Table 22 shows the summarised MAPE results for each cost modelling method.

Test Sample	Linear regression absolute % error	MLP Neural network absolute % error	RBF neural network absolute % error
S001	0.54%	3.60%	0.16%
S002	3.24%	4.76%	4.15%
S003	0.88%	0.64%	1.00%
S004	0.19%	2.23%	1.98%
S005	0.53%	1.95%	1.32%
S006	1.76%	1.08%	0.67%
S007	1.82%	3.01%	9.50%
S008	3.27%	6.20%	7.50%
S009	1.32%	2.15%	2.26%
S010	3.73%	0.12%	14.25%
S011	2.22%	2.87%	3.73%
S012	0.16%	1.00%	3.12%
S013	1.81%	3.47%	3.18%
S014	2.88%	3.41%	3.67%
S015	1.83%	1.22%	2.36%
S016	1.96%	1.03%	4.59%
S017	2.13%	1.63%	0.45%
S018	0.33%	2.10%	1.29%
S019	1.12%	0.17%	2.98%
S020	2.22%	2.08%	3.27%
MAPE	**1.70%**	**2.36%**	**3.70%**
Std Dev	**1.07%**	**1.73%**	**3.46%**

Table 22 – Summary of MAPE results from three cost modelling options

Table 22 shows that the linear regression analysis model performed much better than the two neural network models when using the MAPE as an indicator for accuracy, which was found to be the preferred measure during the literature review. All three models perform more accurately than the best model discovered during the literature review which had a MAPE of 3.98%. This proves baseline estimating with a focus on design related cost drivers is a successful methodology in producing an accurate statistical cost model.

4.3.8 Summary

The results of the statistical analysis on 170 samples of calculated construction costs show that linear regression performed the best using the MAPE as a measure of accuracy. Whilst the multilayered perceptron neural network had a slightly less error percentage than linear regression, it was found linear regression had a better MAPE result and higher consistency when comparing the distribution around the mean within two standard deviations.

A MAPE of 1.70% for the linear regression analysis is an excellent result, however during the case study interviews it was discovered that custom cabinetry such as kitchens, vanities and laundry units were thought by the respondents to add significant cost. This item was not identified as a cost driver due to how difficult it is to apply using simple input quantities. It was recommended from this discovery to trial a statistical analysis without the cost of custom cabinetry included and compare the results to the original models. This allowed for a thorough exploration of available options for the development of the framework. It was expected the result from modelling without custom cabinetry will provide a MAPE at least half that found during the modelling with cabinetry. Unless this increase in accuracy is achieved, it will not be further considered.

4.4 Recommended data analysis with cabinetry removed

The results from the previous statistical models were promising. However, it has been recognised that a more accurate model may be created by removing custom cabinetry from the cost data samples used for analysis. During the case study interviews it was found that this component could add significant cost, so to test this theory a second cost modelling analysis was performed using an identical methodology. The results from this modelling process hope to improve the accuracy to at least half the MAPE of the modelling with cabinetry. This means unless the MAPE is under 0.85% the results will be excluded from further consideration. A framework without custom cabinetry will be incomplete and require additional complication to produce a result, therefore won't be warranted without reaching the target accuracy. This section will analyse the results from each cost modelling option with the cabinetry costs excluded from both the import data and sample testing data.

4.4.1 Results from linear regression without custom cabinetry

The lump sum cost of custom cabinetry was removed from each data set and the import template for SPSS was populated with the revised costs. The exact parameters used for the original linear regression analysis have been used again for this experiment. The results of the first linear regression analysis for the model have identified cost drivers that were not statistically significant and required to be removed. These have been displayed in Table 23 with the yellow highlighted values that have a $P > 0.05$ at a 95% confidence interval.

	Unstandardized Coefficients		Standardized Coefficients		
Cost Driver	B	Std. Error	Beta	t	Sig.
(Constant)	38875.972	15125.653		2.570	0.011
GFA (m2)	362.403	55.516	0.532	6.528	0.000
External areas (m2)	96.394	42.295	0.035	2.279	0.024
Garage area (m2)	-103.607	44.834	-0.024	-2.311	0.022
External walls (lin m)	577.778	199.598	0.163	2.895	0.004
Internal walls (lin m)	121.739	35.751	0.062	3.405	0.001
Eaves (lin m)	11.616	52.554	0.004	0.221	0.825
Compactness (Ext wall area / GFA)	-9147.833	15706.900	-0.025	-0.582	0.561
Area of external openings (m2)	246.818	64.207	0.067	3.844	0.000
No. sets of stacker SGDs	137.344	450.868	0.003	0.305	0.761
Hips / valleys / ridges (lin m)	116.163	21.119	0.094	5.500	0.000
Gable ends (m2)	361.786	51.764	0.132	6.989	0.000
No. of bedrooms (each)	1597.691	734.344	0.026	2.176	0.031
No. of living areas (each)	943.118	538.569	0.021	1.751	0.082
No. of bathrooms (each)	8663.515	1821.069	0.043	4.757	0.000
Additional plumbing outlets (each)	1313.182	302.430	0.059	4.342	0.000

Table 23 – Results from linear regression analysis without cabinetry

The results have identified the same cost drivers for removal from the model as the first experiment except for the number of bedrooms. This cost driver's P-value has been dramatically reduced from 0.825 in the first experiment to 0.031 so remained in the model, moving forward to the next stage. The regression model was run again with the cost drivers identified in Table 24 as not statistically significant being removed.

	Unstandardized Coefficients		Standardized Coefficients		
Cost driver	B	Std. Error	Beta	t	Sig.
(Constant)	31573.465	4347.083		7.263	0.000
GFA (m2)	402.629	22.838	0.591	17.630	0.000
External areas (m2)	77.892	40.977	0.029	1.901	0.059
Garage area (m2)	-117.069	42.593	-0.027	-2.749	0.007
External walls (lin m)	477.932	74.003	0.135	6.458	0.000
Internal walls (lin m)	145.303	32.892	0.074	4.418	0.000
Area of external openings (m2)	255.773	60.743	0.070	4.211	0.000
Hips / valleys / ridges (lin m)	114.699	20.443	0.093	5.611	0.000
Gable ends (m2)	354.087	45.585	0.129	7.768	0.000
No. of bedrooms (each)	1334.544	695.006	0.021	1.920	0.057
No. of bathrooms (each)	8723.253	1805.263	0.043	4.832	0.000
Additional plumbing outlets (each)	1344.164	298.659	0.060	4.501	0.000

Table 24 – Second regression results with cost drivers removed from cost excluding cabinetry

The results from the second regression analysis excluding the cabinetry costs identified two additional cost drivers in this model that are not statistically significant. Like the original experiment that included cabinetry costs, the number of bedrooms are now not significant. However, the inclusion of external areas have also been identified. According to the methodology a third regression analysis is needed until all remaining cost drivers are significant ($P < 0.05$). Table 25 has summarised the results from the third linear regression analysis with cabinetry costs removed.

	Unstandardized Coefficients		Standardized Coefficients		
Cost drivers	B	Std. Error	Beta	t	Sig.
(Constant)	33106.791	4183.005		7.915	0.000
GFA (m2)	433.219	18.059	0.636	23.989	0.000
Garage area (m2)	-128.003	42.862	-0.030	-2.986	0.003
External walls (lin m)	478.288	74.673	0.135	6.405	0.000
Internal walls (lin m)	143.156	30.898	0.073	4.633	0.000
Area of external openings (m2)	244.158	61.243	0.066	3.987	0.000
Hips / valleys / ridges (lin m)	112.580	20.670	0.091	5.446	0.000
Gable ends (m2)	349.094	46.025	0.128	7.585	0.000
No. of bathrooms (each)	8565.022	1827.058	0.042	4.688	0.000
Additional plumbing outlets (each)	1226.038	298.482	0.055	4.108	0.000

Table 25 – Second regression results with cost drivers removed from cost excluding cabinetry

The results from the third linear regression analysis show highly significant remaining cost drivers. To ensure a valid regression model the residual errors must have a constant variance, the errors be normally distributed and each prediction variable be independent of each other. These assumptions were tested and the results summarised below.

1. Residual errors must have a constant variance. Figure 29 shows a scatter plot indicating a random pattern above and below zero. This shows the residual errors have a constant variance.

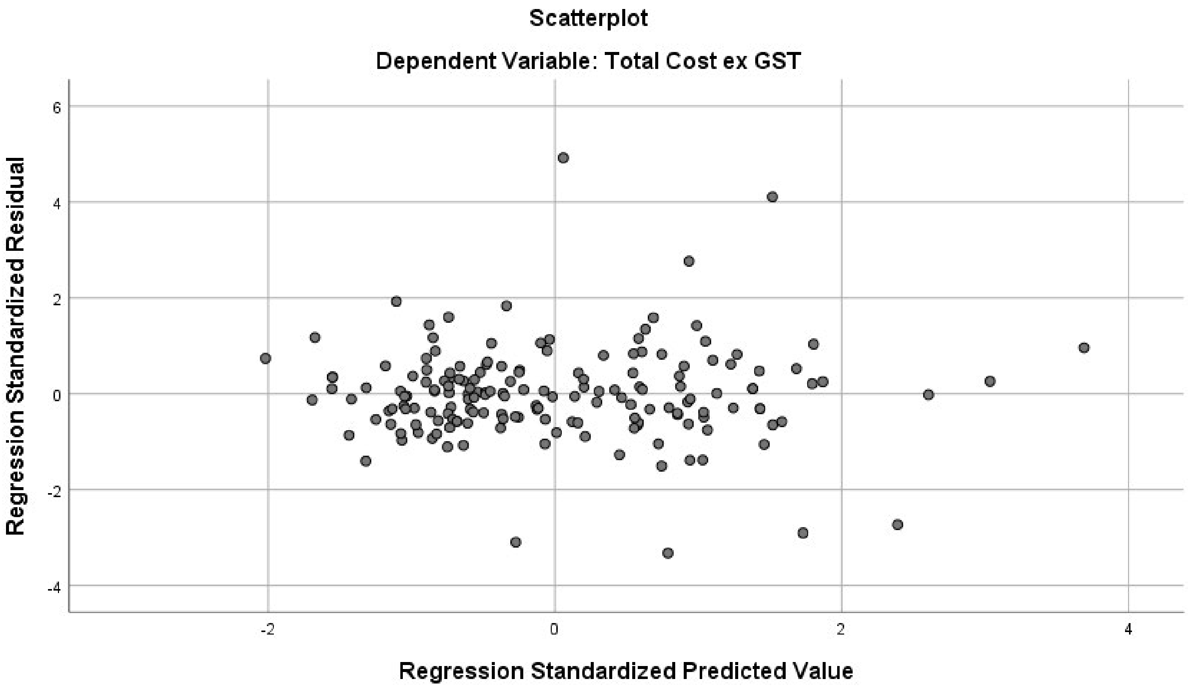


Figure 29 – Scatter plot of residual error versus predicted values for regression analysis without cabinetry

2. The residual errors must be normally distributed. Figure 30 shows the plot of expected versus observed errors and again a rough straight line has indicated this assumption to hold true although with a more pronounced curvature than the results with cabinetry.

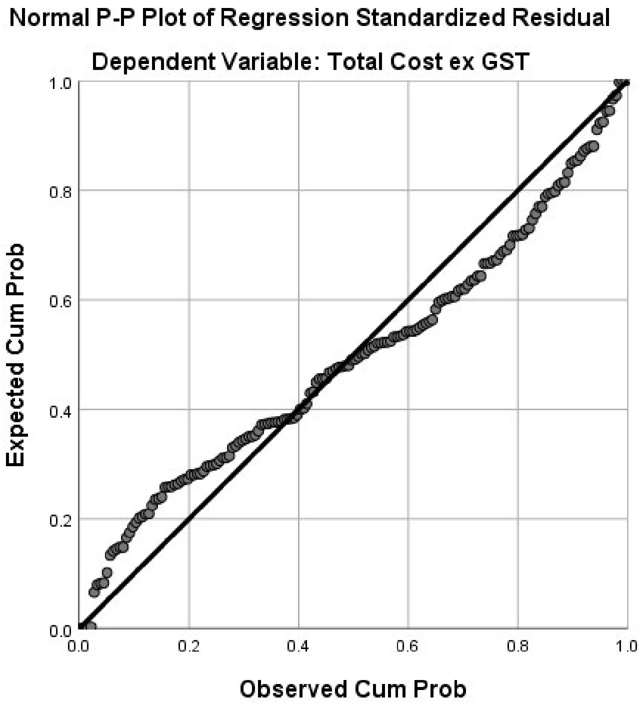


Figure 30 – Regression plot for normality of residual areas for cost excluding cabinetry

3. Each predictor (cost driver) must be independent. Collinearity was tested comparing the variance inflation factor (VIF) for each variable. Table 26 summarised the VIF for each cost driver.

Cost drivers	**VIF**
GFA (m2)	9.732811
Garage area (m2)	1.385231
External walls (lin m)	6.187978
Internal walls (lin m)	3.458681
Area of external openings (m2)	3.845071
Hips / valleys / ridges (lin m)	3.870111
Gable ends (m2)	3.923077
No. of bathrooms (each)	1.128382
Additional plumbing outlets (each)	2.496022

Table 26 – Variation inflation factors for regression model excluding cabinetry

The adjusted R^2 value for this model is 0.988, which is slightly better than the first model which was 0.982. This means this model is a better fit than the model with cabinetry costs as it is closer to 1. Using equation 9, no collinearity occurs if the maximum VIF for the cost driver is below 10 or 83. The results show no collinearity in the model exists.

Satisfying these assumptions show that the linear regression model is viable. Therefore, a linear regression formula can be constructed using the significant cost drivers. Table 27 summarises the significant cost drivers along with the calculated coefficients the model produced.

Variable	Cost driver	B coefficient
x_0	(Constant)	33106.791
x_1	GFA (m2)	433.219
x_2	Garage area (m2)	-128.003
x_3	External walls (lin m)	478.288
x_4	Internal walls (lin m)	143.156
x_5	Area of external openings (m2)	244.158
x_6	Hips / valleys / ridges (lin m)	112.580
x_7	Gable ends (m2)	349.094
x_8	No. of bathrooms (each)	8565.022
x_9	Additional plumbing outlets (each)	1226.038

Table 27 – Cost driver coefficients from regression model without cabinetry

From this information, the following linear regression formula can be developed and used for the calculation of testing sample costs. The complete results from the linear regression analysis can be found in Appendix M.

$$Cost\ (\$) = 33106.79 + 433.22x_1 - 128.00x_2 + 478.29x_3 + 143.16x_4 + 244.16 + 112.58x_6 + 349.09x_7 + 8565.02x_8 + 1226.04x_9 \tag{11}$$

4.4.2 Results from model testing

To analyse whether the linear regression model without cabinetry performs better, the same twenty test samples were used for comparison. The two artificial neural network models were also tested to determine the error variances and provide a complete analysis, the detailed results for both neural networks are found in Appendix N and Appendix O. The results from all three models are summarised in the following tables showing the calculated costs, predicted costs, the percentage error and the absolute percentage error.

Test Sample	Calculated Cost	Linear regression predicted value	MLP Neural network predicted value	RBF neural network predicted value
S001	$247,142.16	$250,532.47	$257,971.33	$249,555.93
S002	$220,599.19	$217,069.06	$221,947.97	$225,557.38
S003	$240,376.80	$235,349.85	$245,869.14	$232,559.61
S004	$253,299.84	$246,155.38	$235,514.28	$263,224.25
S005	$178,352.29	$177,950.11	$180,270.31	$171,914.10
S006	$239,267.39	$236,029.87	$239,405.22	$237,490.89
S007	$175,227.01	$171,689.65	$167,633.72	$172,689.84
S008	$259,735.09	$259,183.63	$264,982.20	$246,368.99
S009	$277,121.87	$277,723.25	$276,485.36	$270,694.97
S010	$288,027.56	$296,923.78	$274,024.98	$246,369.51
S011	$239,836.73	$235,267.25	$244,503.97	$243,369.27
S012	$189,667.44	$188,183.27	$187,387.37	$195,672.82
S013	$208,472.59	$206,316.13	$208,788.77	$197,625.49
S014	$258,468.24	$256,573.30	$262,900.37	$258,620.02
S015	$204,975.52	$203,059.40	$205,916.69	$197,825.26
S016	$209,717.16	$212,490.47	$215,941.07	$204,472.14
S017	$236,180.27	$235,409.59	$236,682.29	$240,324.06
S018	$224,421.95	$221,228.59	$212,765.27	$172,689.87
S019	$189,813.01	$187,675.85	$189,467.16	$193,428.33
S020	$209,827.16	$205,903.93	$204,103.03	$199,566.41
	Mean difference	**-$1,490.72**	**-$898.44**	**-$6,525.51**

Table 28 – Cost variance results from model without cabinetry

The Table 28 shows the first principle calculated costs for each test sample and the predicted cost each model produced. The multilayer perceptron neural network exhibits a smaller variance compared to the linear regression model with the radial basis function neural network performing worse than the other two.

Test Sample	Linear regression % error	MLP Neural network % error	RBF neural network % error
S001	1.37%	4.38%	0.98%
S002	-1.60%	0.61%	2.25%
S003	-2.09%	2.28%	-3.25%
S004	-2.82%	-7.02%	3.92%
S005	-0.23%	1.08%	-3.61%
S006	-1.35%	0.06%	-0.74%
S007	-2.02%	-4.33%	-1.45%
S008	-0.21%	2.02%	-5.15%
S009	0.22%	-0.23%	-2.32%
S010	3.09%	-4.86%	-14.46%
S011	-1.91%	1.95%	1.47%
S012	-0.78%	-1.20%	3.17%
S013	-1.03%	0.15%	-5.20%
S014	-0.73%	1.71%	0.06%
S015	-0.93%	0.46%	-3.49%
S016	1.32%	2.97%	-2.50%
S017	-0.33%	0.21%	1.75%
S018	-1.42%	-5.19%	-23.05%
S019	-1.13%	-0.18%	1.90%
S020	-1.87%	-2.73%	-4.89%
Mean	**-0.72%**	**-0.39%**	**-2.73%**
Std Dev	**1.40%**	**2.99%**	**6.32%**

Table 29 – Percentage errors from models without cabinetry

Table 29 shows the percentage error for the differences between each model. The multilayer perceptron slightly outperforms the linear regression model. The errors for each model are less than the errors found during the original experiment with cabinetry included and summarised in Table 21. This suggests that modelling without cabinetry included in the testing may yield a more accurate model. The final analysis is to determine the mean absolute percentage error which is collated in Table 30.

Test Sample	Linear regression absolute % error	MLP Neural network absolute % error	RBF neural network absolute % error
S001	1.37%	4.38%	0.98%
S002	1.60%	0.61%	2.25%
S003	2.09%	2.28%	3.25%
S004	2.82%	7.02%	3.92%
S005	0.23%	1.08%	3.61%
S006	1.35%	0.06%	0.74%
S007	2.02%	4.33%	1.45%
S008	0.21%	2.02%	5.15%
S009	0.22%	0.23%	2.32%
S010	3.09%	4.86%	14.46%
S011	1.91%	1.95%	1.47%
S012	0.78%	1.20%	3.17%
S013	1.03%	0.15%	5.20%
S014	0.73%	1.71%	0.06%
S015	0.93%	0.46%	3.49%
S016	1.32%	2.97%	2.50%
S017	0.33%	0.21%	1.75%
S018	1.42%	5.19%	23.05%
S019	1.13%	0.18%	1.90%
S020	1.87%	2.73%	4.89%
MAPE	**1.32%**	**2.18%**	**4.28%**
Std Dev	**0.82%**	**2.03%**	**5.34%**

Table 30 – MAPE results from model without cabinetry

The MAPE results are shown in Table 30. The aim of this experiment was to try to produce a more accurate model with a MAPE less than 0.85%. The results show a MAPE higher than this target. Therefore, this option will not be considered further in favour of a statistical model with similar accuracy and easier user input from the first experiment that included custom cabinetry. The results from both models with and without cabinetry have been summarised in Table 31.

	Linear regression	MLP Neural network	RBF Neural network
With cabinetry model MAPE	1.70%	2.36%	3.70%
Without cabinetry model MAPE	1.32%	2.18%	4.28%

Table 31 – Comparison of MAPE results from both modelling options

The results show that linear regression is the best modelling option for both experiments. The model with the costs excluding cabinetry did not reach the target accuracy of 0.85% to warrant consideration in the final framework development. Modelling without cabinetry was no longer considered a valid option to continue with.

4.5 Framework development and testing

The results from the cost modelling from the first experiment with custom cabinetry were used to select and develop the best fit cost model for the framework. The methodology detailed how the model will be selected using a weighted decision matrix. The framework was developed using both Excel and iTWO Cost X software which satisfies the third research objective. The process of selecting the cost model, developing the framework along with a worked example will be detailed in this section.

4.5.1 Framework selection

This section will use the MAPE results from the analysis including custom cabinetry to select an appropriate framework. Table 32 has summarised the weighted results based on the criteria determined in the methodology section.

Model	**Accuracy of model**	**Ease of use / speed**	**Model update ability**	**Score**
Linear regression	3	2	7	3.4
MLP neural network	2	1	5	2.2
RBF neural network	1	1	5	1.8
Weighting	40%	40%	20%	

Table 32 – Weight decision matrix for framework selection

The weighted decision matrix results show linear regression analysis is the best model based on the highest score of 3.4. The linear regression model has been selected for the framework development for this project with both neural networks excluded from further consideration.

4.5.2 Framework development

iTWO Cost X and Excel has been utilised to develop the framework as detailed in the methodology. Cost X has a distinct advantage as it can measure quantities on screen and link these directly to a workbook. The workbook functions like an Excel spreadsheet and can be used for calculations. Cost X is a software platform that requires a yearly subscription and the Company's licensed software has been used. Due to licensing of the Cost X software and the fact Excel is commonly available, the framework has also been developed in Excel. iTWO Cost X provides free viewer software that can be downloaded and installed to be able to see an example of the framework. A link to this software has been provided below.

https://www.itwocostx.com/costx/products/costx-viewer/

Developing the framework involved the use of equation 10 which has been detailed again below. The coefficients from the original linear regression analysis have been assigned to each cost driver, these will be used to calculate a total construction cost.

$$Cost\ (\$) = 34911.76 + 448.78x_1 + 137x_2 - 185.31x_3 + 470.02x_4 + 134.71x_5 + 328.76x_6 + 132.50x_7 + 443.07x_8 + 11000.08x_9 + 2015.82x_{10} \qquad (10)$$

By using the coefficients from equation 10 and assigning them to the relevant cost drivers a framework has been developed in Excel. An example of the framework has been shown in the table below, the working Excel framework template has been provided in Appendix P. The framework example is blank to show which values need to be included to calculate a result, the input cells have been highlighted in yellow.

Cost modelling framework				
Variable identification	**Cost driver**	**Coefficient**	**Input value**	**Result**
x_0	(Constant)	34911.77		0.00
x_1	GFA (m2)	448.78		0.00
x_2	External areas (m2)	137.00		0.00
x_3	Garage area (m2)	-185.31		0.00
x_4	External walls (lin m)	470.02		0.00
x_5	Internal walls (lin m)	134.71		0.00
x_6	Area of external openings (m2)	328.76		0.00
x_7	Hips / valleys / ridges (lin m)	132.50		0.00
x_8	Gable ends (m2)	443.07		0.00
x_9	No. of bathrooms (each)	11000.08		0.00
x_{10}	Additional plumbing outlets (each)	2015.82		0.00
			Construction cost ex GST	$0.00
		GST	10%	$0.00
		Profit mark up	15%	$0.00
			Total price	$0.00

Table 33 – Excel blank cost calculation framework

Input cost driver variables are placed into the highlighted cells for the framework to calculate a construction cost. Quantities from a sample concept plan have been used to demonstrate the use of the framework in Table 34.

Cost modelling framework				
Variable identification	**Cost driver**	**Coefficient**	**Input value**	**Result**
x_0	(Constant)	34911.77		34911.77
x_1	GFA (m2)	448.78	216.99	97381.03
x_2	External areas (m2)	137.00	17.20	2356.43
x_3	Garage area (m2)	-185.31	38.80	-7190.13
x_4	External walls (lin m)	470.02	65.77	30913.13
x_5	Internal walls (lin m)	134.71	87.80	11827.66
x_6	Area of external openings (m2)	328.76	33.75	11095.69
x_7	Hips / valleys / ridges (lin m)	132.50	54.40	7208.17
x_8	Gable ends (m2)	443.07	3.87	1714.69
x_9	No. of bathrooms (each)	11000.08	2.00	22000.15
x_{10}	Additional plumbing outlets (each)	2015.82	2.00	4031.64
			Construction cost ex GST	$216,250.22
		GST	10%	$21,625.02
		Profit mark up	15%	$35,681.29
			Total price	$273,556.53

Table 34 – Populated Excel cost modelling framework.

The framework cost model predicts construction costs using the baseline method determined from case study interviews and the literature review. GST and profit markup have only been included as a possible example to demonstrate how this framework can be practically applied in the industry to determine a tender price for a project. Determining the input variables required calculating the cost driver quantities from the concept plan, this can be a tedious measuring process but far less labour intensive than the first principle estimating process. The framework takes less than ten minutes to apply, however the use of on-screen measuring in iTWO Cost X will increase the speed of this process. The following section will detail how the framework is used in iTWO Cost X with illustrated examples using a sample concept plan.

4.5.3 The framework example in Cost X

This section will briefly show the developed framework in use. Cost X can utilise on screen measuring tools which can live link directly to a workbook. The workbook functionality is like that of Excel so the framework calculations developed in the previous section will be populated in a Cost X workbook and dimension groups added to represent the cost driver input variables. Two Cost X files have been provided, a blank template which represents the final developed framework and a worked example. These files have been provided in Appendix Q and Appendix R and can be viewed using the free viewer provided by iTWO Cost X detailed in the previous section.

The Cost X dimension groups have been created and linked to the relevant workbook values to create the framework template. This relationship has been shown below in Figure 31. The cost drivers used for dimension groups in the framework are gross floor area, external areas, garage areas, external walls, internal walls, gable ends, roof line (hips, valleys and ridges), number of bathrooms and number of additional plumbing fittings. Each group can be assigned units of count, length or area as required.

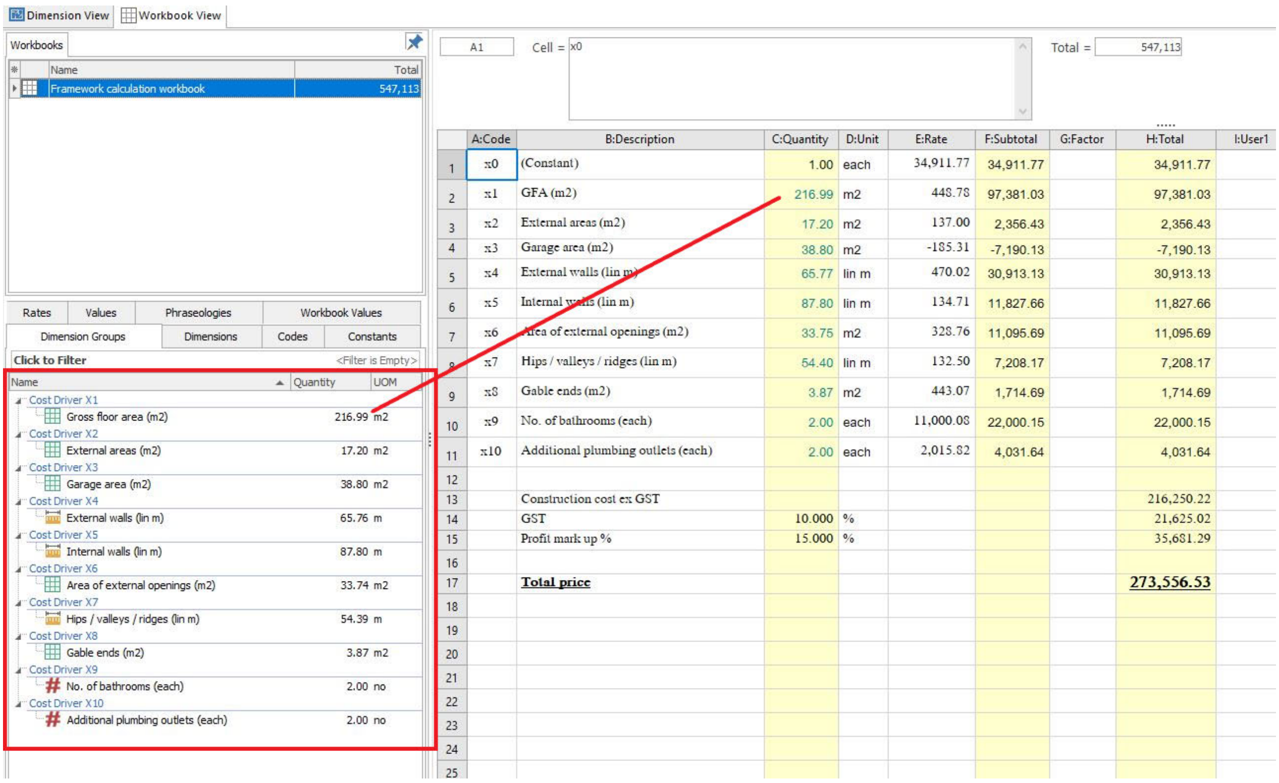


Figure 31 – Cost X framework live link dimension groups

The following figures demonstrate the framework in use on a sample plan with an example of each cost driver group being measured and displayed. Figure 32 shows the gross floor area cost driver being measured on an example plan. Gross floor area is often used for unit rate calculations and has been identified as a major cost driver.

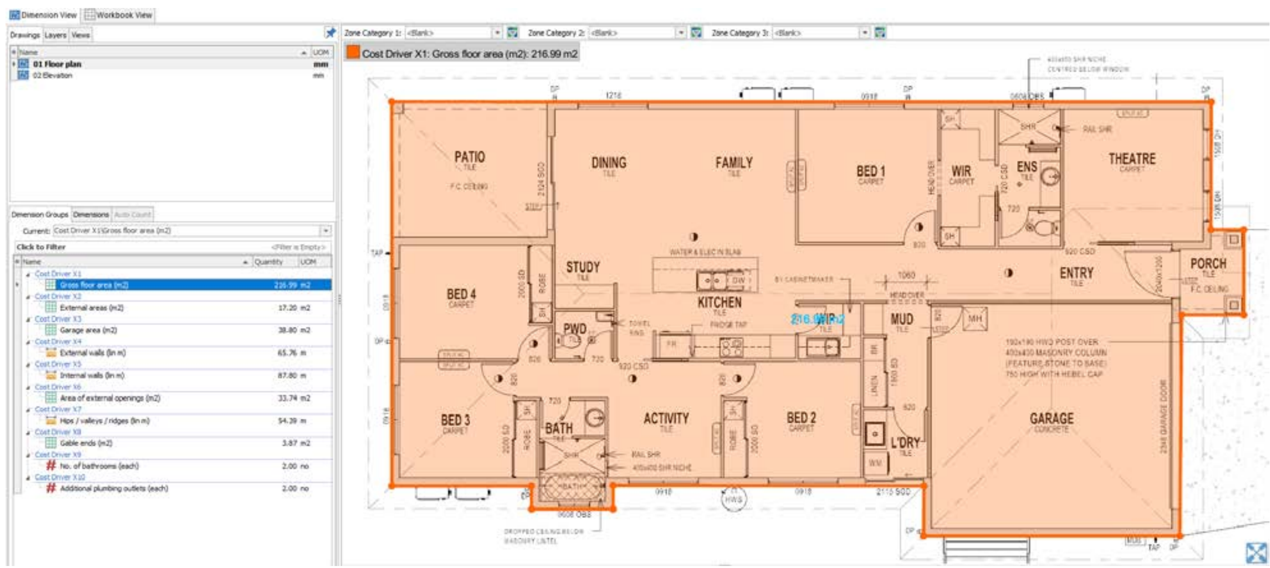


Figure 32 – Gross floor area measured example

The external area cost driver is shown highlighted in Figure 33, on the example plan this represents the porch and patio areas. These spaces are important cost drivers as they separate the ratio of internal conditioned space, which is more expensive compared to external spaces.

Figure 33 – External areas measured example

The location and quantity for the garage area cost driver has been shown in Figure 34. This cost driver, although an internal space, does not contain floor coverings or high cost fit out items.

Figure 34 – Garage area measured example

The external wall cost driver is displayed and quantified in Figure 35. This is a significant cost driver as it typically follows the outline of the building and contributes to design complexity.

Figure 35 – External walls measured example

The internal partition wall cost driver is highlighted and quantified in Figure 36. These walls partition the internal living spaces. These partitions are a function of the number of individual rooms within the dwelling.

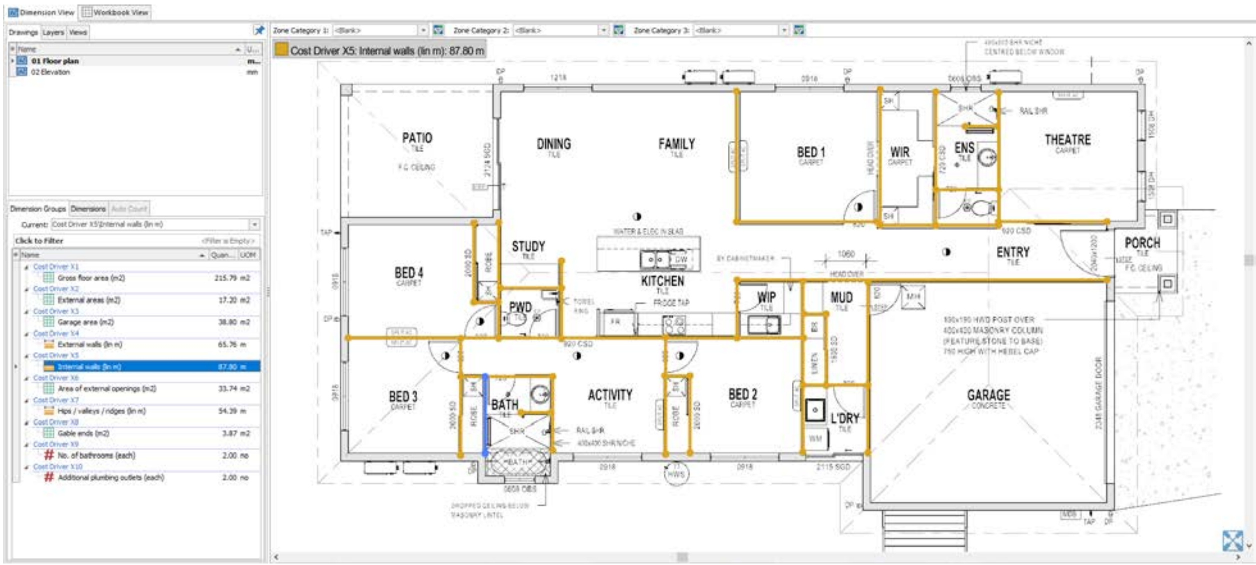


Figure 36 – Internal walls measured example

Openings in the external walls such as doors and windows are shown in Figure 37. This cost driver shows that more openings in an external wall increase the cost of construction.

Figure 37 – External opening measured example

Roof line features as such hips, valleys and ridge lines are displayed in Figure 38. This cost driver shows that a more complex roof line will increase the cost of construction.

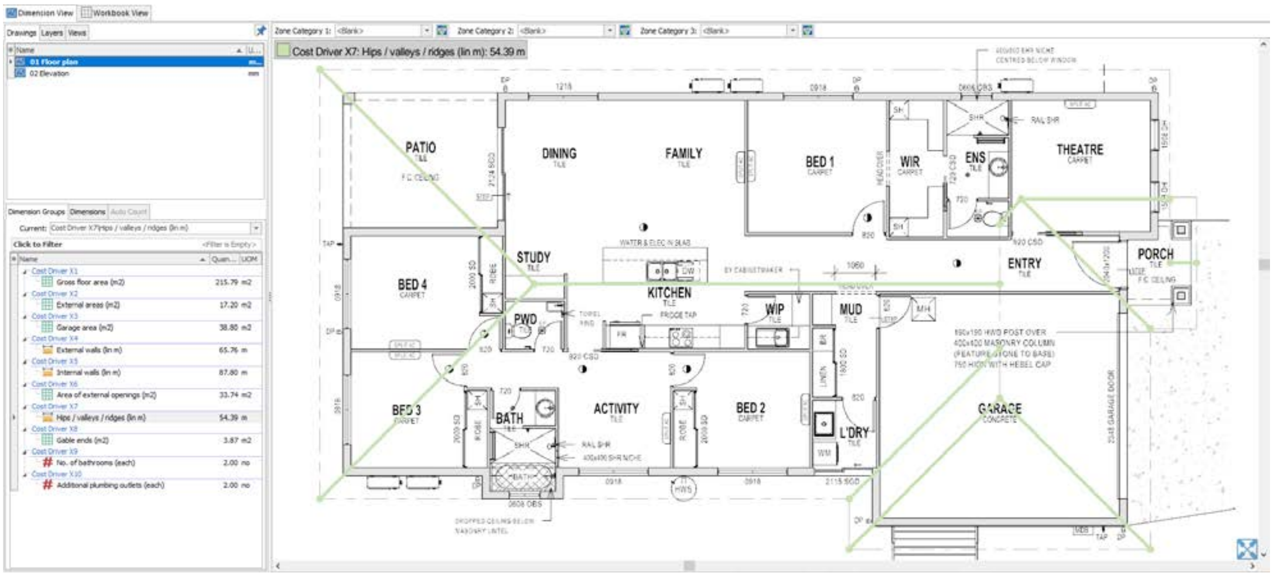


Figure 38 – Hips, valleys and ridge line measured example

The gable ends shown in Figure 39 indicate further complexity to the roof line of a building.

Figure 39 – Gable end measured example

For clarity the measured dimension group highlighted through Cost X has been circled in red. The number of bathrooms in a house is a simple quantification and shown in Figure 40.

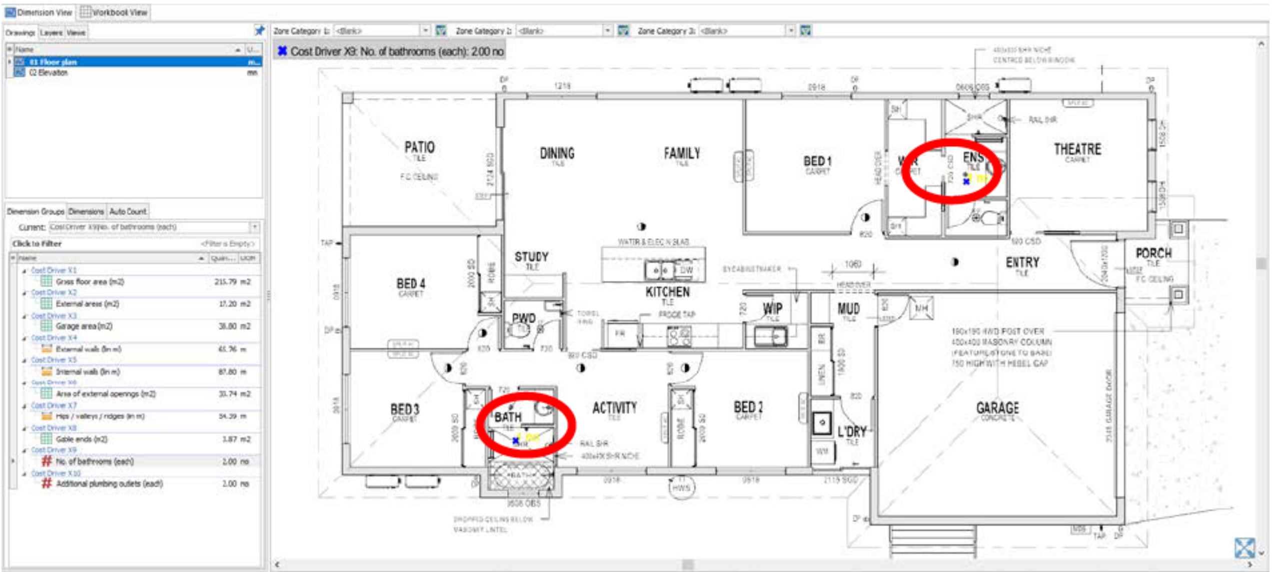


Figure 40 – Number of bathrooms measured example

Additional plumbing fittings are shown in Figure 41. The example plan has identified an additional basin in the powder room and an additional kitchen sink in the pantry, therefore two additional outlets have been included for this cost driver.

Figure 41 – Additional plumbing outlets measured example

The development of this framework in Cost X provides for a fast and easy method of implementing the framework. As discussed earlier, Cost X can live link the measured dimension groups to a workbook. The measured dimension groups shown in the left red box use the coefficients from equation 10 to calculate a result in the H:Total column of the workbook. These results are then added to achieve a total cost of construction like the Excel framework example. Ancillary costs such as mark up and GST percentages can then easily be added to this baseline construction cost estimate to reach a final tender price. This is illustrated in Figure 42.

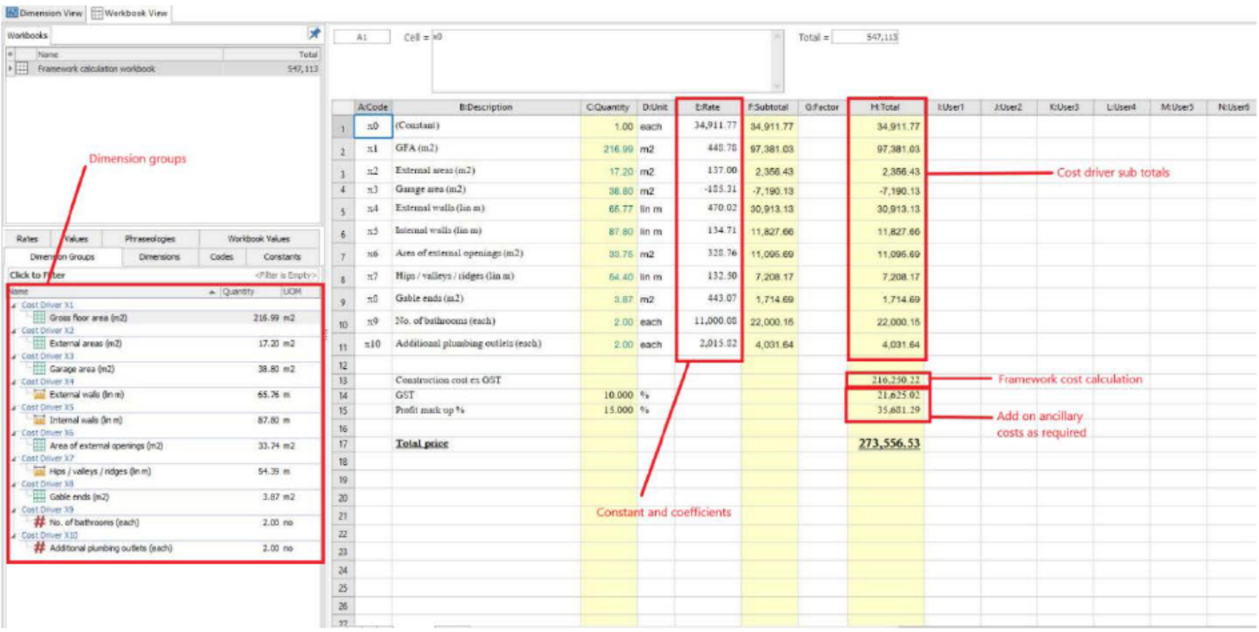


Figure 42 – Framework Cost X workbook calculation

4.5.4 Framework update example

Part of the third objective of this project is to develop a cost modelling framework that is quick to apply using simple input variables. The developed framework has met this requirement by using iTWO Cost X and Excel software. The framework can be easily applied by an end user following the simple worked example contained in the previous section.

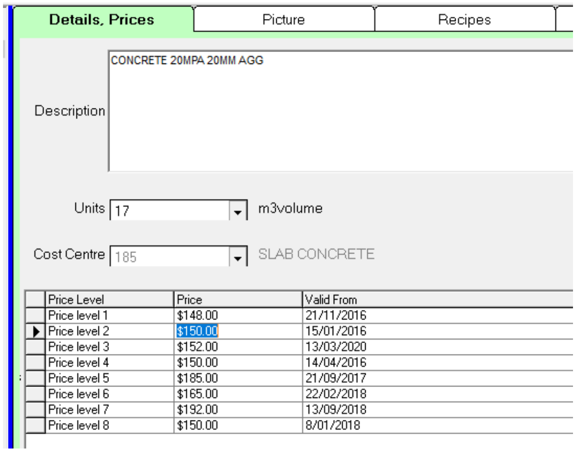
Another part of the third objective is for the framework to be capable of periodic updates. This is critical if the framework is to remain relevant with fluctuating construction costs. For example, if the unit price of concrete changes, the framework must be able to be adjusted to handle this. A procedure has been developed to update the framework periodically to ensure its relevance and the cost output to remain relevant.

As detailed previously, unit cost information is contained within a price catalogue in the estimating software Databuild. The ability to apply any unit cost updates can be achieved through a reprice function within the software which recalculates the total project cost while accounting for all altered unit costs. The following figures detail this process in Databuild.

Figure 43 shows an example of the current unit cost for concrete and the summation of all the costs for the project. If the unit cost for concrete alters then the item's unit cost can be updated within the price catalogue of the software.

Figure 43 – Databuild current unit and project cost

Figure 44 shows the unit price of concrete in the catalogue being changed from $150 to $200. This change can then be used by the software reprice function to apply to the project cost.



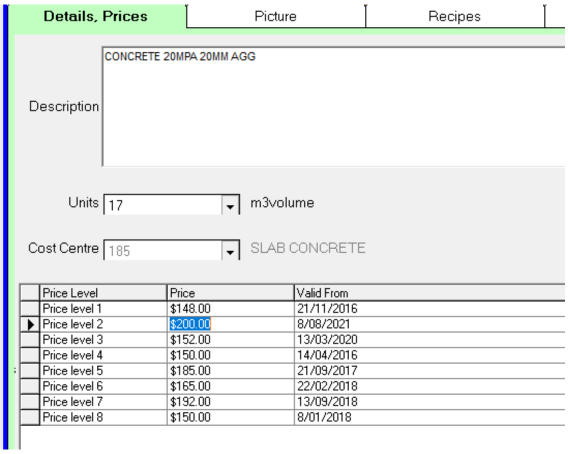


Figure 44 – Unit price update before and after

Figure 45 and Figure 46 show the reprice module and the updated project costs respectively. This demonstrates how a unit price for an item can be updated and then applied to recalculate the total project cost. This procedure can be used periodically to reprice all the sample data and reapply the statistical analysis.

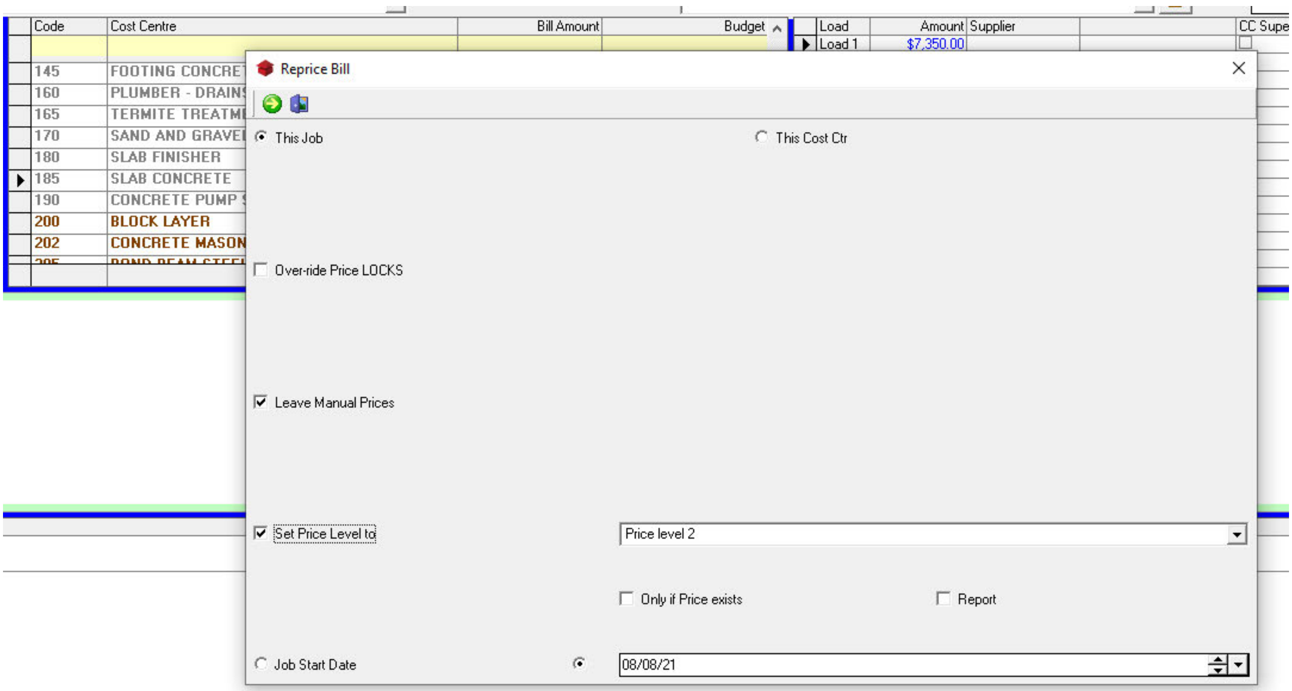


Figure 45 – Software reprice module

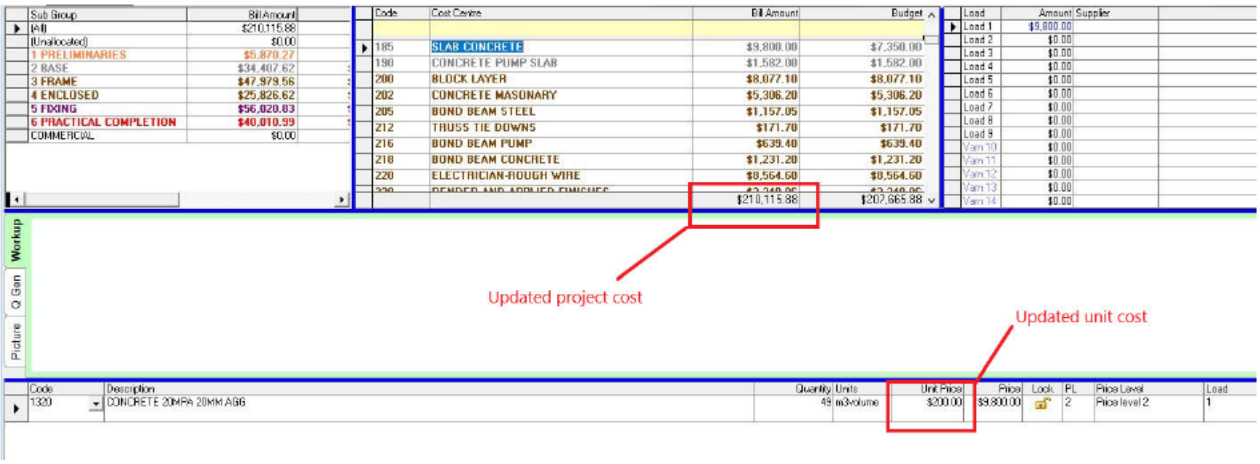


Figure 46 – Updated unit and project cost

The methodology for the statistical analysis used in this project can be reapplied to determine any changes to the linear regression formula (equation 10). The coefficients and constant term can then be updated on the Excel or Cost X version of the framework to ensure a correct construction cost output. The process has been summarised below in Figure 47.

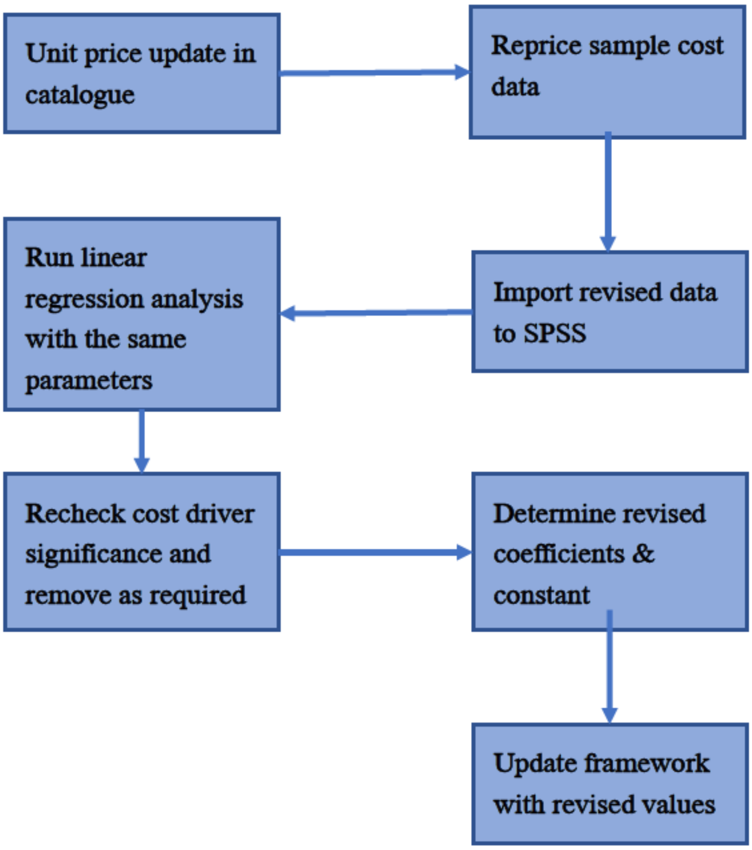


Figure 47 – Summarised framework update process

This section has detailed a procedure to update the cost modelling framework. This has met the final component to complete the third objective for this research project.

4.6 Summary of critical findings and benefits of the framework

The three main objectives of this project are to identify current estimating techniques, potential cost drivers and develop a cost modelling framework for residential construction estimating in the Australian market. The purpose of this chapter is to critically analyse the observations and results to meet these project objectives.

The literature review conducted for this project identified the background for current estimating techniques, their accuracy, methods employed in residential construction and to ascertain the state of research into cost modelling. Further to this, the literature review defined measures of accuracy for the cost model along with testing methodologies. A case study of an estimating company in the Australian construction industry was used to validate and expand the findings from the literature review. The case study found baseline estimating techniques to a standard level of inclusions were common using first principle estimating methods. This method assumes a certain level of fittings and fixtures and often excludes any external factors such as site conditions, environmental factors or mark-up strategies, these items can be adjusted after a baseline cost has been achieved. This discovery proved critical in developing an accurate cost model as the literature review found many studies included irrelevant cost drivers which decreased modelling accuracy. The case study discovered additional design related cost drivers to those found in the literature review. It was important to identify potentially significant cost drivers from both the literature review and from professional sources within the industry to fully analyse their impact on cost. The case study also allowed an understanding of first principle estimating and this technique was critical in gathering relevant sample data used for the cost modelling process which developed the final framework. The literature review and case study provided the results required to meet the first and second objectives of this project.

The data modelling process gathered cost data using first principles estimating methods with cost drivers assigned to each sample set for a linear regression analysis. This process identified any statistically significant cost drivers. The linear regression was then run again, checked for cost driver significance and the formula recorded. Two neural network models were also assessed with their results recorded. The output from the models were compared against test samples to confirm their accuracy. The literature review found that the MAPE was the most common method used to determine model accuracy, the results showed that linear regression performed the best with a MAPE of 1.70%. This result improves the accuracy of the cost models found during the literature review with the best result of 3.98% in a study by Latief, Wibowo and Isvara (2013). This proves that a cost model that considers a narrow focus on design related cost drivers using the baseline method of estimating is a sound methodology and yields superior accuracy.

During the case study, it was discovered that custom cabinetry was thought to significantly impact the cost of construction. This finding prompted further investigation. The same procedure of statistical analysis was run on the same sample models, however this time the cabinetry costs were completely removed. It was expected the cost model would meet a target accuracy of at least a MAPE of 0.85%, however this was not the case. The MAPE for this modelling option did not meet this target and therefore excluded from further consideration.

Linear regression was chosen for framework development using a weighted decision matrix due to its high accuracy along with its simple and easy application. The framework was developed in Excel and Cost X. This meets the third objective of this project with a framework that is accurate, quick to use and can be updated periodically using the Company software and cost database. The development of this framework dramatically reduces the time it takes to achieve a construction cost estimate in comparison to first principle estimating methods from hours to a matter of minutes. The framework has a minimal loss in accuracy when compared to test sample cost calculations. This framework has bridged the gap between long, tedious and accurate first principle estimating methods and quick, inaccurate unit rate estimates found common in the industry.

This project has created a successful methodology for a cost modelling framework using the baseline estimating method. The benefit of this discovery is that the methodology can be applied to other sectors of the industry. This framework can help contractors improve tender turnaround times by offering a less labour-intensive method of estimating that sacrifices very little accuracy. This framework can also benefit companies by offering them a method of estimating that, unlike first principle estimating methods, does not require a high level of training to apply. The framework can be applied by junior estimators with relatively little training compared to a fully trained estimator who is needed for the first principle estimate. As the application of this framework is simple with fewer components to measure compared to a first principle estimate, it also reduces the chance of human error. An estimator applying a first principle estimate must be methodical and during times of pressure can make mistakes. This can result is major costs being excluded and profit margin slippage for the construction project. This framework can benefit the industry by improving productivity, reducing company overheads and minimising human error when producing cost estimates.

5 Conclusion and recommendations

5.1 Conclusions

The purpose of this research project was to develop a framework for construction cost estimating in the residential Australian market. This framework was created using cost modelling which utilises statistical methods to predict the construction cost of a project. Cost modelling was found during the literature review to have been a topic of research for many decades, however a research gap existed. Previous models were too complex and considered too many factors (cost drivers) which yield inaccurate results. Another problem with previous studies was that the model they developed used historical data and merely offered a snapshot in time based on when and where the input cost data was collected. This did not benefit the greater industry in providing a robust model that can be updated when construction costs fluctuate.

This project remedied the problem and narrowed the research gap by creating a model with a focus on design related cost drivers only. This was inspired by observing how a cost estimating company in Australia currently applies first principle estimating using a baseline method. By creating a baseline estimate any external factors such as site conditions, environmental factors, mark-up strategies, risk contingencies or changes to the inclusions can easily be applied by varying the baseline cost. By using the methods and software available through the Company this project has solved the problem by creating a framework that can be periodically updated when construction costs fluctuate. This is critically important as it allows the framework to be employed in a commercial setting with an output that can be relied upon. Three main objectives were defined to solve the problem.

The first objective was to identify current cost estimating techniques. This was completed by validating the literature review findings with the results from the case study. It was concluded that first principle estimating is the technique employed to achieve the highest accuracy, however is the most time consuming method. It was also discovered that residential construction in Australia utilised baseline cost estimating to a standard level of inclusions which can then be manipulated with additions or subtractions based on external factors or client wishes (Lim et al. 2016, p. 14). This baseline methodology has been validated through the case study of the Company. This discovery was pivotal in developing the research methodology by removing many external and non-relevant factors from consideration, something previous studies neglected to do. By narrowing the focus of the cost model to design related factors, this project's cost modelling method has improved upon previous studies.

The second project objective was to identify potential cost drivers. Past research identified as many cost drivers as possible relating to factors such as site conditions, environmental factors, market conditions, project personnel experience and contract types. It was concluded that this approach is problematic as it considers too many irrelevant cost drivers which results in a cost model with undesirable accuracy. A focus on design related factors only will improve the accuracy of a cost model. The design related cost drivers required for this project were compiled through the literature review and case study interviews. It was found that the gross floor area of a building was the most frequently used cost driver. This draws a conclusion as to why the unit rate method of estimating remains common place in the industry albeit inaccurate for anything but a preliminary feasibility analysis. By completing the second objective a detailed list of design related cost drivers were compiled for the statistical analysis required to fulfil the third objective.

The third objective, to develop the cost modelling framework, follows on from the completion of previous objectives. This objective requires the development of a framework that is accurate, relevant and can be periodically updated. By completing this objective several conclusions have been drawn.

1. A statistical analysis determined ten out of a potential fifteen design related cost drivers are statistically significant to the cost of a residential construction project. The significant design related cost drivers that impact the cost are shown in Table 35.

Cost driver	Description	Unit of measure
1	Gross floor area	m^2
2	External areas	m^2
3	Garage area	m^2
4	External walls	Lineal metre
5	Internal walls	Lineal metre
6	Area of external openings	m^2
7	Hips / valleys / ridges	Lineal metre
8	Gable ends	m^2
9	No. of bathrooms	Each
10	Additional plumbing outlets	Each

Table 35 – Summary of significant design related cost drivers

2. The cost of custom cabinetry being removed from the cost data sets does not have a significant effect on the accuracy of the cost model and therefore the cost of construction.
3. The linear regression analysis cost model performs better than the two neural networks tested with a MAPE of 1.70%.
4. A cost model analysis with design related cost drivers and baseline estimating techniques for sample data collection improve upon the accuracy of previous studies which range from 3.98% and 19.60%.
5. Linear regression was the cost model selected using a weighted decision matrix based on accuracy, ease of use and the ability to apply updates to the framework when construction costs fluctuate.
6. Equation 10 derived from the linear regression analysis and detailed below, was used to develop the framework in Excel and iTWO Cost X.

$$Cost\ (\$) = 34911.76 + 448.78x_1 + 137x_2 - 185.31x_3 + 470.02x_4 + 134.71x_5 + 328.76x_6 + 132.50x_7 + 443.07x_8 + 11000.08x_9 + 2015.82x_{10} \qquad (10)$$

7. Updating the framework's cost model is achieved using the Company's cost estimating database by repricing unit costs and reapplying the methodology of statistical analysis. This will update the coefficients and constant in equation 10 which can then be reapplied to the framework.

This project narrowed the research gap by providing an accurate cost modelling framework. The framework's accuracy was improved by not only utilising the baseline method for cost data statistical analysis but by narrowing the focus of the cost drivers from a wide array of irrelevant factors to only design related ones. By simplifying to design related cost drivers only, the project has developed a successful cost modelling methodology which can be applied to other industry sectors such as commercial and civil construction.

This framework benefits contractors and estimators that have difficulty in providing accurate cost estimates within tight deadlines. It was found that first principle estimates are the most accurate however they can take hours to calculate. This framework can be applied in a matter of minutes with a minimal impact on the cost estimate accuracy. This increase in efficiency can reduce company overheads and free resources within the estimating team. Another benefit this framework provides is that it can be easily applied by relatively unskilled or junior estimators. This lowers the cost and time it takes to train an estimator to perform a first principle estimate and allows a company to output tangible deliverables without first investing significant training resources. The return on investment for utilising this framework can come to fruition much faster without a significant reduction in quality output and cost accuracy.

5.2 Limitations

The development of this framework relied upon data gathered from a cost estimating Company. This data represents a small section of the residential industry based within a local area. This suggests that although this research project produced sound results the framework can only be applied through this scope. What this means is that the framework developed cannot be used to calculate residential construction costs for localities all over Australia without some form of indexing for local cost fluctuations. This is because unit prices and construction methodologies can differ between local areas. However, being aware of this limitation can allow locality indexing to be performed and the framework applied successfully.

This project developed a successful methodology that can easily be reapplied to any locality rather than indexing. This can be achieved by altering the unit costs within the Databuild pricing catalogue to suit local rates and recalculating the linear regression equation. By doing this a relevant cost modelling framework can be developed for different locations. As the data gathered for this project took significant time to compile, the project had limited resources available to apply the methodology to other specific locations.

Another limitation of this project is that it utilised proprietary licensed software available through the Company. This software was used to formulate a baseline cost data set for an accurate cost model, which this project succeeded in. However, trying to replicate this methodology would require software with similar functionality to provide the baseline cost data used for statistical analysis and update procedure. Whilst the methodology this project discovered is successful, this limitation should be noted for future research and development in this area.

5.3 Recommendations for further research

Further testing of this framework is recommended and can be implemented into the Company infrastructure over a period to determine the practicality and measurable outcomes in a commercial setting. It is recommended to trial this framework alongside the Company's first principle estimating methods for a period and compile a comparison of output results for analysis. Whilst this project did test the output from the framework, it would be best assessed over a period of six months to a year. This will assess how well the framework can handle periodic updates and determine its predictive power against larger calculated test data sets. Due to time constraints this was not possible within the scope of this project.

There remains a vast area to explore using the successful methodology discovered by this project. The methodology developed was based on a narrow focus of residential dwellings in a single locality using relatively simple single storey designs. Now the methodology has proven successful, expansion into other localities and more complex designs such as multi-storey dwellings is recommended. A similar methodology can be applied to multi-storey designs by using cost drivers related to this additional layer of complexity. Once further developed, the methodology can be considered a viable foundation for the creation of any cost modelling procedure and applied to other sectors of the construction industry.

Any type of construction project can be further researched using the baseline estimating and design only cost driver methodology this project has developed. This framework can positively contribute to the industry by providing an excellent procedure to develop a specific cost model for any contractor or cost estimating professional willing to apply the methodology. This will benefit companies by lowering overhead costs, increasing productivity and reducing the chance of human error.

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Appendix A - Project specification

ENG4111/4112 Research Project

Project Specification

For: Andrew Peter Dixon

Title: Develop a framework for residential construction cost estimating in the Australian market

Major: Construction Management

Supervisor: Dr Amirhossein Heravi

Enrolment: ENG4111 – ONL S1, 2021

ENG4112 – ONL S2, 2021

Project aim: The aim of this project is to develop a framework to reduce the time it takes to estimate construction costs of Australian residential dwellings in comparison to traditional methods through a statistical analysis of design complexity features (cost drivers).

Programme: Version 1, 17th March 2021

1. A literature review will be conducted to identify the various techniques of cost estimating in residential construction.
2. Select a case study and conduct interviews to identify current methods of estimating in Australia and determine appropriate cost drivers which will form the basis of the analysis.
3. A sample set of concept design for typical residential dwellings will be selected and a first principles estimate will be performed on each model.
4. Collate total construction cost for each design along with values for each determined cost driver variable. This data set is required to be formatted specifically for import into the statistical analysis package (SPSS).
5. Run collated data through SPSS for analysis. Determine any cost drivers which are not statistically significant and assess for removal from the model.
6. Test the results of the formulated model against an independent data set to evaluate the reliability and validity the proposed model.

Appendix B – Risk management plan

The approve safety risk management plan ID is RMP_2021_5471. A summary of the details can be found below.

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland Print View

USQ Safety Risk Management System

Version 2.0

Safety Risk Management Plan

Risk Management Plan ID:	Status:	Current User:	Author:	Supervisor:	Approver:
RMP_2021_5471	*Approve*	[redacted]	[redacted]	[redacted]	[redacted]

Assessment Title:	Risk assessment of honours research project	Assessment Date:	3/05/2021
Workplace (Division/Faculty/Section):	204010 - Faculty of Health, Engineering and Sciences	Review Date:	3/05/2026 (5 years maximum)

Approver: *Amirhossein Heravi*	*Supervisor: (for notification of Risk Assessment only)* *Amirhossein Heravi*

Context

DESCRIPTION:

What is the task/event/purchase/project/procedure?	Conducting honours research project		
Why is it being conducted?	Required component of program		
Where is it being conducted?	Home and work premises		
Course code (if applicable)	ENG4111/4112	Chemical Name (if applicable)	

WHAT ARE THE NOMINAL CONDITIONS?

Personnel involved	Andrew Peter Dixon
Equipment	Computer software and desk
Environment	Office
Other	
Briefly explain the procedure/process	Research articles, collect data, run statistical tests, develop model

Assessment Team - who is conducting the assessment?

Assessor(s):	Amirhossein Heravi
Others consulted: (eg elected health and safety representative, other personnel exposed to risks)	

Risk Register and Analysis

	Step 1	Step 2	Step 2a	Step 2b	Step 3			Step 4				
	Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional Controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:* Has the consequence or probability changed?			
					Probability	*Risk Level*	*ALARP*		*Consequence*	*Probability*	*Risk Level*	*ALARP*
	Example											
	Working in temperatures over 35^0 C	*Heat stress/heat stroke/exhaustion leading to serious personal injury/death*	*catastrophic*	*Regular breaks, chilled water available, loose clothing, fatigue management policy.*	*possible*	*high*	*No*	*temporary shade shelters, essential tasks only, close supervision, buddy system*	*catastrophic*	*unlikely*	*mod*	*Yes*
1	Eye strain	Excessive time in front of screen may cause headaches	Minor	Regular breaks	Likely	High	☐	Ensure breaks are taken and use correct lighting in office	Insignifica	Unlikely	Low	☑
2	Sore back fro...	Bad posture issues and lower back pain	Minor	Stand up desk in place at work office which will be used when possible	Possible	Me...	☐	Set an alarm to remind me to stand up regularly	Minor	Unlikely	Low	☑
3	Mental stress...	Mental health impact	Moderate	Regular exercise and relaxation time	Possible	High	☐	Use holidays at work to take time off if needed	Minor	Unlikely	Low	☑
4	Car accident ...	Death	Catastrophic	Good safe driving practice and no driving when tired	Unlikely	Me...	☐	Set up remote log in so work can be done from home	Insignifica	Rare	Low	☑

Step 5 - Action Plan (for controls not already in place)

	Additional Controls:	*Exclude from Action Plan: (repeated control)*	*Resources:*	*Persons Responsible:*	*Proposed Implementation Date:*
1	Ensure breaks are taken and use correct lighting in office	☐	Desk light and alarm clock	Andrew Dixon	3/05/2021
2	Set an alarm to remind me to stand up regularly	☑			
3	Use holidays at work to take time off if needed	☐	Time off available through work	Andrew Dixon	3/05/2021
4	Set up remote log in so work can be done from home	☐	Software availability	Andrew Dixon	3/05/2021

Supporting Attachments

No file attached

Step 6 – Request Approval

Drafters Name: *Andrew Peter Dixon* *Draft Date:* *3/05/2021*

Drafters Comments:

Assessment Approval: **All risks are marked as ALARP**

Maximum Residual Risk Level: **Low - Manager/Supervisor Approval Required**

Document Status: *Approve*

Step 6 – Approval

Approvers Name: *Amirhossein Heravi* *Approvers Position Title:* *Supervisor*

Approvers Comments: *Possible risks are correctly reflected*

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Approval Decision: Approve *Approve / Reject Date:* 24/05/2021 *Document Status:* *Approve*

Appendix C – Case study interview questions phase one

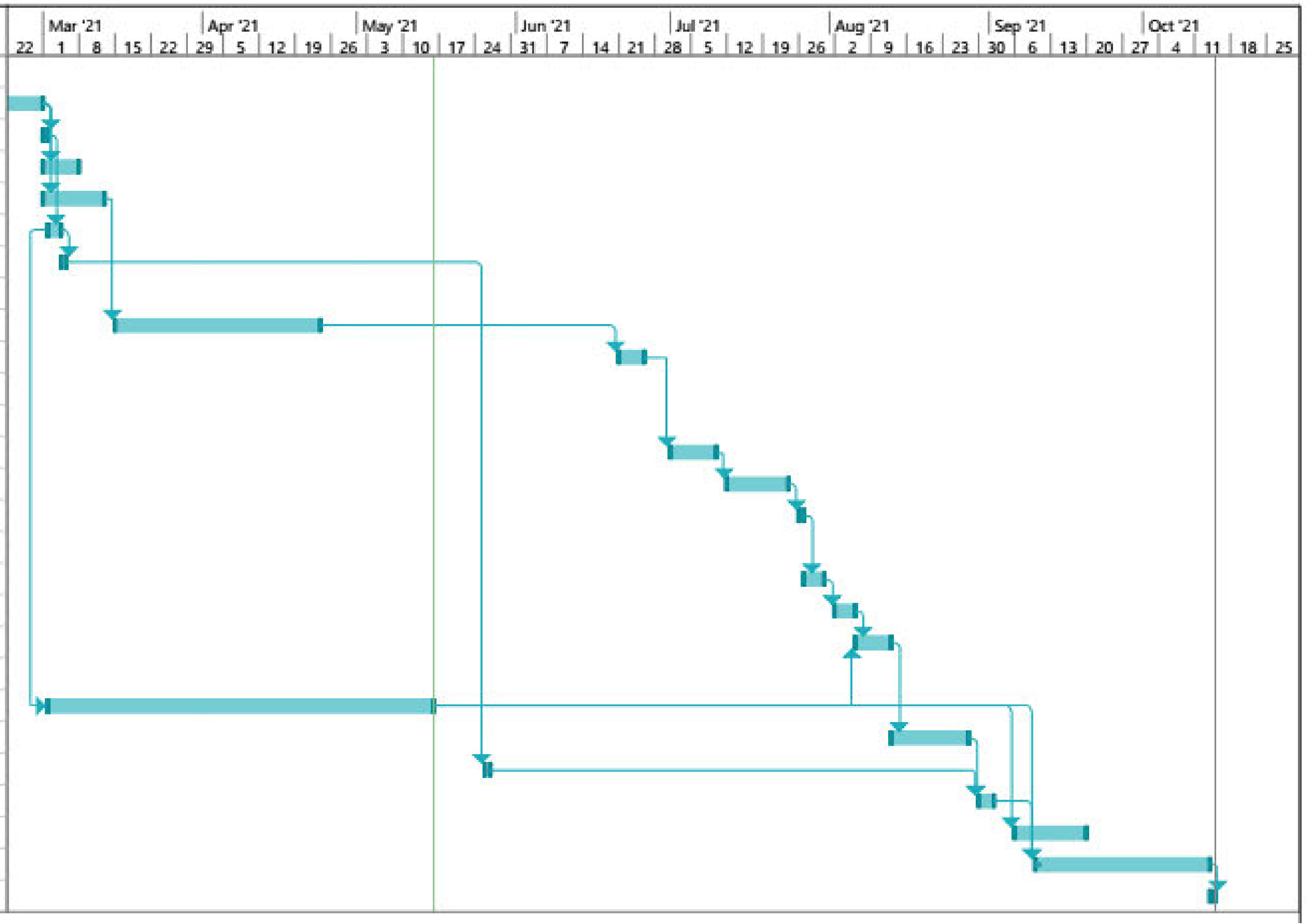
1	What kind of design and specification details are available when you calculate construction costs?
2	How long does a first principle estimate generally take you?
3	Have you found unit rate estimating methods common in the residential industry?
4	Between unit rate and first principle estimating which do you perceive as the most accurate and what variance would one expect?
5	Briefly explain how you calculate the total cost of a project?
6	Can you outline the use of a standard specification in the residential construction industry and its importance.
7	Explain how you modify cost estimates if a consumer wishes to vary the standard inclusions provided by a contractor.
8	Can you name some of the common forms of contracts that are employed by residential contractors?

Appendix D – Case study interview questions phase two

1	Cost driver definition to be stated as "a cost driver for the purpose of this interview is a design related factor that is believed to contribute significantly to the total cost of construction".
2	In your experience can you identify some factors that come to mind that you consider would fall under the definition of a cost driver.
3a	Clarification of an answer from question 2 - Would you please clarify what you mean by that?
3b	Probing of an answer from question 2 - this will depend on the answer and guidance from the interviewer.
4	This question will ask the interviewee about the significance of the cost drivers identified in table 7. It will only be asked if the cost drivers were not previously mentioned by the interviewee.
5	Shape complexity has been identified from previous studies as a cost driver, what does that term mean to you?

Appendix E – Time plan

ID	Task Name	Duration	Start	Finish
1	**1. Preparation**	0 days		
2	Prepare Proposal	6 days	Mon 22/02/21	Sun 28/02/21
3	Submit Proposal	1 day	Mon 1/03/21	Mon 1/03/21
4	Gather resources	6 days	Mon 1/03/21	Sun 7/03/21
5	Select sample models	10 days	Mon 1/03/21	Fri 12/03/21
6	Proposal approved	2.5 days	Tue 2/03/21	Thu 4/03/21
7	Project Specification Due	1 day	Thu 4/03/21	Fri 5/03/21
8	**2. Collect data**	0 days		
9	Measure & compile sample model costs	30 days	Mon 15/03/21	Fri 23/04/21
10	Case study interviews	5 days	Mon 21/06/21	Fri 25/06/21
11	Assign cost drivers to each model	2 days	Mon 29/06/2C	Tue 30/06/20
12	**3. Analyse Data**	0 days		
13	Use SPSS linear regression analysis	7 days	Thu 1/07/21	Fri 9/07/21
14	Compile model formula	10 days	Mon 12/07/21	Fri 23/07/21
15	Add formula to Excel for testing	1 day	Mon 26/07/21	Mon 26/07/21
16	**4. Test Data**	0 days		
17	Select test models	4 days	Tue 27/07/21	Fri 30/07/21
18	Measure & compile test model costs	4 days	Mon 2/08/21	Thu 5/08/21
19	Analyse model accuracy with test models	5 days	Fri 6/08/21	Thu 12/08/21
20	**5. Presentation & write up**	0 days		
21	Literature review & methodology	55 days	Tue 2/03/21	Sat 15/05/21
22	Data analysis and results write up	11 days	Fri 13/08/21	Fri 27/08/21
23	Progress report due	1 day	Wed 26/05/21	Wed 26/05/21
24	Partial draft dissertation	3 days	Mon 30/08/21	Wed 1/09/21
25	Results for presentation during PP2	11 days	Mon 6/09/21	Sun 19/09/21
26	Finalise disseration	24 days	Fri 10/09/21	Wed 13/10/21
27	Submit dissertation	1 day	Thu 14/10/21	Thu 14/10/21



Appendix F – Ethical approval

USQ HREC ID: H21REA138
Project title: Develop a framework for residential construction cost estimating in the Australian market
Approval date: 29/06/2021
Expiry date: 29/06/2022
USQ HREC status: Approved
The standard conditions of this approval are:

a) responsibly conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal;.

(b) advise the University (email:ResearchIntegrity@usq.edu.au) immediately of any complaint pertaining to the conduct of the research or any other issues in relation to the project which may warrant review of the ethical approval of the project;

(c) promptly report any adverse events or unexpected outcomes to the University (email: ResearchIntegrity@usq.edu.au) and take prompt action to deal with any unexpected risks;

(d) make submission for any amendments to the project and obtain approval prior to implementing such changes;

(e) provide a progress 'milestone report' when requested and at least for every year of approval.

(f) provide a final 'milestone report' when the project is complete;

(g) promptly advise the University if the project has been discontinued, using a final 'milestone report'.

The additional conditionals of approval for this project are:

(a) Nil.

Appendix G - Interview responses

Interview summary – Participant 1

Position – Estimator

Time in residential construction – 9 years

Service at company- 3 years

Questions related to estimating techniques

1. **What kind of design and specification details are available when you calculate construction costs?**

- A concept design consisting of site plan, floor plan and elevation.
- Often a soil investigation report if available.
- Contour plan.
- Brief scope of inclusions from client.
- Full design documentation such as detailed architectural and structural plans often not provided.

2. **How long does a first principle estimate generally take you?**

- Usually 2 hours for a standard design.
- More complex designs with larger levels of inclusions including double storey designs take much longer.

3. **Have you found unit rate estimating methods common in the residential industry?**

- Never really heard of it being used effectively.
- Heard terrible stories about projects loosing money as this was the only method used to estimate the initial cost.

4. **Between unit rate and first principle estimating which do you perceive as the most accurate and what variance would one expect?**

- Use a first principle estimating method with software developed for the projects we often price. The unit rate is too inaccurate.
- First principle method approx. 1-2%.
- Unit rate method 20%.

5. **Briefly explain how you calculate the total cost of a project?**

- First principle estimate of construction costs.
- Apply margin build up.
- Vary specification inclusions from standard if required.

6. **Can you outline the use of a standard specification in the residential construction industry and its importance?**

- A standard specification is very common.
- Often there are different levels of specification aimed at different market entry points such as a high level (more expensive) and entry level (very cheap).
- A standard specification keeps pricing accurate and consistent.
- It allows a builder to “brand” their product with a specific level of quality or range of fittings.

7. **Explain how you modify cost estimates if a consumer wishes to vary the standard inclusions provided by a contractor.**

- We use our baseline estimate to a standard specification as a starting point.
- Then modify any inclusions as an adjustment to that baseline cost on the Excel proposal sheet that gets presented to the client so they can see the cost applicable to the change request.

8. **Can you name some of the common forms of contracts that are employed by residential contractors?**

- Housing Industry Australia (HIA).
- Master Builders.

Questions related to cost driver identification

Cost driver definition to the be stated as "a cost driver for the purpose of this interview is a design related factor that is believed to contribute significantly to the total cost of construction".

1. **In your experience can you identify some factors that come to mind that you consider would fall under the definition of a cost driver.**

- Layout complexity.
- Roof design.
- Bathroom number.
- Kitchens and plumbing outlets.
- Wall height.
- Window types.

2. **A - Clarification of an answer from question 2 - Would you please clarify what you mean by that?**

Layout complexity

- Comes into play regarding number of bedrooms and living spaces within the dwelling.
- The shape of the external perimeter of the building.

Roofline

- More complex geometric roof layouts often add cost.
- Features such as gable ends, fly over roofing, hips, valleys and eaves.

Window types

- Windows come in many shapes and configurations.
- Sliding windows are cheap.
- Louvres, awning, casement windows often more expensive if there are a significant amount.
- Large sliding doors with multiple leafs are also very high cost drivers.

Kitchens and plumbing outlets

- Custom kitchens can add up quickly depending on the length of cupboards and features included. Often detailed in the proposal as a Provisional Sum.
- Additional plumbing fixtures such as sinks, basins, shower outlets, WCs often are cost significant.

3. B - Probing of an answer from question 2 - this will depend on the answer and guidance from the interviewer.

Summary of probing explanation provided above under appropriate heading.

4. **This question will ask the interviewee about the significance of the cost drivers identified in table 5. It will only be asked if the cost drivers were not previously mentioned by the interviewee.**

- External area is cheaper than internal area as it does not need air conditioning, electrical fittings, expensive floor coverings, windows, partition walls and doors.
- Gross floor area is the main driver of cost.
- A compact plan is much more expensive than a large open plan so this is significant.
- Internal and external wall lengths are relatively significant.
- External wall openings will depend on opening type, however can be a cost driver.

5. **Shape complexity has been identified from previous studies as a cost driver, what does that term mean to you?**

The lengths and interactions of geometric features of the house such as roof lines, external walls and slab and footing layouts. A shape with a longer perimeter versus area is often times much more expensive and than simple shape of the same size.

Cost driver	**Unit**	**Calculation definition**
Gross internal floor area	m^2	Internal living area measured of outside face of wall
Gross external floor area	m^2	Floor area of alfresco, patios, porches etc.
Gross floor area	m^2	Total floor area of dwelling measured to outside face of wall
Compactness	ratio	Area of external walls / gross floor area
Internal walls	m	Length of internal walls
External walls	m	Length of external walls
Proportion of openings	m^2	The area of all external wall openings
Building volume	m^3	External wall length x wall height x internal floor area
Shape complexity	N/A	This will be further developed from interview data

Interview summary – Participant 2

Position – Senior Estimator

Time in residential construction – 15 years

Service at company- 11 years

Questions related to estimating techniques

9. **What kind of design and specification details are available when you calculate construction costs?**

Typically we are provided with a concept plan, that is a floor plan, elevations and a site plan. Full design documentation is often not available when producing an initial tender in residential construction. Sometimes clients have full design documents done when they have had their project developed with the help of an architect or building designer, however for design and construct contractors this is not common.

The contractor generally has a standard level of inclusions available for us to use when pricing the initial tender with the client being able to request variations to those inclusions to be included in the proposal.

10. **How long does a first principle estimate generally take you?**

It really depends on the complexity of the build. A simple design with no extenuating site conditions can take 1-1.5 hours depending on experience. A difficult and complex design with specialised inclusions can take one to two days.

11. **Have you found unit rate estimating methods common in the residential industry?**

Yes, it is common in the residential industry. This is a method most contractors employ initially as they lack the time and skill to perform a detailed quantity take off. Often contractors approach our company because they have employed this method prior to contracting and found out they lost money or had a severely reduced profitability for the project. It works well as an indicator but certainly not a predictor.

12. **Between unit rate and first principle estimating which do you perceive as the most accurate and what variance would one expect?**

- Definitely the first principle method, however it is more time consuming.
- A unit rate estimate, depending on the skill of the person applying it, can vary up to 10-15% of actual cost of the project. This often impacts profit margins.
- First principle estimates vary between 1-4% depending on complexity of project.

13. **Briefly explain how you calculate the total cost of a project?**

We use software to quickly extract quantities, manipulate them and then formulate a first principle bill of quantities to calculate total construction costs. 3 key software tools we use are Excel, Cost X and Databuild. The company has set these up to work together. A typical build up of cost attributes rates to plant, labour, sub contractor and fee allowances. These are specific to each contractor we work with and also the each local area we operate in. A database of unit costs for all components are keep on file and updated when required, this means projects are live priced and updates to the price catalogue can be applied immediately.

Typically we product an estimate for the total construction costs of the project based on a standard level of specification, we then modify or change that if the client requests specific alterations to the standard inclusion level. We find measuring to a baseline estimate much quicker, easier to replicate and also provides a price comparison for future similar projects if the inclusions are identical. This helps us provide ball park estimates to ensure the design of the project can meet the required budget.

14. **Can you outline the use of a standard specification in the residential construction industry and its importance.**

A standard specification or level of inclusions is a common tool residential contractors use to show potential clients their level of finish and what they are receiving for their proposal. Some contractors do not allow significant variation to these inclusions, however this is more common in larger project home builders. Most contractors are happy to accommodate changes. The standard specification is common to many contractors especially those that have "display homes" in villages to show off their product. It also provides a point with which to base initial estimates and we use this in formulating a construction cost.

15. **Explain how you modify cost estimates if a consumer wishes to vary the standard inclusions provided by a contractor.**

A mentioned we typically produce an estimate to a standard level of inclusions which is based on the contractor's standard specification. This provides us a baseline estimate. We can then vary costs for the tender if the client would like to change something.

An example would be wet area tiling. The contractor's standard may be only tiling the shower recess area to 2.1m above the floor level. The client may require tiling to all the walls in the bathroom to the full height of the wall. This additional cost can easily be applied to the tender proposal build up sheet for inclusion in the total cost of the works.

16. **Can you name some of the common forms of contracts that are employed by residential contractors?**

Design and construct contracts are very common in the residential market. Contractors often belong to industry bodies such as HIA or Master Builders. These bodies produce standard form contracts for the contractor to use. These are by far the most common seen in the residential sector.

Questions related to cost driver identification

Cost driver definition to the be stated as "a cost driver for the purpose of this interview is a design related factor that is believed to contribute significantly to the total cost of construction".

6. **In your experience can you identify some factors that come to mind that you consider would fall under the definition of a cost driver.**

- Gross floor area.
- External wall complexity/layout.
- Roof line complexity.
- Number of bedrooms.
- Number of bathrooms.
- External openings and window complexity.
- Number plumbing outlets.
- Number of separate living areas.
- Amount of custom cabinetry.

7. **A - Clarification of an answer from question 2 - Would you please clarify what you mean by that?**

Roofline complexity

- Often made up of geometric planes.
- Hips, valleys, eaves.
- Gable ends and parapets.

Number of plumbing outlets

- Typically a standard number of outlets in a bathroom is assumed. 1 shower, 1 basin, 1 WC & 1 bath.
- Additional basins and shower outlets attract significant supply and fitting charges and if there are many can increase costs significantly.

Separate living area

- These could be media rooms, rumpus rooms, separate dining areas. These all require additional electrical fittings, air conditioning and partition walls/windows to make them habitable and can drive costs.

Custom cabinetry

- This can vary significantly and depends entirely on the design and layout of bathrooms, kitchens and laundries.
- A large kitchen with a walk in pantry will be significantly more expensive than a simple galley kitchen.
- This variable is difficult to define in a project and often a Provision Sum allowance is used so the client can discuss their needs with a cabinetmaker once contracted.

8. **B - Probing of an answer from question 2 - this will depend on the answer and guidance from the interviewer.**

Any probing was summarised above in the clarification asked.

9. **This question will ask the interviewee about the significance of the cost drivers identified in table 5. It will only be asked if the cost drivers were not previously mentioned by the interviewee.**

Gross floor area is the single most significant cost driver. The proportion of external area vs internal area is also important as internal area signifies conditioned liveable space which often costs a larger amount.

A lot of the items like compactness, building volume and shape complexity look to be functioned of each other.

Personally do not think internal walls are significant as these are a function of the number of rooms in the house, however I has noticed that houses with a lot of dead space i.e long hallways are often not very cost efficient.

10. **Shape complexity has been identified from previous studies as a cost driver, what does that term mean to you?**

This means the complexity of the outside perimeter of the building, a building perimeter with a significant amount of ins and outs will significantly increase the length of external walls. This will drive costs.

Cost driver	Unit	Calculation definition
Gross internal floor area	m^2	Internal living area measured of outside face of wall
Gross external floor area	m^2	Floor area of alfresco, patios, porches etc.
Gross floor area	m^2	Total floor area of dwelling measured to outside face of wall
Compactness	ratio	Area of external walls / gross floor area
Internal walls	m	Length of internal walls
External walls	m	Length of external walls
Proportion of openings	m^2	The area of all external wall openings
Building volume	m^3	External wall length x wall height x internal floor area
Shape complexity	N/A	This will be further developed from interview data

Interview summary – Participant 3

Position – Director of estimating company

Time in residential construction – 26 years

Service at company- 15 years

Questions related to estimating techniques

17. **What kind of design and specification details are available when you calculate construction costs?**

- Varies according to scope of project.
- Generally only a concept plan with site plan, elevations and floor plan.
- Rarely do we have full design documents available.
- We aim to price accurately on a concept plan and given the nature of residential construction projects they tend to be predictable in regards to structural design.

18. **How long does a first principle estimate generally take you?**

- The company has developed systems to cater for rapid estimating methods however generally around 1 hour for a simple standard project.
- A complex build can take 1-2 days however these are heavily involved and quite complex.

19. **Have you found unit rate estimating methods common in the residential industry?**

- These method is extremely common among builders with little understanding of project costing, often taking contracts based on a unit rate estimate only.
- Very dangerous.

20. **Between unit rate and first principle estimating which do you perceive as the most accurate and what variance would one expect?**

- Obviously first principle. Unit rate can work if the design is very similar with similar feature however advised as a ball park estimate only.
- First principle – 2-3%
- Unit rate – 10-15%

21. **Briefly explain how you calculate the total cost of a project?**

- Calculate construction cost only using our software programs.
- Add any statutory fees and charges and percentage of contract related items such as commission.
- Apply profit margins plus any risk factor percentages or retentions.

22. **Can you outline the use of a standard specification in the residential construction industry and its importance?**

- Very important, it provides a contractual link between the concept and final drawings to ensure what was priced was included in the final plans.

- It serves as a communication document to relay the proposal cost plus the inclusions in that cost to the client and other stake holders.
- It helps monitor project variations as it provides a baseline of inclusions that can easily identify cost variances for actioning.

23. **Explain how you modify cost estimates if a consumer wishes to vary the standard inclusions provided by a contractor.**

- Often modify the proposal by adding or subtracting the cost from the initial baseline tender cost.
- It depends on the change required however most changes to fittings, fixtures and inclusions can be adjusted this way.
- Any major redesigns will result in a recalculation of costs through a first principle estimate.

24. **Can you name some of the common forms of contracts that are employed by residential contractors?**

- Queensland Master Builders Association (QMBA).
- Housing Industry Australia (HIA).

Questions related to cost driver identification

Cost driver definition to the be stated as "a cost driver for the purpose of this interview is a design related factor that is believed to contribute significantly to the total cost of construction".

11. **In your experience can you identify some factors that come to mind that you consider would fall under the definition of a cost driver.**

    - Gross floor area
    - Number of bathroom
    - External length of wall
    - Roof configuration
    - Number of rooms
    - Joinery
    - External areas such as alfresco or garage

12. **A - Clarification of an answer from question 2 - Would you please clarify what you mean by that?**

Roof configuration

- Shape of roof plane.
- Hips, valleys add to cost and complexity of truss design making it harder to install.
- Gable ends and parapets.
- Eaves and box gutters.

Joinery

- Massive cost and a single factor to determine a high end or low end house. Million dollar houses often have $300-$400k worth of joinery where as $400k houses may only include $20k.

Number of rooms

- More rooms means more internal walls, electrical fittings, windows.
- They cost more to fit out therefore the larger number of separate rooms the more likely it will impact the total cost.

13. **B - Probing of an answer from question 2 - this will depend on the answer and guidance from the interviewer.**

Explanation of probing provided as a summary above

14. **This question will ask the interviewee about the significance of the cost drivers identified in table 5. It will only be asked if the cost drivers were not previously mentioned by the interviewee.**

- A lot of those seem to be functions of each other such as volume and compactness comparing to external walls.
- Gross floor area is the single most important factor as most costs when building up an estimate can be related back to square metres or a derivative of.
- Internal spacing is more expensive due to fitout costs, linings, conditioning of space etc. It would be relevant to separate out external vs internal floor space.

15. **Shape complexity has been identified from previous studies as a cost driver, what does that term mean to you?**

- The most efficient shape is a circle however this would not be cost effective in a build where most things need to be square or straight.
- An exact square or rectangle would be the most efficient and cost effective however when there ends up being returns walls or more complex layouts the costs can increase.
- Complexity would refer to the difference between a square/rectangular building and a building with a more complex external layout increasing the perimeter of the building while keeping the area similar.

Cost driver	Unit	Calculation definition
Gross internal floor area	m^2	Internal living area measured of outside face of wall
Gross external floor area	m^2	Floor area of alfresco, patios, porches etc.
Gross floor area	m^2	Total floor area of dwelling measured to outside face of wall
Compactness	ratio	Area of external walls / gross floor area
Internal walls	m	Length of internal walls
External walls	m	Length of external walls
Proportion of openings	m^2	The area of all external wall openings
Building volume	m^3	External wall length x wall height x internal floor area
Shape complexity	N/A	This will be further developed from interview data

Appendix H – Data analysis import template

Sample #	Total Cost ex GST	GFA (m2)	External areas (m2)	Garage area (m2)	External walls (lin m)	Internal walls (lin m)	Eaves (lin m)	Compactness (Ext wall area / GFA)	Area of external openings (m2)	No. sets of stacker SGDs	Hips / valleys / ridges (lin m)	Gable ends (m2)	No. of bedrooms (each)	No. of living areas (each)	No. of bathrooms (each)	Additional plumbing outlets (each)
A001	$256,470.60	266.20	26.20	38.80	75.90	97.40	96.00	0.7698	48.00	2	55.00	32.00	4	3	2	2
A002	$203,229.45	196.93	17.66	35.20	63.00	68.60	67.20	0.8638	39.60	0	64.50	0.00	3	2	2	0
A003	$234,250.75	257.91	3.21	36.40	67.60	65.23	73.41	0.7077	41.64	0	75.73	0.00	4	2	2	2
A004	$243,551.36	259.60	23.90	40.00	71.20	94.00	75.60	0.7405	47.59	1	93.40	0.00	4	3	2	0
A005	$257,068.89	283.60	45.20	36.20	74.30	97.90	79.80	0.7074	50.86	2	83.70	0.00	4	3	2	2
A006	$278,226.47	306.20	40.48	64.80	88.40	102.40	90.80	0.7795	67.62	1	90.80	11.20	4	2	2	0
A007	$205,565.30	205.56	19.78	36.50	63.50	78.60	70.90	0.8341	37.62	0	55.10	4.20	4	2	2	1
A008	$207,065.02	195.94	16.80	36.40	66.00	71.90	67.80	0.9095	46.04	2	65.40	0.00	3	2	2	0
A009	$260,259.71	287.34	45.20	41.80	78.30	103.30	80.30	0.7357	56.56	3	83.40	0.00	4	3	2	0
A010	$234,757.14	247.20	23.40	36.30	70.10	83.20	75.80	0.7657	48.60	2	87.10	0.00	4	2	2	-1
A011	$280,925.29	312.50	57.70	41.50	72.40	110.90	82.30	0.6255	46.74	0	93.10	0.00	4	2	2	2
A012	$278,418.73	302.80	37.60	36.10	82.50	102.10	87.30	0.7356	56.18	3	129.70	0.00	4	3	2	1
A013	$271,357.16	274.70	38.90	41.80	87.80	82.30	82.00	0.8630	60.83	1	103.60	0.00	4	3	2	1
A014	$229,310.38	236.50	20.30	38.90	74.20	93.80	76.60	0.8471	40.30	1	82.70	0.00	4	2	2	1
A015	$220,366.20	215.40	26.70	40.60	64.00	80.90	75.30	0.8022	43.61	2	56.90	0.00	4	1	2	0
A016	$247,771.20	265.95	29.20	36.30	76.00	97.40	80.80	0.7716	49.12	1	111.50	0.00	4	2	2	0
A017	$281,878.27	288.40	35.80	36.10	95.60	105.70	99.60	0.8950	58.14	1	101.70	0.00	4	3	2	4
A018	$231,603.23	225.69	21.40	36.40	67.80	85.10	76.40	0.8111	40.77	0	105.50	0.00	4	2	2	1
A019	$208,429.35	213.60	23.20	35.60	63.40	71.60	71.80	0.8014	37.53	0	73.70	0.00	4	2	2	0
A020	$235,966.18	245.91	25.50	36.20	70.00	87.00	75.40	0.7686	38.79	0	98.50	0.00	4	3	2	1
A021	$261,891.05	289.00	43.30	39.70	76.60	94.30	77.40	0.7156	45.95	2	79.00	0.00	4	3	2	2
A022	$190,778.26	177.88	16.86	36.50	57.80	61.50	67.00	0.8773	34.83	0	68.70	0.00	3	1	2	1
A023	$170,844.18	147.18	14.08	27.80	56.40	46.90	60.00	1.0347	22.20	0	61.30	0.00	3	1	2	-1
A024	$249,587.38	257.34	26.70	37.20	78.00	89.70	78.20	0.8184	53.26	1	83.50	0.00	4	3	2	3
A025	$260,647.23	276.81	34.30	36.10	75.40	106.70	82.20	0.7355	45.86	1	97.50	0.00	4	2	2	1
A026	$224,201.97	231.30	21.80	36.00	78.00	77.30	73.80	0.9105	39.66	0	83.30	0.00	4	2	2	0
A027	$171,890.92	148.58	16.00	26.20	59.40	49.20	62.20	1.0794	26.32	0	66.90	0.00	3	1	2	-1
A028	$184,135.54	169.48	16.20	35.50	64.40	52.90	65.60	1.0260	38.55	0	69.10	0.00	3	1	2	-1
A029	$195,151.61	189.14	19.50	35.40	68.40	63.20	70.80	0.9764	35.55	0	70.60	0.00	4	1	2	-1
A030	$193,732.18	179.62	11.38	35.20	65.80	67.90	61.50	0.9891	36.81	0	55.30	0.00	4	2	2	-1
A031	$202,673.75	193.20	15.80	36.40	64.80	70.60	68.40	0.9056	42.93	2	61.00	0.00	4	2	2	0
A032	$203,965.96	202.26	16.80	35.10	64.80	78.80	68.80	0.8650	37.89	0	62.80	0.00	4	2	2	0
A033	$185,377.45	173.36	15.52	35.00	58.40	59.70	67.20	0.9096	34.92	0	67.00	0.00	4	2	2	-1
A034	$280,121.54	303.90	29.60	37.10	87.80	110.10	85.60	0.7801	48.19	1	110.40	0.00	4	5	2	5
A035	$200,454.48	194.42	12.40	36.20	64.00	69.00	66.40	0.8888	35.13	0	73.70	0.00	3	2	2	0
A036	$195,578.82	185.91	12.20	35.10	62.00	72.00	64.80	0.9004	37.17	0	59.80	0.00	4	2	2	0
A037	$191,999.23	186.72	14.30	35.20	62.20	62.90	66.00	0.8994	33.30	0	60.60	0.00	3	2	2	-1
A038	$254,756.23	266.32	34.30	36.10	74.20	97.80	80.40	0.7523	47.44	2	93.00	0.00	5	2	2	1
A039	$262,318.22	282.20	34.72	36.30	79.20	103.80	78.80	0.7578	52.26	1	90.00	0.00	4	3	2	4
A040	$183,599.01	174.84	26.00	35.10	62.20	52.10	66.80	0.9605	33.30	0	65.90	0.00	3	1	2	-1
A041	$195,989.27	191.64	32.50	36.90	73.60	45.00	68.00	1.0369	41.94	0	58.80	0.00	3	1	2	0

A042	$219,545.11	223.49	20.80	36.40	69.60	82.00	73.60	0.8408	37.53	0	78.00	0.00	4	1	2	0
A043	$246,441.99	264.60	25.90	36.30	72.80	98.80	79.20	0.7429	47.10	0	96.40	0.00	4	3	2	1
A044	$223,343.53	226.98	22.30	36.20	65.40	85.10	73.80	0.7780	40.23	0	99.40	0.00	4	2	2	0
A045	$204,979.69	184.75	15.40	37.30	71.40	62.30	71.60	1.0435	42.99	2	84.90	0.00	3	1	2	1
A046	$217,497.84	218.20	19.70	37.10	67.40	73.40	72.30	0.8340	37.16	1	75.90	0.00	4	2	2	0
A047	$202,460.30	195.98	15.20	36.80	62.80	73.00	68.00	0.8652	36.00	2	70.80	0.00	3	2	2	0
A048	$282,308.33	319.31	35.60	38.90	86.00	97.00	84.60	0.7272	46.07	1	101.60	0.00	5	3	2	5
A049	$200,405.12	194.26	3.70	36.80	64.80	75.80	71.10	0.9006	42.90	1	49.60	5.60	3	2	2	-1
A050	$212,310.27	219.41	20.20	37.30	63.80	88.60	68.60	0.7851	38.52	1	61.40	0.00	4	2	2	0
A051	$188,216.85	182.40	15.10	36.40	60.00	68.50	63.60	0.8882	34.56	0	59.40	0.00	3	2	2	-1
A052	$193,490.86	189.70	12.70	36.20	61.00	76.80	57.60	0.8682	33.51	0	61.70	0.00	4	2	2	0
A053	$198,680.40	186.00	14.30	38.00	64.00	70.50	66.50	0.9290	37.38	0	61.80	0.00	3	2	2	1
A054	$225,145.75	235.00	29.00	36.00	66.00	86.80	69.80	0.7583	42.30	0	75.28	0.00	4	2	2	0
A055	$212,059.26	219.40	21.70	36.10	65.80	80.60	69.40	0.8098	39.24	0	67.00	0.00	4	2	2	0
A056	$220,947.82	232.00	32.03	37.60	65.00	83.91	70.80	0.7565	42.76	1	59.00	0.00	3	3	2	2
A057	$211,205.30	215.80	24.50	38.10	62.10	78.90	75.30	0.7770	38.04	1	64.70	0.00	4	2	2	0
A058	$195,409.85	194.70	23.40	36.20	59.00	72.30	66.60	0.8182	33.30	2	45.20	4.00	3	2	2	-1
A059	$220,877.22	217.20	21.70	36.40	64.10	69.70	71.80	0.7968	48.44	0	81.00	0.00	4	3	2	0
A060	$201,553.35	181.03	11.41	37.01	61.20	74.30	66.00	0.9128	35.04	0	85.10	0.00	4	1	2	0
A061	$278,418.73	302.80	37.60	36.10	82.50	102.10	87.30	0.7356	56.18	3	129.70	0.00	4	4	2	1
A062	$299,487.03	338.10	50.00	43.40	80.80	114.60	85.80	0.6453	50.11	1	99.80	0.00	4	3	2	1
A063	$207,665.88	202.14	19.10	36.40	62.00	78.50	69.10	0.8281	38.64	0	55.20	4.60	4	2	2	1
A064	$263,623.87	278.70	38.19	36.30	79.60	100.00	81.62	0.7712	52.82	1	83.30	5.38	4	2	2	2
A065	$260,550.93	277.80	33.60	37.30	76.70	111.40	84.60	0.7455	54.50	1	84.80	0.00	4	2	2	3
A066	$224,085.01	213.00	27.10	36.30	71.30	69.40	71.40	0.9038	52.89	2	63.40	0.00	4	2	2	2
A067	$224,904.99	224.61	20.40	36.40	69.60	86.30	74.20	0.8367	40.74	1	70.80	0.00	4	2	2	2
A068	$206,649.08	208.00	14.40	38.40	63.40	84.80	69.80	0.8230	35.82	0	70.20	0.00	4	2	2	1
A069	$230,316.90	233.63	22.60	41.10	67.00	85.28	75.00	0.7743	43.08	0	100.60	0.00	4	2	2	0
A070	$256,810.91	272.10	35.30	42.10	70.40	97.00	88.50	0.6986	51.22	1	80.00	13.50	4	3	2	1
A071	$200,975.03	193.40	12.34	36.30	61.20	71.75	75.50	0.8544	37.72	0	50.20	3.02	3	3	2	-1
A072	$245,905.31	266.75	49.30	38.70	70.00	86.60	75.20	0.7085	42.56	1	62.70	6.60	4	2	2	2
A073	$301,898.33	303.43	33.60	44.60	81.90	113.60	93.20	0.7288	59.07	1	28.50	59.40	5	2	2	4
A074	$278,226.47	306.20	40.48	64.80	88.40	102.40	90.80	0.7795	67.62	1	90.80	11.20	4	2	2	0
A075	$206,692.68	200.46	2.50	35.10	60.40	89.40	67.80	0.8135	45.78	0	62.30	0.00	4	3	2	0
A076	$201,247.68	217.02	19.67	38.00	65.57	68.10	70.61	0.8158	53.79	1	87.66	0.00	4	2	2	0
A077	$198,931.60	192.71	13.22	36.50	61.20	74.20	52.10	0.8575	37.32	1	18.20	21.00	4	2	2	0
A078	$200,073.29	189.30	13.10	38.50	60.60	80.50	64.00	0.8643	34.80	0	61.90	1.80	4	2	2	-1
A079	$238,404.83	259.00	37.90	36.30	70.20	90.60	76.20	0.7318	40.86	0	87.20	0.00	4	3	2	-1
A080	$231,469.51	244.67	30.29	36.70	61.80	73.80	80.50	0.6820	37.08	2	96.52	0.00	4	2	2	0
A081	$273,300.74	299.70	28.79	36.40	74.20	100.70	85.20	0.6685	51.29	1	82.20	0.00	4	2	2	2
A082	$199,597.73	198.90	19.42	36.40	64.40	69.50	68.00	0.8742	39.24	0	67.60	0.00	3	2	2	1
A083	$248,167.15	263.03	27.60	36.50	74.60	102.00	80.80	0.7658	46.26	1	94.30	0.00	4	3	2	1
A084	$212,801.61	209.06	18.50	36.40	64.40	71.10	68.80	0.8317	37.98	0	64.60	0.00	4	3	2	1
A085	$225,102.24	223.00	21.60	42.31	65.10	76.07	97.58	0.7882	47.19	0	3.00	39.91	4	1	2	1
A086	$251,753.48	241.93	22.23	49.85	76.70	80.90	86.30	0.8560	52.16	1	51.40	30.00	3	2	2	2
A087	$204,517.60	204.19	18.38	41.08	63.00	61.80	65.00	0.8330	39.21	1	71.50	0.00	4	1	2	0
A088	$180,817.92	169.40	16.85	37.76	56.20	46.60	60.90	0.8957	38.66	1	48.70	11.00	3	1	2	-1

A089	$206,003.35	199.50	14.24	37.08	59.20	71.80	70.90	0.8012	44.60	1	52.40	0.00	3	2	2	0
A090	$217,580.32	219.94	20.90	41.01	65.80	78.60	69.00	0.8078	44.06	1	74.80	0.00	3	3	2	0
A091	$272,929.53	263.62	27.32	38.35	81.30	84.90	85.50	0.8327	60.35	1	111.70	0.00	3	3	2	4
A092	$378,428.20	398.22	50.33	57.82	113.00	115.60	122.50	0.7662	74.66	1	149.70	5.30	4	4	3	7
A093	$242,508.38	242.90	24.33	38.61	75.00	76.60	80.70	0.8337	42.44	0	83.30	4.10	4	2	2	1
A094	$164,693.01	147.12	12.30	42.07	55.80	45.20	57.90	1.0241	35.25	1	48.30	0.00	2	2	2	-1
A095	$270,429.51	288.64	54.00	38.27	77.20	81.10	83.80	0.7221	55.34	1	90.90	0.00	4	2	2	1
A096	$176,848.06	166.04	22.95	23.73	52.20	57.40	60.20	0.8488	41.12	0	35.20	6.80	3	1	2	-1
A097	$290,608.17	294.75	48.29	44.96	76.20	101.50	81.88	0.6980	56.90	0	124.83	1.74	4	2	2	4
A098	$225,288.57	228.80	27.33	38.88	73.20	69.80	81.00	0.8638	41.98	1	45.60	13.10	4	2	2	1
A099	$171,373.88	156.60	22.35	40.89	56.40	44.62	67.59	0.9724	34.47	0	18.20	22.77	3	1	2	-1
A100	$205,110.72	204.37	16.96	42.88	64.20	70.50	69.00	0.8482	43.86	1	75.10	0.00	3	2	2	-1
A101	$221,715.00	226.71	18.25	42.88	63.30	88.60	70.70	0.7539	44.37	1	77.60	0.00	4	2	2	-1
A102	$183,803.64	178.08	14.28	35.20	63.00	54.90	67.80	0.9552	38.43	0	52.10	0.00	3	1	2	0
A103	$254,085.63	263.25	33.97	0.00	70.80	89.10	79.20	0.7262	44.42	2	72.20	0.00	4	3	2	1
A104	$217,552.36	208.43	18.90	39.40	67.20	82.60	71.30	0.8705	39.60	1	51.80	4.90	3	2	2	0
A105	$208,851.94	202.20	13.20	35.90	64.40	78.10	66.40	0.8599	37.14	0	83.50	0.00	4	2	2	2
A106	$316,051.06	362.05	60.57	40.71	84.80	67.80	97.40	0.6324	68.70	1	74.00	40.90	4	2	2	3
A107	$188,122.95	181.47	17.54	36.40	59.60	60.30	62.40	0.8868	33.54	0	52.03	13.36	4	1	2	0
A108	$160,631.84	124.51	18.40	0.00	45.40	51.60	50.20	0.9845	24.24	0	47.60	0.00	3	2	2	-1
A109	$302,408.13	320.54	47.84	43.80	77.80	111.00	89.60	0.6553	64.45	2	114.80	10.50	4	5	2	5
A110	$268,423.72	282.30	44.50	42.80	81.00	93.90	85.00	0.7747	63.02	1	98.70	0.00	4	2	2	1
A111	$231,212.12	223.40	27.10	38.40	70.60	71.20	77.20	0.8533	47.34	2	94.20	0.00	3	3	2	1
A112	$209,824.03	205.00	17.65	38.60	64.80	74.50	69.40	0.8535	40.90	1	69.42	0.00	4	1	2	0
A113	$213,738.73	220.62	31.58	44.38	66.80	54.10	70.20	0.8175	41.04	0	77.10	0.00	3	2	2	-1
A114	$253,435.57	269.03	32.19	32.97	73.40	85.90	98.00	0.7366	47.24	1	0.00	31.98	4	3	2	1
A115	$249,372.21	261.40	30.54	37.39	78.00	46.80	111.20	0.8057	54.60	1	0.00	38.96	4	1	2	2
A116	$245,260.86	254.46	32.50	51.19	74.00	83.30	79.40	0.7852	49.23	1	89.50	0.00	4	1	2	1
A117	$216,917.47	223.90	19.22	41.90	66.20	88.10	74.20	0.7983	35.82	0	59.00	3.90	4	2	2	1
A118	$171,521.63	149.50	11.90	26.20	57.20	55.00	59.50	1.0330	27.60	0	62.50	0.00	3	2	2	-1
A119	$250,703.41	236.92	22.36	42.36	71.20	69.60	78.40	0.8114	48.39	0	103.00	0.00	4	1	2	0
A120	$328,966.90	348.67	46.70	48.50	101.20	98.50	120.20	0.7837	55.36	1	0.00	76.24	4	3	2	4
A121	$253,453.87	255.40	21.60	39.60	78.00	100.80	74.40	0.8246	52.38	3	63.40	0.00	4	2	3	2
A122	$187,947.80	176.35	12.52	35.70	59.10	70.10	63.80	0.9048	32.79	0	79.00	0.00	4	1	2	0
A123	$279,634.12	262.63	25.36	38.97	80.00	80.30	90.40	0.8224	57.58	1	3.50	45.10	4	2	2	5
A124	$216,718.63	207.59	24.30	39.12	74.00	58.00	71.20	0.9625	43.89	0	85.50	0.00	3	1	2	1
A125	$351,833.15	384.00	52.90	39.40	95.40	133.00	75.70	0.6708	58.74	1	25.00	47.75	5	3	2	6
A126	$233,316.47	221.72	5.04	0.00	68.60	86.90	82.00	0.8354	50.44	2	111.40	0.00	4	2	2	1
A127	$198,179.27	194.20	13.70	36.50	61.20	68.20	68.50	0.8509	33.27	0	54.30	3.30	4	2	2	0
A128	$212,034.02	213.10	20.40	36.10	61.80	71.40	111.80	0.7830	41.64	1	0.00	23.60	3	2	2	3
A129	$202,813.65	206.84	25.30	36.50	61.00	67.90	65.80	0.7963	29.58	1	55.60	0.00	3	2	2	-1
A130	$198,228.63	199.40	31.00	36.80	61.00	52.70	71.70	0.8260	39.39	1	91.30	0.00	3	1	2	-1
A131	$243,569.25	281.20	3.50	42.40	71.90	89.30	79.10	0.6904	52.22	2	74.80	7.50	4	2	2	2
A132	$188,887.72	178.89	12.30	39.29	63.70	51.00	65.90	0.9614	36.45	1	56.90	0.00	3	2	2	0
A133	$205,228.36	192.60	15.60	36.40	62.90	63.90	66.60	0.8818	39.72	0	79.50	0.00	3	2	2	2
A134	$259,458.61	278.51	55.80	39.96	72.80	69.50	79.20	0.7058	43.26	0	98.40	0.00	4	2	2	2
A135	$271,885.65	278.20	40.68	38.35	76.80	77.30	94.80	0.7454	60.08	1	64.50	23.35	4	2	2	4

A136	$312,382.14	303.73	41.18	40.96	80.70	84.00	92.80	0.7174	71.83	1	3.00	47.00	4	2	2	3
A137	$193,899.80	179.19	3.75	36.76	57.60	58.30	65.50	0.8679	34.90	0	58.20	1.90	4	2	2	0
A138	$264,662.45	265.58	32.40	36.90	74.80	93.00	79.60	0.7604	53.22	2	108.30	0.00	4	3	2	3
A139	$203,082.35	192.44	15.30	36.20	66.00	72.60	70.50	0.9260	43.56	2	80.70	0.00	3	2	2	1
A140	$183,429.29	161.68	14.17	39.92	63.40	46.00	57.70	1.0588	37.78	1	55.60	0.00	3	1	2	0
A141	$259,313.59	266.84	34.30	36.40	74.20	88.40	80.40	0.7508	48.86	2	93.10	0.00	5	2	2	1
A142	$279,962.98	279.81	49.20	40.50	79.00	103.10	93.00	0.7623	42.53	2	80.40	18.50	3	2	3	2
A143	$203,129.98	205.25	10.73	61.52	71.60	54.10	71.40	0.9419	48.97	1	60.30	0.00	4	1	2	1
A144	$277,234.56	314.60	66.90	39.60	72.00	83.80	78.60	0.6179	48.32	2	72.20	0.00	4	2	2	1
A145	$191,923.59	163.66	17.80	0.00	55.20	66.30	65.60	0.9107	33.48	1	102.70	0.00	3	2	2	0
A146	$270,437.18	290.40	31.70	42.50	74.30	95.30	108.25	0.6908	43.77	1	0.00	47.70	4	3	2	3
A147	$198,109.12	180.74	16.89	40.80	62.80	51.00	84.50	0.9381	41.31	1	12.70	33.68	3	1	2	0
A148	$236,707.70	242.10	23.30	36.90	72.00	88.90	76.80	0.8030	41.40	1	84.40	0.00	4	1	2	1
A149	$193,128.89	190.16	19.85	36.40	61.00	58.92	70.93	0.8661	36.96	0	41.23	12.00	3	2	2	0
A150	$200,523.95	201.45	20.67	45.13	61.60	67.20	66.40	0.8256	36.42	0	59.30	0.00	3	1	2	1
A151	$216,317.52	215.32	19.70	38.80	66.80	85.20	70.60	0.8376	39.69	1	67.90	0.00	5	3	2	0
A152	$265,935.84	271.81	40.12	43.35	77.00	75.00	81.80	0.7649	54.78	1	105.90	0.00	3	2	2	1
A153	$255,059.40	271.60	21.60	39.60	65.00	94.60	86.00	0.6462	33.81	1	142.60	0.00	4	3	2	0
A154	$269,203.96	275.35	33.05	56.36	88.33	72.60	93.40	0.8661	53.43	0	135.10	0.00	5	2	3	0
A155	$199,387.26	194.10	12.50	35.60	63.10	80.40	67.80	0.8777	37.85	0	76.30	0.00	4	2	2	0
A156	$245,478.85	264.43	36.28	43.63	73.60	79.39	82.67	0.7515	53.16	0	116.98	0.00	4	2	2	0
A157	$183,721.57	181.94	14.04	38.98	60.10	58.10	59.60	0.8919	37.55	1	49.40	0.00	3	2	2	0
A158	$188,421.97	187.13	33.10	36.60	58.00	65.30	67.00	0.8369	36.54	0	60.60	0.00	3	1	2	0
A159	$245,482.13	254.61	23.40	39.70	67.80	91.00	74.40	0.7190	49.21	1	60.90	0.00	4	2	2	3
A160	$207,043.49	194.00	26.50	38.10	77.80	62.00	69.80	1.0828	36.23	1	70.20	0.00	4	1	2	1
A161	$280,676.14	303.80	42.30	42.80	80.77	111.05	82.80	0.7178	62.49	1	104.78	11.41	5	3	2	1
A162	$255,271.86	258.40	45.53	35.30	72.80	86.41	82.11	0.7607	52.02	1	93.30	3.20	4	2	2	2
A163	$194,923.58	202.88	27.48	49.45	66.00	62.00	73.20	0.8784	43.41	1	86.40	1.20	3	1	1	0
A164	$186,313.70	182.00	19.90	38.00	54.00	61.00	61.30	0.8011	38.63	0	51.50	2.85	3	1	2	-1
A165	$265,061.52	288.70	61.90	38.40	73.30	99.90	99.90	0.6855	55.48	1	83.70	9.80	4	3	2	2
A166	$171,952.71	155.50	15.60	38.30	56.00	48.90	60.20	0.9723	30.72	0	57.20	0.30	3	1	2	-1
A167	$313,855.80	327.64	50.30	52.00	91.40	100.50	96.60	0.7532	57.10	1	65.50	28.20	4	3	2	2
A168	$177,432.47	162.50	23.00	23.50	51.80	54.00	60.50	0.8607	33.60	0	31.00	9.60	3	1	2	-1
A169	$281,305.34	325.50	38.20	41.00	78.40	102.70	96.50	0.6503	61.39	1	126.40	7.50	4	2	2	2
A170	$215,975.56	219.94	20.90	41.01	65.80	78.60	69.00	0.8078	44.06	1	74.80	0.00	3	3	2	1

Appendix I – Linear regression SPSS data output

```
REGRESSION
 /DESCRIPTIVES MEAN STDDEV CORR SIG N
 /MISSING LISTWISE
 /STATISTICS COEFF OUTS CI(95) BCOV R ANOVA COLLIN TOL CHANGE ZPP
 /CRITERIA=PIN(.05) POUT(.10)
 /NOORIGIN
 /DEPENDENT TotalCostexGST
 /METHOD=ENTER GFAm2 Externalareasm2 Garageaream2 Externalwallslinm Internalwallslinm
  Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach
  Additionalplumbingoutletseach
 /SCATTERPLOT=(*ZRESID ,*ZPRED)
 /RESIDUALS DURBIN HISTOGRAM(ZRESID) NORMPROB(ZRESID).
```

Regression

Notes

Output Created		26-JUL-2021 10:44:43
Comments		
Input	Active Dataset	DataSet4
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	170
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.

Syntax		REGRESSION /DESCRIPTIVES MEAN STDDEV CORR SIG N /MISSING LISTWISE /STATISTICS COEFF OUTS CI(95) BCOV R ANOVA COLLIN TOL CHANGE ZPP /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT TotalCostexGST /METHOD=ENTER GFAm2 Externalareasm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach /SCATTERPLOT=(*ZRESID ,*ZPRED) /RESIDUALS DURBIN HISTOGRAM(ZRESID) NORMPROB(ZRESID).
Resources	Processor Time	00:00:00.59
	Elapsed Time	00:00:00.56
	Memory Required	9280 bytes
	Additional Memory Required for Residual Plots	536 bytes

Descriptive Statistics

	Mean	Std. Deviation	N

TotalCostexGST	229763.4036182353700	38952.37408782187400	170
GFAm2	232.944823529411700	50.837316108743110	170
Externalareasm2	25.971294117647050	12.698730010417580	170
Garageaream2	37.933529411764720	8.080665170623119	170
Externalwallslinm	69.489235294117600	9.803135291422954	170
Internalwallslinm	78.943705882352920	17.712517147485425	170
Areaofexternalopeningsm2	44.374176470588246	9.422153906035970	170
Hipsvalleysridgeslinm	72.348588235294120	28.006933615437188	170
Gableendsm2	5.437647058823529	12.664206574385911	170
No.ofbathroomseach	2.02	.171	170
Additionalplumbingoutletseach	.85	1.558	170

Correlations

		TotalCostexGST	GFAm2	Externalareasm2	Garageaream2	Externalwallslinm	Internalwallslinm	Areaofexternalopeningsm2	Hipsvalleysridgeslinm	Gableendsm2	No.ofbathroomseach	Additionalplumbingoutletseach
Pearson Correlation	TotalCostexGST	1.000	.979	.773	.363	.905	.806	.850	.329	.412	.264	.767
	GFAm2	.979	1.000	.792	.389	.878	.821	.827	.355	.354	.209	.718
	Externalareasm2	.773	.792	1.000	.279	.663	.551	.646	.274	.269	.133	.504
	Garageaream2	.363	.389	.279	1.000	.457	.223	.433	.082	.196	.133	.208
	Externalwallslinm	.905	.878	.663	.457	1.000	.684	.821	.338	.345	.296	.713
	Internalwallslinm	.806	.821	.551	.223	.684	1.000	.622	.386	.161	.182	.602
	Areaofexternalopeningsm2	.850	.827	.646	.433	.821	.622	1.000	.286	.356	.171	.645
	Hipsvalleysridgeslinm	.329	.355	.274	.082	.338	.386	.286	1.000	-.596	.155	.111
	Gableendsm2	.412	.354	.269	.196	.345	.161	.356	-.596	1.000	.017	.412
	No.ofbathroomseach	.264	.209	.133	.133	.296	.182	.171	.155	.017	1.000	.188
	Additionalplumbingoutletseach	.767	.718	.504	.208	.713	.602	.645	.111	.412	.188	1.000
Sig. (1-tailed)	TotalCostexGST	.	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
	GFAm2	.000	.	.000	.000	.000	.000	.000	.000	.000	.003	.000
	Externalareasm2	.000	.000	.	.000	.000	.000	.000	.000	.000	.042	.000
	Garageaream2	.000	.000	.000	.	.000	.002	.000	.144	.005	.042	.003
	Externalwallslinm	.000	.000	.000	.000	.	.000	.000	.000	.000	.000	.000
	Internalwallslinm	.000	.000	.000	.002	.000	.	.000	.000	.018	.009	.000
	Areaofexternalopeningsm2	.000	.000	.000	.000	.000	.000	.	.000	.000	.013	.000
	Hipsvalleysridgeslinm	.000	.000	.000	.144	.000	.000	.000	.	.000	.022	.074

	Gableendsm2	.000	.000	.000	.005	.000	.018	.000	.000	.	.412	.000
	No.ofbathroomseach	.000	.003	.042	.042	.000	.009	.013	.022	.412	.	.007
	Additionalplumbingoutletseach	.000	.000	.000	.003	.000	.000	.000	.074	.000	.007	.
N	TotalCostexGST	170	170	170	170	170	170	170	170	170	170	170
	GFAm2	170	170	170	170	170	170	170	170	170	170	170
	Externalareasm2	170	170	170	170	170	170	170	170	170	170	170
	Garageaream2	170	170	170	170	170	170	170	170	170	170	170
	Externalwallslinm	170	170	170	170	170	170	170	170	170	170	170
	Internalwallslinm	170	170	170	170	170	170	170	170	170	170	170
	Areaofexternalopeningsm2	170	170	170	170	170	170	170	170	170	170	170
	Hipsvalleysridgeslinm	170	170	170	170	170	170	170	170	170	170	170
	Gableendsm2	170	170	170	170	170	170	170	170	170	170	170
	No.ofbathroomseach	170	170	170	170	170	170	170	170	170	170	170
	Additionalplumbingoutletseach	170	170	170	170	170	170	170	170	170	170	170

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Additionalplumbing outletseach, Hipsvalleysridgeslin m, Garageaream2, No.ofbathroomseac h, Externalareasm2, Internalwallslinm, Areaofexternalopen ingsm2, Gableendsm2, Externalwallslinm, GFAm2[b]	.	Enter

a. Dependent Variable: TotalCostexGST

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.992[a]	.983	.982	5202.96020881481 300	.983	931.326	10	159	.000	1.959

a. Predictors: (Constant), Additionalplumbingoutletseach, Hipsvalleysridgeslinm, Garageaream2, No.ofbathroomseach, Externalareasm2, Internalwallslinm, Areaofexternalopeningsm2, Gableendsm2, Externalwallslinm, GFAm2

b. Dependent Variable: TotalCostexGST

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	252117322161.530	10	25211732216.153	931.326	.000[b]
	Residual	4304256394.587	159	27070794.935		
	Total	256421578556.117	169			

a. Dependent Variable: TotalCostexGST

b. Predictors: (Constant), Additionalplumbingoutletseach, Hipsvalleysridgeslinm, Garageaream2, No.ofbathroomseach, Externalareasm2, Internalwallslinm, Areaofexternalopeningsm2, Gableendsm2, Externalwallslinm, GFAm2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	34911.766	5738.616		6.084	.000	23578.022	46245.510					
	GFAm2	448.781	30.635	.586	14.649	.000	388.277	509.285	.979	.758	.151	.066	15.142
	Externalareasm2	137.002	55.328	.045	2.476	.014	27.729	246.274	.773	.193	.025	.324	3.082
	Garageaream2	-185.313	58.579	-.038	-3.163	.002	-301.006	-69.619	.363	-.243	-.033	.715	1.399
	Externalwallslinm	470.019	101.773	.118	4.618	.000	269.017	671.020	.905	.344	.047	.161	6.214
	Internalwallslinm	134.711	44.257	.061	3.044	.003	47.305	222.118	.806	.235	.031	.261	3.836
	Areaofexternalopeningsm2	328.761	83.295	.080	3.947	.000	164.253	493.269	.850	.299	.041	.260	3.845
	Hipsvalleysridgeslinm	132.503	28.155	.095	4.706	.000	76.897	188.110	.329	.350	.048	.258	3.882
	Gableendsm2	443.071	62.785	.144	7.057	.000	319.072	567.071	.412	.488	.073	.253	3.947
	No.ofbathroomseach	11000.077	2485.330	.048	4.426	.000	6091.560	15908.593	.264	.331	.045	.886	1.129
	Additionalplumbingoutletseach	2015.819	408.810	.081	4.931	.000	1208.421	2823.217	.767	.364	.051	.395	2.531

a. Dependent Variable: TotalCostexGST

Coefficient Correlations[a]

Model			Additionalplumbingoutletseach	Hipsvalleysridgeslinm	Garageaream2	No.ofbathroomseach	Externalareasm2	Internalwallslinm	Areaofexternalopeningsm2	Gableendsm2	Externalwallslinm	GFAm2
1	Correlations	Additionalplumbingoutletseach	1.000	.122	.217	-.018	.118	-.061	-.075	-.044	-.256	-.174
		Hipsvalleysridgeslinm	.122	1.000	.116	-.024	.055	.026	-.101	.816	-.195	-.254
		Garageaream2	.217	.116	1.000	-.017	.099	.135	-.136	.065	-.233	-.116
		No.ofbathroomseach	-.018	-.024	-.017	1.000	.019	-.017	.091	.021	-.231	.043
		Externalareasm2	.118	.055	.099	.019	1.000	.314	.007	.078	.065	-.598
		Internalwallslinm	-.061	.026	.135	-.017	.314	1.000	.102	.161	.086	-.647
		Areaofexternalopeningsm2	-.075	-.101	-.136	.091	.007	.102	1.000	-.107	-.260	-.245
		Gableendsm2	-.044	.816	.065	.021	.078	.161	-.107	1.000	-.138	-.296
		Externalwallslinm	-.256	-.195	-.233	-.231	.065	.086	-.260	-.138	1.000	-.337
		GFAm2	-.174	-.254	-.116	.043	-.598	-.647	-.245	-.296	-.337	1.000
	Covariances	Additionalplumbingoutletseach	167125.649	1402.916	5184.879	-18234.355	2671.808	-1105.799	-2544.464	-1131.004	-10646.852	-2178.493
		Hipsvalleysridgeslinm	1402.916	792.720	190.894	-1652.849	85.599	31.910	-235.856	1442.029	-557.611	-219.243
		Garageaream2	5184.879	190.894	3431.530	-2504.457	319.668	350.572	-664.523	237.523	-1390.768	-208.791
		No.ofbathroomseach	-18234.355	-1652.849	-2504.457	6176863.136	2620.107	-1820.396	18798.739	3317.107	-58427.599	3255.829
		Externalareasm2	2671.808	85.599	319.668	2620.107	3061.200	768.147	33.447	269.405	365.488	-1013.078
		Internalwallslinm	-1105.799	31.910	350.572	-1820.396	768.147	1958.643	376.076	448.726	385.636	-877.026
		Areaofexternalopeningsm2	-2544.464	-235.856	-664.523	18798.739	33.447	376.076	6938.109	-558.016	-2203.172	-625.828
		Gableendsm2	-1131.004	1442.029	237.523	3317.107	269.405	448.726	-558.016	3941.896	-882.094	-568.490
		Externalwallslinm	-10646.852	-557.611	-1390.768	-58427.599	365.488	385.636	-2203.172	-882.094	10357.778	-1050.126

GFAm2	-2178.493	-219.243	-208.791	3255.829	-1013.078	-877.026	-625.828	-568.490	-1050.126	938.506

a. Dependent Variable: TotalCostexGST

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	GFAm2	Externalareasm2	Garageaream2	Externalwallslinm	Internalwallslinm	Areaofexternalopeningsm2	Hipsvalleysridgeslinm	Gableendsm2	No.ofbathroomseach	Additionalplumbingoutletseach
1	1	9.208	1.000	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	2	1.074	2.927	.00	.00	.00	.00	.00	.00	.00	.00	.12	.00	.08
	3	.499	4.295	.00	.00	.00	.00	.00	.00	.00	.00	.13	.00	.36
	4	.111	9.104	.00	.00	.44	.01	.00	.00	.00	.00	.00	.00	.13
	5	.038	15.588	.00	.00	.10	.24	.00	.02	.00	.43	.37	.00	.08
	6	.029	17.766	.02	.00	.02	.45	.00	.06	.00	.23	.09	.02	.00
	7	.019	22.212	.02	.01	.04	.09	.00	.37	.00	.09	.04	.06	.10
	8	.012	27.432	.00	.00	.04	.13	.00	.03	.72	.12	.12	.02	.06
	9	.004	50.125	.06	.16	.09	.05	.30	.18	.26	.05	.06	.42	.02
	10	.003	54.417	.81	.13	.10	.02	.08	.05	.02	.08	.05	.46	.15
	11	.002	66.147	.08	.70	.17	.00	.61	.29	.00	.00	.01	.01	.01

a. Dependent Variable: TotalCostexGST

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	155860.9531250000000	372330.9375000000000	229763.4036182354600	38624.06599943295400	170
Residual	-18003.94140625000000	20980.08593750000000	-.00000000011967	5046.67937846619900	170
Std. Predicted Value	-1.913	3.691	.000	1.000	170
Std. Residual	-3.460	4.032	.000	.970	170

a. Dependent Variable: TotalCostexGST

Appendix J – Multilayered Perceptron Neural Network detailed output

```
*Multilayer Perceptron Network.
MLP TotalCostexGST (MLEVEL=S) WITH GFAm2 Externalareasm2 Garageaream2 Externalwallslinm
    Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach
    Additionalplumbingoutletseach
 /RESCALE COVARIATE=STANDARDIZED
  /PARTITION  TRAINING=7  TESTING=3  HOLDOUT=0
  /ARCHITECTURE   AUTOMATIC=YES (MINUNITS=1 MAXUNITS=50)
  /CRITERIA TRAINING=BATCH OPTIMIZATION=SCALEDCONJUGATE
LAMBDAINITIAL=0.0000005
    SIGMAINITIAL=0.00005 INTERVALCENTER=0 INTERVALOFFSET=0.5 MEMSIZE=1000
  /PRINT CPS NETWORKINFO SUMMARY
  /PLOT NETWORK PREDICTED RESIDUAL
  /SAVE PREDVAL
  /STOPPINGRULES  ERRORSTEPS= 1 (DATA=AUTO) TRAININGTIMER=ON (MAXTIME=15)
MAXEPOCHS=AUTO
    ERRORCHANGE=1.0E-4 ERRORRATIO=0.001
 /MISSING USERMISSING=EXCLUDE .
```

Multilayer Perceptron

Notes

Output Created		26-JUL-2021 08:22:45
Comments		
Input	Data	C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\With Cabinetry\Data formated prior to MLP.sav
	Active Dataset	DataSet2
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	190
Missing Value Handling	Definition of Missing	User- and system-missing values are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables used by the procedure.
Weight Handling		not applicable

Syntax	MLP TotalCostexGST (MLEVEL=S) WITH GFAm2 Externalareasm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach /RESCALE COVARIATE=STANDARDIZED /PARTITION TRAINING=7 TESTING=3 HOLDOUT=0 /ARCHITECTURE AUTOMATIC=YES (MINUNITS=1 MAXUNITS=50) /CRITERIA TRAINING=BATCH OPTIMIZATION=SCALEDCONJUGATE LAMBDAINITIAL=0.0000005 SIGMAINITIAL=0.00005 INTERVALCENTER=0 INTERVALOFFSET=0.5 MEMSIZE=1000 /PRINT CPS NETWORKINFO SUMMARY /PLOT NETWORK PREDICTED RESIDUAL /SAVE PREDVAL /STOPPINGRULES ERRORSTEPS= 1 (DATA=AUTO) TRAININGTIMER=ON (MAXTIME=15) MAXEPOCHS=AUTO

		ERRORCHANGE=1.0E-4 ERRORRATIO=0.001 /MISSING USERMISSING=EXCLUDE .
Resources	Processor Time	00:00:00.95
	Elapsed Time	00:00:00.69
Variables Created or Modified	Predicted Value	MLP_PredictedValue

Case Processing Summary

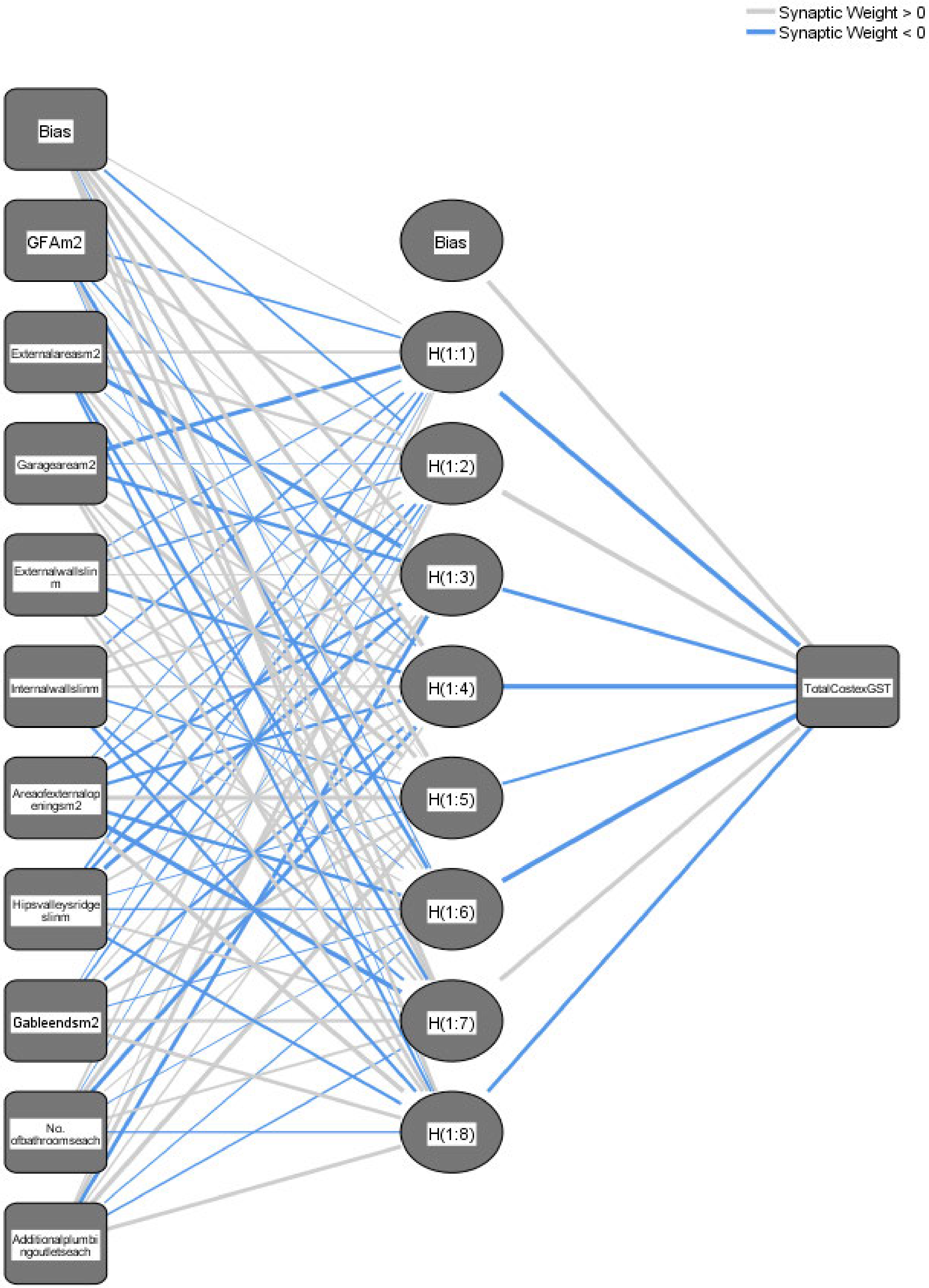
		N	Percent
Sample	Training	122	71.8%
	Testing	48	28.2%
Valid		170	100.0%
Excluded		20	
Total		190	

Network Information

Input Layer	Covariates	1	GFA (m2)
		2	External areas (m2)
		3	Garage area (m2)
		4	External walls (lin m)
		5	Internal walls (lin m)
		6	Area of external openings (m2)
		7	Hips / valleys / ridges (lin m)
		8	Gable ends (m2)
		9	No. of bathrooms (each)
		10	Additional plumbing outlets (each)
	Number of Units[a]		10
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		1
	Number of Units in Hidden Layer 1[a]		8
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	Total Cost ex GST
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity

Error Function	Sum of Squares

a. Excluding the bias unit



Hidden layer activation function: Hyperbolic tangent

Output layer activation function: Identity

Model Summary

Training	Sum of Squares Error	1.264
	Relative Error	.021
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.02
Testing	Sum of Squares Error	.945
	Relative Error	.041

Dependent Variable: Total Cost ex GST

a. Error computations are based on the testing sample.

Appendix K – Radial Basis Function Neural Network detailed output

```
*Radial Basis Function Network.
RBF TotalCostexGST (MLEVEL=S) WITH GFAm2 Externalareasm2 Garageaream2 Externalwallslinm
    Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach
    Additionalplumbingoutletseach
 /RESCALE COVARIATE=STANDARDIZED  DEPENDENT=STANDARDIZED
  /PARTITION  TRAINING=7  TESTING=3  HOLDOUT=0
  /ARCHITECTURE MINUNITS=AUTO MAXUNITS=AUTO HIDDENFUNCTION=NRBF
  /CRITERIA OVERLAP=AUTO
  /PRINT CPS NETWORKINFO SUMMARY CLASSIFICATION
  /PLOT NETWORK PREDICTED RESIDUAL
  /SAVE PREDVAL
 /MISSING USERMISSING=EXCLUDE .
```

Radial Basis Function

Notes

Output Created		26-JUL-2021 08:28:47
Comments		
Input	Data	C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\With Cabinetry\Data formated prior to MLP.sav
	Active Dataset	DataSet2
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	190
Missing Value Handling	Definition of Missing	User- and system-missing values are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables used by the procedure.
Weight Handling		not applicable

Syntax		RBF TotalCostexGST (MLEVEL=S) WITH GFAm2 Externalareasm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach /RESCALE COVARIATE=STANDARDIZED DEPENDENT=STANDARDIZED /PARTITION TRAINING=7 TESTING=3 HOLDOUT=0 /ARCHITECTURE MINUNITS=AUTO MAXUNITS=AUTO HIDDENFUNCTION=NRBF /CRITERIA OVERLAP=AUTO /PRINT CPS NETWORKINFO SUMMARY CLASSIFICATION /PLOT NETWORK PREDICTED RESIDUAL /SAVE PREDVAL /MISSING USERMISSING=EXCLUDE .
Resources	Processor Time	00:00:00.83
	Elapsed Time	00:00:00.74
Variables Created or Modified	Predicted Value	RBF_PredictedValue

Case Processing Summary

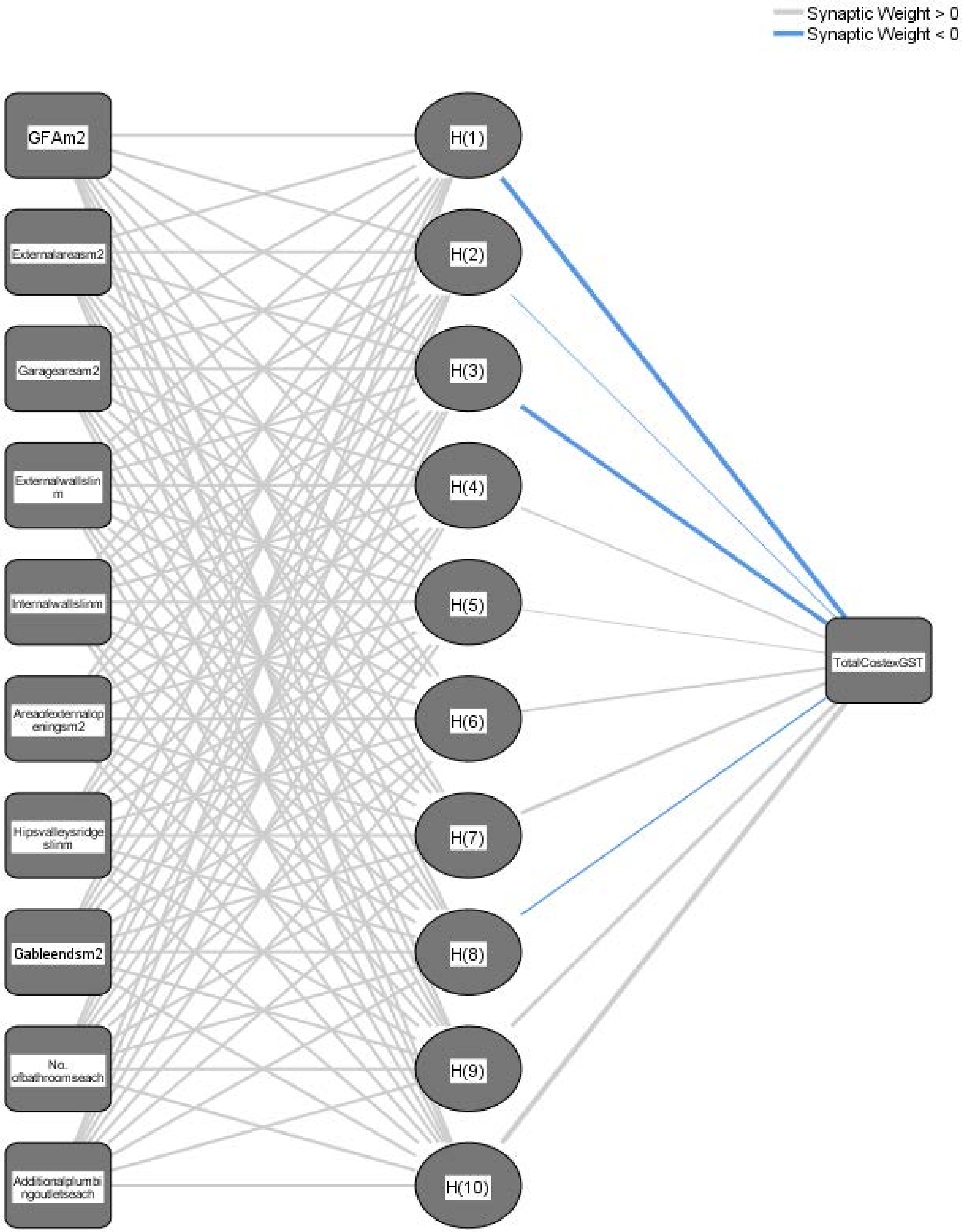
		N	Percent
Sample	Training	116	68.2%
	Testing	54	31.8%
Valid		170	100.0%
Excluded		20	
Total		190	

Network Information

Input Layer	Covariates	1	GFA (m2)
		2	External areas (m2)
		3	Garage area (m2)
		4	External walls (lin m)
		5	Internal walls (lin m)
		6	Area of external openings (m2)
		7	Hips / valleys / ridges (lin m)
		8	Gable ends (m2)
		9	No. of bathrooms (each)
		10	Additional plumbing outlets (each)

	Number of Units		10
	Rescaling Method for Covariates		Standardized
Hidden Layer	Number of Units		10[a]
	Activation Function		Softmax
Output Layer	Dependent Variables	1	Total Cost ex GST
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

a. Determined by the testing data criterion: The "best" number of hidden units is the one that yields the smallest error in the testing data.



Hidden layer activation function: Softmax

Output layer activation function: Identity

Model Summary

Training	Sum of Squares Error	4.233
	Relative Error	.074
	Training Time	0:00:00.23
Testing	Sum of Squares Error	5.610[a]
	Relative Error	.165

Dependent Variable: Total Cost ex GST

a. The number of hidden units is determined by the testing data criterion: The "best" number of hidden units is the one that yields the smallest error in the testing data.

Appendix L – Linear regression sample testing

Test model	GFA (m2)	External areas (m2)	Garage area (m2)	External walls (lin m)	Internal walls (lin m)	Area of external openings (m2)	Hips / valleys / ridges (lin m)	Gable ends (m2)	No. of bathrooms (each)	Additional plumbing outlets (each)	Predicted Cost	Calculated Cost	Difference in cost (Pred vs Calc)	Absolute % error	% error
S001	302.30	46.30	45.60	80.00	92.80	56.64	76.10	0.00	2	1	$271,294.45	$269,845.36	$1,449.08	0.54%	0.54%
S002	244.33	24.51	39.38	67.20	94.20	48.23	65.70	0.00	2	1	$233,475.42	$241,288.69	-$7,813.26	3.24%	-3.24%
S003	273.60	51.10	37.60	72.40	86.80	44.07	90.50	2.70	2	2	$257,161.76	$259,434.80	-$2,273.04	0.88%	-0.88%
S004	274.61	39.18	40.23	73.00	91.75	63.10	0.00	49.90	2	1	$269,605.37	$270,115.64	-$510.27	0.19%	-0.19%
S005	184.85	18.50	36.40	60.20	66.40	32.28	59.60	1.80	2	-1	$190,189.54	$191,207.60	-$1,018.06	0.53%	-0.53%
S006	272.50	27.40	37.20	74.00	105.30	46.26	95.40	0.00	2	0	$252,880.80	$257,411.03	-$4,530.24	1.76%	-1.76%
S007	158.20	2.40	0.00	56.60	71.30	32.52	57.50	0.00	2	1	$184,771.95	$188,202.31	-$3,430.36	1.82%	-1.82%
S008	284.70	22.90	39.80	82.40	104.60	51.20	109.40	4.90	3	1	$279,777.53	$289,247.39	-$9,469.86	3.27%	-3.27%
S009	331.80	37.98	42.78	89.80	97.33	60.23	24.40	32.10	2	3	$301,716.72	$305,755.27	-$4,038.56	1.32%	-1.32%
S010	350.40	42.60	40.50	90.20	115.80	58.60	111.70	0.00	3	4	$323,620.58	$311,996.76	$11,623.82	3.73%	3.73%
S011	262.90	28.00	38.40	71.20	115.40	43.76	79.20	6.30	2	3	$254,347.21	$260,118.56	-$5,771.35	2.22%	-2.22%
S012	197.40	24.30	37.50	61.40	66.30	38.82	68.10	0.00	2	1	$203,473.55	$203,807.14	-$333.59	0.16%	-0.16%
S013	228.50	36.60	36.10	65.70	78.90	38.22	85.80	0.00	2	0	$223,225.88	$219,262.09	$3,963.78	1.81%	1.81%
S014	294.75	48.29	45.22	76.20	101.50	56.90	124.83	1.74	2	4	$280,995.88	$289,336.00	-$8,340.12	2.88%	-2.88%
S015	218.10	18.50	36.00	66.50	85.00	39.66	82.50	0.00	2	0	$217,331.26	$221,375.79	-$4,044.53	1.83%	-1.83%
S016	239.40	24.20	39.40	70.70	81.10	46.80	44.30	5.00	2	0	$227,990.94	$223,609.16	$4,381.78	1.96%	1.96%
S017	269.50	37.60	37.80	72.00	107.53	50.10	99.45	0.00	2	0	$253,980.13	$259,505.08	-$5,524.95	2.13%	-2.13%
S018	234.90	33.90	0.00	67.20	87.30	36.30	92.80	8.10	2	2	$242,171.38	$241,368.56	$802.82	0.33%	0.33%
S019	195.98	15.20	36.80	62.80	73.00	36.00	70.80	0.00	2	0	$200,694.71	$202,958.42	-$2,263.71	1.12%	-1.12%
S020	215.90	18.20	36.10	70.40	82.80	42.00	97.50	0.00	2	0	$220,577.87	$225,592.66	-$5,014.79	2.22%	-2.22%
Mean													**-$2,107.77**	**1.70%**	**-0.86%**
Std Dev													**$4,846.84**	**1.04%**	**1.79%**

Appendix M – Linear regression results without cabinetry costs

```
REGRESSION
  /DESCRIPTIVES MEAN STDDEV CORR SIG N
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS CI(95) R ANOVA COLLIN TOL CHANGE ZPP
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT TotalCostexGST
  /METHOD=ENTER GFAm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2
    Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach
  /PARTIALPLOT ALL
  /SCATTERPLOT=(*ZRESID ,*ZPRED)
  /RESIDUALS DURBIN HISTOGRAM(ZRESID) NORMPROB(ZRESID).
```

Regression

Notes

Output Created		30-JUL-2021 14:40:52
Comments		
Input	Data	C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\Without cabinetry\Linear regression with sig drivers removed 3.sav
	Active Dataset	DataSet2
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	170
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.

Syntax		REGRESSION /DESCRIPTIVES MEAN STDDEV CORR SIG N /MISSING LISTWISE /STATISTICS COEFF OUTS CI(95) R ANOVA COLLIN TOL CHANGE ZPP /CRITERIA=PIN(.05) POUT(.10) /NOORIGIN /DEPENDENT TotalCostexGST /METHOD=ENTER GFAm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach /PARTIALPLOT ALL /SCATTERPLOT=(*ZRESID ,*ZPRED) /RESIDUALS DURBIN HISTOGRAM(ZRESID) NORMPROB(ZRESID).
Resources	Processor Time	00:00:02.11
	Elapsed Time	00:00:01.84
	Memory Required	8272 bytes
	Additional Memory Required for Residual Plots	3368 bytes

[DataSet2] C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\Without cabinetry\Linear regression with sig drivers removed 3.sav

Descriptive Statistics

	Mean	Std. Deviation	N
Total Cost ex GST	212901.7709064704500	34653.21884158749000	170
GFA (m2)	232.944823529411700	50.837316108743110	170
Garage area (m2)	37.933529411764720	8.080665170623119	170
External walls (lin m)	69.489235294117600	9.803135291422954	170
Internal walls (lin m)	78.943705882352920	17.712517147485425	170
Area of external openings (m2)	44.374176470588246	9.422153906035970	170
Hips / valleys / ridges (lin m)	72.348588235294120	28.006933615437188	170
Gable ends (m2)	5.437647058823529	12.664206574385911	170
No. of bathrooms (each)	2.02	.171	170
Additional plumbing outlets (each)	.85	1.558	170

Correlations

		Total Cost ex GST	GFA (m2)	Garage area (m2)	External walls (lin m)	Internal walls (lin m)	Area of external openings (m2)	Hips / valleys / ridges (lin m)	Gable ends (m2)	No. of bathrooms (each)	Additional plumbing outlets (each)
Pearson Correlation	Total Cost ex GST	1.000	.984	.374	.911	.819	.850	.344	.398	.262	.759
	GFA (m2)	.984	1.000	.389	.878	.821	.827	.355	.354	.209	.718
	Garage area (m2)	.374	.389	1.000	.457	.223	.433	.082	.196	.133	.208
	External walls (lin m)	.911	.878	.457	1.000	.684	.821	.338	.345	.296	.713
	Internal walls (lin m)	.819	.821	.223	.684	1.000	.622	.386	.161	.182	.602
	Area of external openings (m2)	.850	.827	.433	.821	.622	1.000	.286	.356	.171	.645
	Hips / valleys / ridges (lin m)	.344	.355	.082	.338	.386	.286	1.000	-.596	.155	.111
	Gable ends (m2)	.398	.354	.196	.345	.161	.356	-.596	1.000	.017	.412
	No. of bathrooms (each)	.262	.209	.133	.296	.182	.171	.155	.017	1.000	.188
	Additional plumbing outlets (each)	.759	.718	.208	.713	.602	.645	.111	.412	.188	1.000
Sig. (1-tailed)	Total Cost ex GST	.	.000	.000	.000	.000	.000	.000	.000	.000	.000
	GFA (m2)	.000	.	.000	.000	.000	.000	.000	.000	.003	.000
	Garage area (m2)	.000	.000	.	.000	.002	.000	.144	.005	.042	.003
	External walls (lin m)	.000	.000	.000	.	.000	.000	.000	.000	.000	.000
	Internal walls (lin m)	.000	.000	.002	.000	.	.000	.000	.018	.009	.000
	Area of external openings (m2)	.000	.000	.000	.000	.000	.	.000	.000	.013	.000
	Hips / valleys / ridges (lin m)	.000	.000	.144	.000	.000	.000	.	.000	.022	.074
	Gable ends (m2)	.000	.000	.005	.000	.018	.000	.000	.	.412	.000

	No. of bathrooms (each)	.000	.003	.042	.000	.009	.013	.022	.412	.	.007
	Additional plumbing outlets (each)	.000	.000	.003	.000	.000	.000	.074	.000	.007	.
N	Total Cost ex GST	170	170	170	170	170	170	170	170	170	170
	GFA (m2)	170	170	170	170	170	170	170	170	170	170
	Garage area (m2)	170	170	170	170	170	170	170	170	170	170
	External walls (lin m)	170	170	170	170	170	170	170	170	170	170
	Internal walls (lin m)	170	170	170	170	170	170	170	170	170	170
	Area of external openings (m2)	170	170	170	170	170	170	170	170	170	170
	Hips / valleys / ridges (lin m)	170	170	170	170	170	170	170	170	170	170
	Gable ends (m2)	170	170	170	170	170	170	170	170	170	170
	No. of bathrooms (each)	170	170	170	170	170	170	170	170	170	170
	Additional plumbing outlets (each)	170	170	170	170	170	170	170	170	170	170

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Additional plumbing outlets (each), Hips / valleys / ridges (lin m), Garage area (m2), No. of bathrooms (each), Internal walls (lin m), Area of external openings (m2), Gable ends (m2), External walls (lin m), GFA (m2)[b]	.	Enter

a. Dependent Variable: Total Cost ex GST

b. All requested variables entered.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.994[a]	.988	.988	3825.58302973945600	.988	1522.986	9	160	.000	1.851

a. Predictors: (Constant), Additional plumbing outlets (each), Hips / valleys / ridges (lin m), Garage area (m2), No. of bathrooms (each), Internal walls (lin m), Area of external openings (m2), Gable ends (m2), External walls (lin m), GFA (m2)

b. Dependent Variable: Total Cost ex GST

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	200601288675.230	9	22289032075.026	1522.986	.000[b]
	Residual	2341613682.789	160	14635085.517		
	Total	202942902358.019	169			

a. Dependent Variable: Total Cost ex GST

b. Predictors: (Constant), Additional plumbing outlets (each), Hips / valleys / ridges (lin m), Garage area (m2), No. of bathrooms (each), Internal walls (lin m), Area of external openings (m2), Gable ends (m2), External walls (lin m), GFA (m2)

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	33106.791	4183.005		7.915	.000	24845.768	41367.814					
	GFA (m2)	433.219	18.059	.636	23.989	.000	397.555	468.884	.984	.885	.204	.103	9.733
	Garage area (m2)	-128.003	42.862	-.030	-2.986	.003	-212.650	-43.356	.374	-.230	-.025	.722	1.385
	External walls (lin m)	478.288	74.673	.135	6.405	.000	330.817	625.760	.911	.452	.054	.162	6.188
	Internal walls (lin m)	143.156	30.898	.073	4.633	.000	82.136	204.176	.819	.344	.039	.289	3.459
	Area of external openings (m2)	244.158	61.243	.066	3.987	.000	123.209	365.107	.850	.301	.034	.260	3.845

Hips / valleys / ridges (lin m)	112.580	20.670	.091	5.446	.000	71.758	153.402	.344	.395	.046	.258	3.870
Gable ends (m2)	349.094	46.025	.128	7.585	.000	258.200	439.988	.398	.514	.064	.255	3.923
No. of bathrooms (each)	8565.022	1827.058	.042	4.688	.000	4956.763	12173.281	.262	.348	.040	.886	1.128
Additional plumbing outlets (each)	1226.038	298.482	.055	4.108	.000	636.566	1815.509	.759	.309	.035	.401	2.496

a. Dependent Variable: Total Cost ex GST

Collinearity Diagnostics[a]

				Variance Proportions									
Model	Dimension	Eigenvalue	Condition Index	(Constant)	GFA (m2)	Garage area (m2)	External walls (lin m)	Internal walls (lin m)	Area of external openings (m2)	Hips / valleys / ridges (lin m)	Gable ends (m2)	No. of bathrooms (each)	Additional plumbing outlets (each)
1	1	8.315	1.000	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	2	1.072	2.785	.00	.00	.00	.00	.00	.00	.00	.12	.00	.09
	3	.496	4.094	.00	.00	.00	.00	.00	.00	.00	.13	.00	.38
	4	.044	13.787	.01	.00	.15	.00	.01	.00	.37	.30	.01	.20
	5	.030	16.688	.02	.00	.57	.00	.06	.01	.08	.02	.03	.00
	6	.020	20.495	.02	.02	.05	.00	.33	.00	.25	.14	.05	.12
	7	.013	25.311	.00	.01	.18	.00	.11	.60	.16	.17	.01	.05
	8	.005	42.788	.01	.53	.04	.12	.38	.36	.11	.12	.01	.05
	9	.003	49.949	.67	.04	.00	.04	.00	.02	.01	.00	.89	.04
	10	.002	59.188	.28	.40	.02	.84	.12	.01	.01	.00	.00	.07

a. Dependent Variable: Total Cost ex GST

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	143329.2500000000000	340027.1875000000000	212901.7709064704000	34452.71939655804000	170
Residual	-12714.67285156250200	18818.48437500000000	.00000000010614	3722.32484678906580	170
Std. Predicted Value	-2.019	3.690	.000	1.000	170
Std. Residual	-3.324	4.919	.000	.973	170

a. Dependent Variable: Total Cost ex GST

Appendix N – Multilayered Perceptron Neural Network detailed results without cabinetry

GET

FILE='C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\Without cabinetry\Data import prior to reg analysis.sav'.

DATASET NAME DataSet1 WINDOW=FRONT.

SAVE OUTFILE='C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real '+

'results\Without cabinetry\Data prior to neural netwiork.sav'

/COMPRESSED.

*Multilayer Perceptron Network.

MLP TotalCostexGST (MLEVEL=S) WITH GFAm2 Garageaream2 Externalwallslinm Internalwallslinm

Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach

Additionalplumbingoutletseach

/RESCALE COVARIATE=STANDARDIZED

/PARTITION TRAINING=7 TESTING=3 HOLDOUT=0

/ARCHITECTURE AUTOMATIC=YES (MINUNITS=1 MAXUNITS=50)

/CRITERIA TRAINING=BATCH OPTIMIZATION=SCALEDCONJUGATE LAMBDAINITIAL=0.0000005

SIGMAINITIAL=0.00005 INTERVALCENTER=0 INTERVALOFFSET=0.5 MEMSIZE=1000

/PRINT CPS NETWORKINFO SUMMARY

/PLOT NETWORK PREDICTED RESIDUAL

/SAVE PREDVAL

/STOPPINGRULES ERRORSTEPS= 1 (DATA=AUTO) TRAININGTIMER=ON (MAXTIME=15) MAXEPOCHS=AUTO

ERRORCHANGE=1.0E-4 ERRORRATIO=0.001

/MISSING USERMISSING=EXCLUDE .

Multilayer Perceptron

Notes

Output Created		01-AUG-2021 07:32:35
Comments		
Input	Data	C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\Without cabinetry\Data prior to neural netwiork.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	190
Missing Value Handling	Definition of Missing	User- and system-missing values are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables used by the procedure.
Weight Handling		not applicable

Syntax	MLP TotalCostexGST (MLEVEL=S) WITH GFAm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach /RESCALE COVARIATE=STANDARDIZED /PARTITION TRAINING=7 TESTING=3 HOLDOUT=0 /ARCHITECTURE AUTOMATIC=YES (MINUNITS=1 MAXUNITS=50) /CRITERIA TRAINING=BATCH OPTIMIZATION=SCALEDCONJUGATE LAMBDAINITIAL=0.0000005 SIGMAINITIAL=0.00005 INTERVALCENTER=0 INTERVALOFFSET=0.5 MEMSIZE=1000 /PRINT CPS NETWORKINFO SUMMARY /PLOT NETWORK PREDICTED RESIDUAL /SAVE PREDVAL /STOPPINGRULES ERRORSTEPS= 1 (DATA=AUTO) TRAININGTIMER=ON (MAXTIME=15) MAXEPOCHS=AUTO ERRORCHANGE=1.0E-4 ERRORRATIO=0.001

		/MISSING USERMISSING=EXCLUDE .
Resources	Processor Time	00:00:03.17
	Elapsed Time	00:00:02.78
Variables Created or Modified	Predicted Value	MLP_PredictedValue

[DataSet1] C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\Without cabinetry\Data prior to neural netwiork.sav

Case Processing Summary

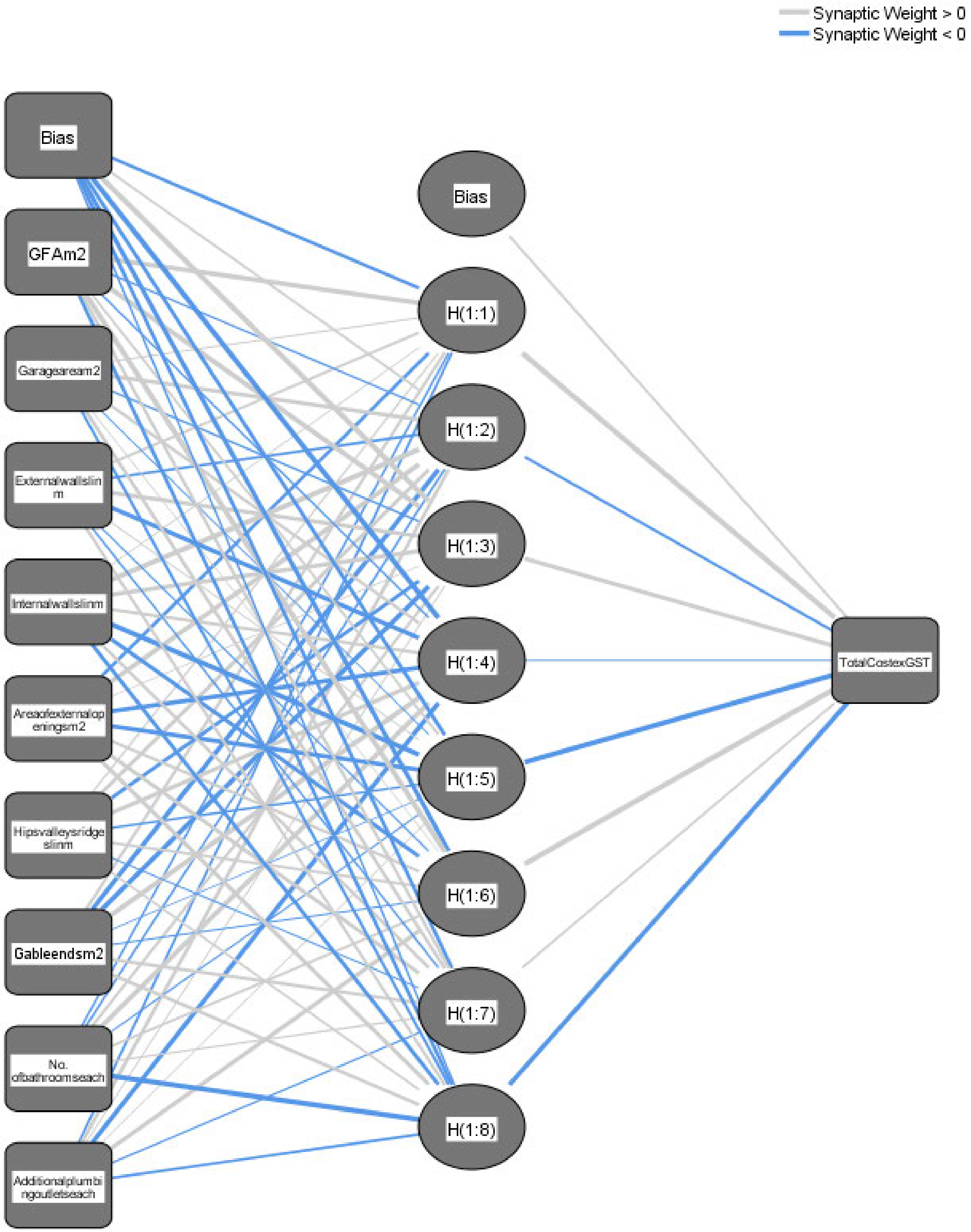
		N	Percent
Sample	Training	119	70.0%
	Testing	51	30.0%
Valid		170	100.0%
Excluded		20	
Total		190	

Network Information

Input Layer	Covariates	1	GFA (m2)
		2	Garage area (m2)
		3	External walls (lin m)
		4	Internal walls (lin m)
		5	Area of external openings (m2)
		6	Hips / valleys / ridges (lin m)
		7	Gable ends (m2)
		8	No. of bathrooms (each)
		9	Additional plumbing outlets (each)
	Number of Units[a]		9
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		1
	Number of Units in Hidden Layer 1[a]		8
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	Total Cost ex GST
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized

	Activation Function	Identity
	Error Function	Sum of Squares

a. Excluding the bias unit



Hidden layer activation function: Hyperbolic tangent

Output layer activation function: Identity

Model Summary

Training	Sum of Squares Error	2.868
	Relative Error	.049
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.02
Testing	Sum of Squares Error	3.627
	Relative Error	.087

Dependent Variable: Total Cost ex GST

a. Error computations are based on the testing sample.

Appendix O – Radial Basis Function neural network detailed output excluding cabinetry

```
*Radial Basis Function Network.
RBF TotalCostexGST (MLEVEL=S) WITH GFAm2 Garageaream2 Externalwallslinm Internalwallslinm
    Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach
    Additionalplumbingoutletseach
 /RESCALE COVARIATE=STANDARDIZED  DEPENDENT=STANDARDIZED
  /PARTITION  TRAINING=7  TESTING=3  HOLDOUT=0
  /ARCHITECTURE MINUNITS=AUTO MAXUNITS=AUTO HIDDENFUNCTION=NRBF
  /CRITERIA OVERLAP=AUTO
  /PRINT CPS NETWORKINFO SUMMARY
  /PLOT NETWORK PREDICTED RESIDUAL
  /SAVE PREDVAL
 /MISSING USERMISSING=EXCLUDE .
```

Radial Basis Function

Notes

Output Created		01-AUG-2021 07:34:41
Comments		
Input	Data	C:\Uni Info\2021 Courses\ENG4111 - Project part 1\Data experiments\Real results\Without cabinetry\Data prior to neural netwiork.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	190
Missing Value Handling	Definition of Missing	User- and system-missing values are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables used by the procedure.
Weight Handling		not applicable

Syntax		RBF TotalCostexGST (MLEVEL=S) WITH GFAm2 Garageaream2 Externalwallslinm Internalwallslinm Areaofexternalopeningsm2 Hipsvalleysridgeslinm Gableendsm2 No.ofbathroomseach Additionalplumbingoutletseach /RESCALE COVARIATE=STANDARDIZED DEPENDENT=STANDARDIZED /PARTITION TRAINING=7 TESTING=3 HOLDOUT=0 /ARCHITECTURE MINUNITS=AUTO MAXUNITS=AUTO HIDDENFUNCTION=NRBF /CRITERIA OVERLAP=AUTO /PRINT CPS NETWORKINFO SUMMARY /PLOT NETWORK PREDICTED RESIDUAL /SAVE PREDVAL /MISSING USERMISSING=EXCLUDE .
Resources	Processor Time	00:00:01.75
	Elapsed Time	00:00:00.81
Variables Created or Modified	Predicted Value	RBF_PredictedValue

Case Processing Summary

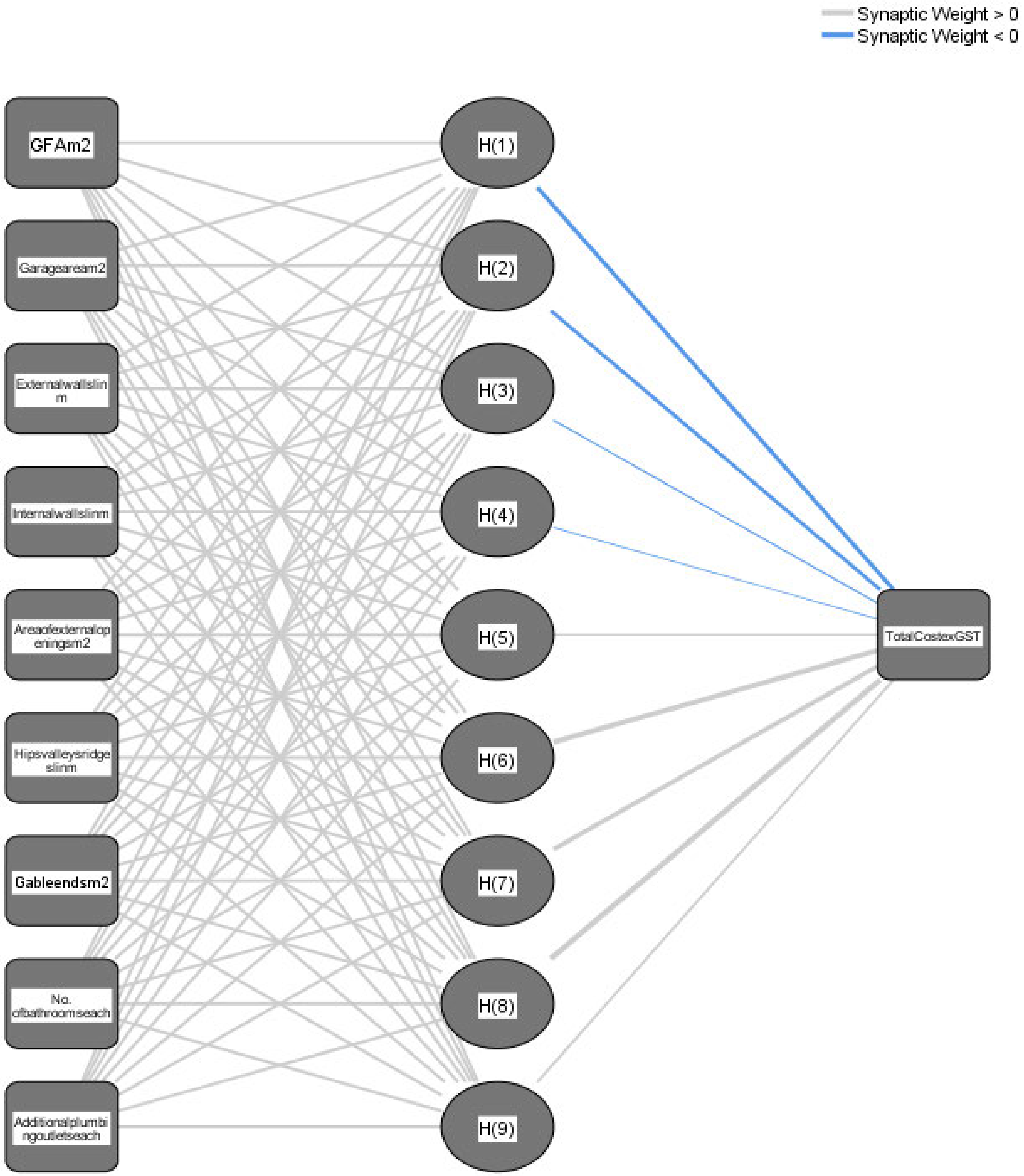
		N	Percent
Sample	Training	122	71.8%
	Testing	48	28.2%
Valid		170	100.0%
Excluded		20	
Total		190	

Network Information

Input Layer	Covariates	1	GFA (m2)
		2	Garage area (m2)
		3	External walls (lin m)
		4	Internal walls (lin m)
		5	Area of external openings (m2)
		6	Hips / valleys / ridges (lin m)
		7	Gable ends (m2)
		8	No. of bathrooms (each)
		9	Additional plumbing outlets (each)

	Number of Units		9
	Rescaling Method for Covariates		Standardized
Hidden Layer	Number of Units		9[a]
	Activation Function		Softmax
Output Layer	Dependent Variables	1	Total Cost ex GST
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

a. Determined by the testing data criterion: The "best" number of hidden units is the one that yields the smallest error in the testing data.



Hidden layer activation function: Softmax

Output layer activation function: Identity

Model Summary

Training	Sum of Squares Error	7.041
	Relative Error	.116
	Training Time	0:00:00.13
Testing	Sum of Squares Error	7.184[a]
	Relative Error	.312

Dependent Variable: Total Cost ex GST

a. The number of hidden units is determined by the testing data criterion: The "best" number of hidden units is the one that yields the smallest error in the testing data.

Appendix P – Excel framework template

Note that this file has been uploaded separately. If not available please contact Peter Dixon (q1023548@umail.usq.edu.au).

Appendix Q – Cost X framework template

Note that this file has been uploaded separately. If not available please contact Peter Dixon (q1023548@umail.usq.edu.au).

Appendix R – Cost X framework worked example

Note that this file has been uploaded separately. If not available please contact Peter Dixon (q1023548@umail.usq.edu.au).

Appendix S – Example first principle estimate

Please see following pages for this appendix document.

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

005 PRELIMINARIES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0050	SITE SIGNAGE ALLOWANCE	1	each	$100.00	**$100.00**	2	1
0060	CONTRACT	1	each	$20.00	**$20.00**	2	1
	Total 005 PRELIMINARIES				**$120.00**		

015 CONSULTANCY FEES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0098	COLOUR CONSULTANT FEE - STANDARD FEE	1	$	$400.00	**$400.00**	2	1
	Total 015 CONSULTANCY FEES				**$400.00**		

030 SOIL TEST

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0141	ENGINEER'S SOIL TESTING & SITE CLASSIFICATION	1	item	$375.00	**$375.00**	2	1
	Total 030 SOIL TEST				**$375.00**		

035 ENGINEER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0142	SLAB AND FOOTINGS CERTIFICATION	1	item	$600.00	**$600.00**	2	1
01432	INSPECTION ALLOWANCE- BOND BEAM	1	each	$100.00	**$100.00**	2	1
0145	FRAME CERTIFICATION	1	each	$30.00	**$30.00**	2	1
	Total 035 ENGINEER				**$730.00**		

045 ENERGY EFFICIENCY

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0358	ENERGY EFFICIENCY ASSESSMENT	1	item	$120.00	**$120.00**	2	1
	Total 045 ENERGY EFFICIENCY				**$120.00**		

055 WORKPLACE HEALTH & SAFETY

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0170	WORKPLACE HEALTH & SAFETY OFFICER STANDARD HOUSE	1	each	$227.27	**$227.27**	2	1
	Total 055 WORKPLACE HEALTH & SAFETY				**$227.27**		

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

070 CERTIFICATION AND COUNCIL FEES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0359	BUILDING FEES FIXED COSTS	1	each	$1,700.00	**$1,700.00**	2	1
0363	PLAN LODGEMENT FEES	1	item	$70.00	**$70.00**	2	1
0365	DRIVEWAY PERMIT	1	item	$125.00	**$125.00**	2	1
	Total 070 CERTIFICATION AND COUNCIL FEES				**$1,895.00**		

075 COUNCIL FEES - HYDRAULICS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0368	PLUMBING & DRAINAGE PLAN APPROVAL	1	each	$278.00	**$278.00**	2	1
0370	PLUMBING AND DRAINAGE FEES	1	each	$735.00	**$735.00**	2	1
0375	WATER METER (INCLUDES SERVICE CONNECTION)	1	each	$990.00	**$990.00**	2	1
	Total 075 COUNCIL FEES - HYDRAULICS				**$2,003.00**		

100 SURVEYOR

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0381	SURVEYOR PS ALLOWANCE	250	each	$0.91	**$227.28**	2	1
	Total 100 SURVEYOR				**$227.28**		

105 EQUIPMENT HIRE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0385	CHEMICAL TOILET 8 WEEK HIRE	1	each	$450.00	**$450.00**	2	1
0386	ADDITIONAL TOILET HIRE (PER WEEK)	12	each	$27.50	**$330.00**	2	1
0387	ADDITIONAL TOILET CLEAN	4	each	$70.00	**$280.00**	2	1
	Total 105 EQUIPMENT HIRE				**$1,060.00**		

115 EARTHWORKS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0451	EARTHWORKS AREA ALLOWANCE	156.6	m2	$2.00	**$313.20**	2	1
	Total 115 EARTHWORKS				**$313.20**		

130 PLANT MACHINE HIRE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0650	BOBCAT HIRE -GENERAL	9	hour	$90.00	**$810.00**	2	1
0660	BOBCAT HIRE -TRENCHING GENERAL	82.5	lin.m	$4.30	**$354.75**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

130 PLANT MACHINE HIRE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0670	BOBCAT TRAVEL	1	hour	$90.00	**$90.00**	2	1
			Total 130 PLANT MACHINE HIRE		**$1,254.75**		

135 CONCRETE PUMP FOOTING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0694	FOOTING PUMP ALLOWANCE - PER HOUR	2	hour	$180.00	**$360.00**	2	1
0695	FOOTING PUMP ALLOWANCE - PER M3 PUMPED	12.4	m3	$9.00	**$111.60**	2	1
0696	FOOTING PUMP ALLOWANCE - TRAVEL TO SITE	1	hour	$100.00	**$100.00**	2	1
0697	FOOTING PUMP ALLOWANCE - OFF SITE DUMPING & PRIMING	1	hour	$141.00	**$141.00**	2	1
			Total 135 CONCRETE PUMP FOOTING		**$712.60**		

140 FOOTING / SLAB REINFORCING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0763	L11TM3 X 6M	30	each	$23.42	**$702.60**	2	1
0769	N12S6 DBAR 6Mx12mm	30	each	$8.40	**$252.00**	2	1
0773	R10 X 1400 COGGED & HOOKED SLAB TIE SB1014	116	each	$1.58	**$183.28**	2	1
0775	N12 X 1400 COGGED & HOOKED STARTER BAR	54	each	$2.84	**$153.58**	2	1
0776	N16 X 1400 COGGED & HOOKED STARTER BAR	4	each	$4.34	**$17.36**	2	1
0785	N12 X 500 GALVANISED COGGED DOWEL BAR SB1261	44	each	$2.80	**$123.20**	2	1
0803	SL82 MESH SQRE	13	each	$83.52	**$1,085.76**	2	1
0814	BAR CHAIRS 50/65	300	each (per	$0.15	**$45.00**	2	1
0815	TMS60- BAR CHAIRS TO SUIT TRENCH MESH (PER BAG OF 25)	7	each	$7.40	**$51.80**	2	1
0820	TIE WIRE- 1.42KG IDLCOILA	1	roll	$3.50	**$3.50**	2	1
0831	POLYTHENE 50Mx4M BLACK 200um FB2450	2	roll	$82.00	**$164.00**	2	1
0840	DUCT POLY TAPE 48mm X 30 mtr TPP30	4	roll	$3.50	**$14.00**	2	1
0961	DELIVERY	1	each	$100.00	**$100.00**	2	1
1622	N12C- N12 BAR CUT & BENT	36	lin.m	$1.35	**$48.60**	2	1
1624	N16 BAR CUT & BENT	66	lin.m	$2.40	**$158.40**	2	1
1630	N12 600 X 600 CORNER BAR CB1206	14	each	$1.81	**$25.29**	2	1
			Total 140 FOOTING / SLAB REINFORCING		**$3,128.36**		

145 FOOTING CONCRETE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0970	FOOTING CONCRETE 20/20	12.4	m3	$150.00	**$1,860.00**	2	1
			Total 145 FOOTING CONCRETE		**$1,860.00**		

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

160 PLUMBER - DRAINS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1071	DRAINAGE 45M UP TO 8 POINTS SINGLE FLOOR SLAB ON GROUND DWELLING	1	each	$2,600.00	**$2,600.00**	2	1
1073	ADDITIONAL DRAINAGE POINTS	-1	each	$40.00	**-$40.00**	2	1
1075	DRAINAGE TO ENSUITE	1	each	$200.00	**$200.00**	2	1
1076	EXTRA FOR ISLAND BENCH PLUMBING	1	each	$150.00	**$150.00**	2	1
1196	DRAINAGE POINT FOR AC CONDENSATE TO 5M	4	each	$0.00	**$0.00**	2	1
				Total 160 PLUMBER - DRAINS	**$2,910.00**		

165 TERMITE TREATMENT

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1223	TERMITE PROTECTION TO PENETRATIONS (EACH)	19	each	$16.00	**$304.00**	2	1
1225	TERMITE PROTECTION - TREATMENT TO PIERS	4	each	$20.00	**$80.00**	2	1
1226	TERMITE PROTECTION - PERIMETER TREATMENT	117.3	lin m	$17.50	**$2,052.75**	2	1
				Total 165 TERMITE TREATMENT	**$2,436.75**		

170 SAND AND GRAVEL

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1241	SCREENED DECO INCL DELIVERY	60	m3	$30.26	**$1,815.60**	2	1
				Total 170 SAND AND GRAVEL	**$1,815.60**		

180 SLAB FINISHER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1068	FORM SHOWER / BATHROOM RECESS IN SLAB	2	each	$75.00	**$150.00**	2	1
1069	FORM SLIDING GLASS DOOR REBATE IN SLAB	1	each	$60.00	**$60.00**	2	1
13152	SETOUT, SAND, STEEL,PLACE AND FINISH SLAB 'H1' CLASS	156.6	m2	$28.00	**$4,384.80**	2	1
				Total 180 SLAB FINISHER	**$4,594.80**		

185 SLAB CONCRETE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1320	CONCRETE 20MPA 20MM AGG	42.4	m3	$150.00	**$6,360.00**	2	1
				Total 185 SLAB CONCRETE	**$6,360.00**		

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

190 CONCRETE PUMP SLAB

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
13250	CONCRETE PUMP ALLOWANCE - PER HOUR	4.25	hour	$180.00	**$765.00**	2	1
13252	CONCRETE PUMP ALLOWANCE - PER M3 PUMPED	42.4	m3	$9.00	**$381.60**	2	1
13254	CONCRETE PUMP ALLOWANCE - TRAVEL TO SITE	1	hour	$100.00	**$100.00**	2	1
13255	CONCRETE PUMP ALLOWANCE - OFF SITE DUMPING & PRIMING	1	hour	$141.00	**$141.00**	2	1
	Total 190 CONCRETE PUMP SLAB				**$1,387.60**		

200 BLOCK LAYER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
13301	LAY 200 SERIES BLOCKS FOR BASE	619	each	$3.30	**$2,042.70**	2	1
1331	LAY 200 SERIES BLOCKS	1590	each	$3.30	**$5,247.00**	2	1
1334	EXTRA FOR CUTS	4	each	$3.30	**$13.20**	2	1
1340	HEADS FOR WINDOWS, DOORS & LINTELS UP TO 5.6M	14	each	$10.00	**$140.00**	2	1
1341	PROPS FOR OPENINGS >2.0M	5	each	$10.00	**$50.00**	2	1
	Total 200 BLOCK LAYER				**$7,492.90**		

202 CONCRETE MASONARY

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1391	20.01 STANDARD	892	each	$2.20	**$1,962.40**	2	1
1391	20.01 STANDARD	207	each	$2.20	**$455.40**	2	2
1392	20.02 THREE QUARTER	10	each	$2.20	**$22.00**	2	1
1393	20.03 HALF	70	each	$2.20	**$154.00**	2	1
1401	20.12 LINTEL	62	each	$2.20	**$136.40**	2	1
1404	20.16 LINTEL/ KNOCK OUT	9	each	$2.20	**$19.80**	2	1
1406	20.20 K/OUT BOND BEAM	303	each	$2.20	**$666.60**	2	1
1406	20.20 K/OUT BOND BEAM	207	each	$2.20	**$455.40**	2	2
1407	20.21 K/O B/BEAM CORNER	18	each	$2.20	**$39.60**	2	1
1412	15.38 SILL 1/2 HEIGHT	60	each	$2.20	**$132.00**	2	1
1422	20.71 STANDARD 1/2 HEIGHT	105	each	$2.20	**$231.00**	2	1
1422	20.71 STANDARD 1/2 HEIGHT	207	each	$2.20	**$455.40**	2	2
1424	20.73 HALF 1/2 HEIGHT	7	each	$2.20	**$15.40**	2	1
1425	30.02 THREE QUARTER	56	each	$3.30	**$184.80**	2	1
1544	STANDARD HOUSE TAKE-OFF COST PER FLOOR	1	each	$35.00	**$35.00**	2	1
	Total 202 CONCRETE MASONARY				**$4,965.20**		

205 BOND BEAM STEEL

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1605	N12 DBAR X 6000MM	22	each	$7.00	**$154.00**	2	1
1607	N16 DBAR X 6000MM	8	each	$13.30	**$106.40**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

205 BOND BEAM STEEL

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1612	N12 x 2500MM X 200mm WALL BARS WB1225	8	each	$5.08	$40.62	2	1
16121	N12 x 2600MM X 200mm WALL BARS WB1226	46	each	$5.42	$249.26	2	1
1618	N16 x 2600MM x 200mm WALL BARS WB1626	4	each	$9.42	$37.69	2	1
1630	N12 600 X 600 CORNER BAR CB1206	18	each	$1.81	$32.51	2	1
1635	R8 X 230MM HOOK BAR	25	each	$0.76	$19.00	2	1
1636	R8 X 430MM HOOK BAR	174	each	$0.94	$163.02	2	1
1642	BOND BEAM BLOCK OUT PLATES (BAG 100)	2	bag	$62.22	$124.44	2	1
164206	BOND BEAM STEEL DELIVERY	1	each	$108.00	$108.00	2	1
		Total 205 BOND BEAM STEEL			$1,034.94		

212 TRUSS TIE DOWNS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
16430	200 X 50 X 6MM HOT DIPPED GAL TRUSS PLATES	82	each	$1.70	$139.40	2	1
		Total 212 TRUSS TIE DOWNS			$139.40		

216 BOND BEAM PUMP

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1690	CONCRETE PUMP ALLOWANCE COLUMNS	4	each	$15.00	$60.00	2	1
169900	BOND BEAM PUMP ALLOWANCE - PER HOUR	1.75	hour	$180.00	$315.00	2	1
169902	BOND BEAM PUMP ALLOWANCE - PER M3 PUMPED	7.2	m3	$9.00	$64.80	2	1
169904	BOND BEAM PUMP ALLOWANCE - TRAVEL TO SITE	1	hour	$100.00	$100.00	2	1
169906	BOND BEAM PUMP ALLOWANCE - OFF SITE DUMPING & PRIMING	1	hour	$141.00	$141.00	2	1
		Total 216 BOND BEAM PUMP			$680.80		

218 BOND BEAM CONCRETE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1710	BOND BEAM CONCRETE 20/10	7.2	m3	$162.00	$1,166.40	2	1
		Total 218 BOND BEAM CONCRETE			$1,166.40		

223 ELECTRICIAN

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1910	UNDERGROUND MAINS TO 15M	1	each	$250.00	$250.00	2	1
1913	SWITCHBOARD	1	each	$500.00	$500.00	2	1
1915	CONNECT HWS	1	each	$120.00	$120.00	2	1
1916	CONNECT STOVE OR OVEN & COOKTOP	1	each	$160.00	$160.00	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

223 ELECTRICIAN

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1918	LIGHT POINT	26	each	$50.00	**$1,300.00**	2	1
1933	FAN POINT	6	each	$55.00	**$330.00**	2	1
19331	EXHAUST FAN WIRE & FIT-	2	each	$80.00	**$160.00**	2	1
193311	EXTRA FOR DUCTED / VENTILATED EXHAUST FAN	2	each	$140.00	**$280.00**	2	1
1939	2 WAY SWITCH	2	each	$40.00	**$80.00**	2	1
1940	DIMMER SWITCH	1	each	$130.00	**$130.00**	2	1
1942	DOOR BELL SUPPLY WIRE & FIT	1	each	$200.00	**$200.00**	2	1
1945	SUPPLY WIRE & FIT SMOKE DETECTOR	6	each	$90.00	**$540.00**	2	1
1950	TV AERIAL & BRACKET ONLY	1	each	$135.00	**$135.00**	2	1
1951	TV POINTS	2	each	$55.00	**$110.00**	2	1
19571	SPLIT SYSTEM AC CONNECTION INCL ISOLATOR	4	each	$180.00	**$720.00**	2	1
1961	DPP 10A	25	each	$65.00	**$1,625.00**	2	1
1963	EXTRA FOR WEATHERPROOF POWER POINT	2	each	$25.00	**$50.00**	2	1
1968	LEAD IN & INITIAL TELEPHONE POINT	1	each	$465.00	**$465.00**	2	1
19682	DATA POINT	2	each	$55.00	**$110.00**	2	1
19780	CONDUIT ONLY FOR FUTURE SOLAR SYSTEM	1	each	$50.00	**$50.00**	2	1
198000	EXTRA TO CONNECT CIRCUIT TO TARIFF 33	1	each	$250.00	**$250.00**	2	1
				Total 223 ELECTRICIAN	**$7,565.00**		

230 RENDER AND APPLIED FINISHES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1986	2 COAT ACRYLIC RENDER TO EXTERNAL WALLS	151.6	m2	$21.00	**$3,183.60**	2	1
				Total 230 RENDER AND APPLIED FINISHES	**$3,183.60**		

235 SCAFFOLDING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
03995	BOND BEAM SCAFFOLD ALLOWANCE	56.6	lin.m	$5.50	**$311.30**	2	1
				Total 235 SCAFFOLDING	**$311.30**		

255 CRANE HIRE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
0700	CRANE HIRE- TRUSSES & BEAMS	3.25	hour	$195.00	**$633.75**	2	1
				Total 255 CRANE HIRE	**$633.75**		

260 TRUSSES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

260 TRUSSES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2021	TRUSS ALLOWANCE /M2 TIMBER N2/C1 20 DEGREE PITCH	156.6	m2	$19.00	**$2,975.40**	2	1
2022	ALLOWANCE FOR EAVES	18.84	m2	$3.60	**$67.82**	2	1
2023	EXTRA FOR 5 DEG PITCH INCREASE	78.32	m2	$3.60	**$281.95**	2	1
2026	EXTRA FOR TRUSSES WITH SPAN > 10M	156.6	m2	$6.00	**$939.60**	2	1
			Total 260 TRUSSES		**$4,264.78**		

270 NON-STRUCTURAL FRAMING TIMBER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
21075	F5 (MGP7) PINE 70 X 35MM STUDS X 2.7M	100	each	$6.01	**$601.00**	2	1
21081	MGP10 PINE 70 X 45MM PLATES	10.8	lin m	$2.98	**$32.18**	2	1
21085	F5 (MGP7) PINE 70 X 35MM PLATES	102.6	lin m	$2.01	**$206.23**	2	1
21102	MGP10 PINE 90 X 35MM STUDS	54	lin m	$2.60	**$140.40**	2	1
21104	MGP10 PINE 90 X 35MM PLATES	21.6	lin m	$2.60	**$56.16**	2	1
2182	BRACEPLY 2745 X 900 X 4.0MM HWD F27	4	sheet	$20.75	**$83.00**	2	1
21980	CAVITY SLD DOOR UNIT EVOLUTION 2040X820	2	each	$119.70	**$239.40**	2	1
2310	DELIVER WALL FRAMING	1	each	$95.00	**$95.00**	2	1
			Total 270 NON-STRUCTURAL FRAMING TIMBER		**$1,453.37**		

275 STRUCTURAL FRAMING TIMBER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2103	MGP12 PINE 70 X 45MM STUDS X 2.7M	17	each	$9.45	**$160.65**	2	1
2104	MGP12 PINE 70 X 35MM PLATES	27	lin m	$2.95	**$79.65**	2	1
2104	MGP12 PINE 70 X 35MM PLATES	48.6	lin m	$2.95	**$143.37**	2	2
21041	MGP12 PINE 70 X 35MM STUDS	10.8	lin m	$3.06	**$33.05**	2	1
21089	MGP12 PINE 90 X 35MM STUDS	37.8	lin m	$3.79	**$143.26**	2	1
2109	MGP12 PINE 90 X 35MM PLATES	10.8	lin m	$3.86	**$41.69**	2	1
2109	MGP12 PINE 90 X 35MM PLATES	27	lin m	$3.86	**$104.22**	2	2
2110	MGP12 PINE 90 X 45MM PLATES	16.2	lin m	$5.54	**$89.75**	2	1
2182	BRACEPLY 2745 X 900 X 4.0MM HWD F27	2	sheet	$20.75	**$41.50**	2	1
2269	SMART LVL15 170 X 35	1.2	lin m	$13.73	**$16.48**	2	1
2303	SMART LVL15 150 X 58	6.3	lin m	$21.38	**$134.69**	2	1
2318	PINE 42 X 35MM UNDER EAVE PINE BATTEN FJ F7	86.4	lin m	$1.77	**$152.93**	2	1
2319	METAL CEILING BATTENS- (6.1m X FURRING CHANNEL)	451.4	lin m	$0.86	**$388.20**	2	1
2340	DELIVER STRUCTURAL T MBER	1	each	$95.00	**$95.00**	2	1
			Total 275 STRUCTURAL FRAMING TIMBER		**$1,624.44**		

285 FC SHEETING / CLADDING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

285 FC SHEETING / CLADDING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2317	F5 PINE 70 X 35MM NOGGIN	43.2	lin m	$2.58	$111.46	2	1
2525	PINE 42 X 35MM UNDER EAVE BATTEN	172.8	lin m	$1.65	$285.12	2	1
25257	31 X 12MM DAR MOULDING	70.2	lin m	$0.75	$52.65	2	1
2530	HARDIFLEX M2 RATE 6.0MM	13.32	m2	$12.41	$165.30	2	1
2536	HARDIFLEX 2400X600X4 5MM EAVES SHEET	22	sheet	$11.72	$257.84	2	1
2547	PVC JOINER STRIP 4.5 X 3000MM	5	each	$1.69	$8.45	2	1
2548	PVC JOINER STRIP 6.0 X 3000MM	5	each	$3.59	$17.95	2	1
2552	SUPPLY WINDOW/DOOR HEAD FLASHING	7.2	lin m	$8.27	$59.54	2	2
2576	HARDIPLANK SMOOTH 4200X230MM	27	sheet	$16.67	$450.09	2	1
25767	HARDIES CORNER FLASHING 75X75MM - 3M LENGTHS	2	each	$23.01	$46.02	2	1
257691	HARDIES ALUMINIUM SNAP ON CORNER 2 PART - 3M LENGTH	3	each	$39.30	$117.90	2	1
2581	32 X19 PRE PRIMED PINE STOP	21.6	lin m	$1.63	$35.16	2	1
2599	DELIVERY BODY TRUCK	1	each	$95.00	$95.00	2	1
		Total 285 FC SHEETING / CLADDING			$1,702.49		

290 FRAME HARDWARE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2210	M12 X 3000 THREADED CYCLONE ROD GAL	16	each	$5.58	$89.23	2	1
2212	NUTS M12 & SQUARE WASHERS GAL	16	each	$0.86	$13.76	2	1
2235	DYNABOLT M12 X 99MM	4	each	$1.39	$5.56	2	1
2344	MISCELLANEOUS HARDWARE ALLOWANCE	1	each	$300.00	$300.00	2	1
2348	BATTEN SCREWS 14-10x75mm ZP (BOX 100) T17	1	box	$30.00	$30.00	2	1
2350	BUILDING PAPER 60M X 1350MM ANTI GLARE	1	each	$90.00	$90.00	2	1
2351	FOIL FIX STRIP (PER BOX 10)	7	box	$8.50	$59.50	2	1
2355	PORTA STRAP 30MM X 1MM X 30M ROLL	1	each	$22.34	$22.34	2	1
2358	LOOPED CYCLONE STRAPS X600MM EACH	6	each	$0.72	$4.32	2	1
2360	MULTI- GRIPS 100 X 35MM	100	each	$0.36	$36.00	2	1
23610	CHEMSET 101 INJECTION C101C - 380mL TUBE	1	each	$22.50	$22.50	2	1
2362	M12 CHEMSET STUD ANCHOR	10	each (per	$1.14	$11.40	2	1
23631	M12 X 65MM CUP HEAD BOLTS GAL INCL NUT AND WASHER	64	each	$1.27	$81.28	2	1
23726	M16 X 75MM HEX HEAD BOLTS GAL GAL INCL NUT AND WASHER	5	each	$0.86	$4.30	2	1
		Total 290 FRAME HARDWARE			$770.19		

298 EXTERNAL FRAME CARPENTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2605	SET UP BOND BEAM AND POUR	56.6	lin.m	$5.00	$283.00	2	1
2608	EXTRA TO STAND TRUSSES AND BATTEN FOR SPANS 8.0M AND OVER	156.6	m2	$1.10	$172.26	2	1
2609	STAND & BRACE TRUSSES ONLY-BATTENS BY OTHERS	156.6	m2	$6.60	$1,033.56	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

298 EXTERNAL FRAME CARPENTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2613	GABLE END CONSTRUCTION	22.8	m2	$19.80	**$451.44**	2	1
2623	FABRICATE & STAND EXTERNAL/ INTERNAL LOAD BEARING WALL FRAMES INCL CYCLONE RODS	10	lin.m	$26.40	**$264.00**	2	1
	Total 298 EXTERNAL FRAME CARPENTER				**$2,204.26**		

300 INTERNAL FRAME CARPENTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2622	FABRICATE & STAND INTERNAL WALL FRAMES	39.5	lin.m	$22.00	**$869.00**	2	1
2634	INSTALL METAL CEILING BATTENS	156.6	m2	$1.40	**$219.24**	2	1
2636	PLY BRACING INSTALLATION	6	sheet	$13.20	**$79.20**	2	1
26361	TIMBER BRACE WALL CONSTRUCTION	2	each	$0.00	**$0.00**	2	1
2680	FIX NOGGIN	1	each	$16.50	**$16.50**	2	1
	Total 300 INTERNAL FRAME CARPENTER				**$1,183.94**		

320 ROOF SUNDRIES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2724	SUPPLY & INSTALL PINK BATTS R2.5	134.28	m2	$5.68	**$762.71**	2	1
	Total 320 ROOF SUNDRIES				**$762.71**		

325 ROOF CONTRACTOR

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2701	SUPPLY AND INSTALL COLORBOND FASCIA AND GUTTER (NETT LENGTH)	37.8	lin m	$28.67	**$1,083.73**	2	1
2702	SUPPLY AND INSTALL COLORBOND FASCIA (NETT LENGTH)	31.5	lin m	$16.78	**$528.57**	2	1
2703	SUPPLY AND INSTALL PVC DOWNPIPES TO 3.0M	6	each	$50.00	**$300.00**	2	1
2709	SUPPLY AND INSTALL 0.75 BMT CYCLONIC RATED METAL ROOF BATTENS	307.5	lin m	$5.14	**$1,580.55**	2	1
27095	SUPPLY AND INSTALL INTERMEDIATE SAFETY BATTENS	115.9	lin m	$1.79	**$207.46**	2	1
2755	SUPPLY AND INSTALL COLORBOND CUSTOM ORB (NETT AREA)	203.2	m2	$22.21	**$4,513.07**	2	1
2765	SUPPLY AND INSTALL COLORBOND BARGE CAPPING (NETT LENGTH)	31.5	lin m	$23.69	**$746.24**	2	1
2767	SUPPLY AND INSTALL COLORBOND ROLL TOP RIDGE (NETT LENGTH)	18.3	lin m	$15.80	**$289.14**	2	1
2771	SUPPLY AND INSTALL COLORBOND APRON FLASHING (NETT LENGTH)	4.8	lin m	$23.69	**$113.71**	2	1
2780	ALLOWANCE FOR EDGE RESTRAINT	67.8	lin m	$13.16	**$892.25**	2	1
	Total 325 ROOF CONTRACTOR				**$10,254.71**		

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

335 PLUMBER - ROUGH IN

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1170	STANDARD WATER SERVICE SINGLE FLOOR SLAB ON GROUND	1	each	$1,900.00	**$1,900.00**	2	1
1172	EXTRA FOR WATER SERVICE TO ENSUITE	1	each	$200.00	**$200.00**	2	1
1173	WATER SERVICE TO EACH ADDITIONAL FIXTURE	-1	each	$110.00	**-$110.00**	2	1
				Total 335 PLUMBER - ROUGH IN	**$1,990.00**		

355 WINDOWS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
321130	SL 06-12 OBS XO	2	each	$128.52	**$257.04**	2	1
321220	SL 06-18 XO	5	each	$100.44	**$502.20**	2	1
321260	SL 06-24 OXXO	1	each	$208.17	**$208.17**	2	1
321930	S1218 XO	1	each	$226.19	**$226.19**	2	1
322840	S1818 OX/OX	1	each	$411.70	**$411.70**	2	1
324790	S2330 OXXO SGD	1	each	$1,123.05	**$1,123.05**	2	1
326440	INSTALL PINE REVEALS & DPC TO WINDOWS & SGDS	3	each	$10.00	**$30.00**	2	1
326450	PINE REVEALS 116X19 MM	15.9	lin m	$10.00	**$159.00**	2	1
326470	INSTALL WINDOWS	6	each	$55.00	**$330.00**	2	2
326490	INSTALL COMBINATION WINDOWS	1	each	$85.00	**$85.00**	2	2
326530	INSTALL OX SLIDING GLASS DOORS	1	each	$95.00	**$95.00**	2	2
326570	DELIVERY WINDOWS	1	each	$80.00	**$80.00**	2	1
				Total 355 WINDOWS	**$3,507.35**		

360 LOCK-UP CARPENTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2624	FIX FC TO RAKING EAVES/SOFFITS	28.8	lin.m	$11.00	**$316.80**	2	1
2625	FIX FC TO HORIZONTAL EAVES/SOFFITS	31.4	lin.m	$11.00	**$345.40**	2	1
263700	WALL CLADDING (STRIA CLADDING OR SIMILAR WEATHERBOARD)	20.08	m2	$33.00	**$662.64**	2	1
26375	WALL CLADDING SHEETING- HARDITEX/AXON OR SIMILAR	11.12	m2	$16.50	**$183.48**	2	1
2661	FIT EXTERNAL DOOR IN TIMBER FRAME INCLUDING WEATHERSEAL	2	each	$82.50	**$165.00**	2	1
2663	FIT INTERNAL DOORS INCL JAMBS, STOPS ARCS & HARDWARE	1	each	$71.50	**$71.50**	2	1
2668	FIT WINDOWS & SGDs	3	each	$55.00	**$165.00**	2	1
26687	INSTALL FLASHING TO WINDOW/DOOR HEAD	6.3	lin.m	$13.20	**$83.16**	2	2
2845	INSTALL SISALATION	35.76	m2	$1.00	**$35.76**	2	1
				Total 360 LOCK-UP CARPENTER	**$2,028.74**		

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

365 EXTERNAL DOORS / FRAMES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3778	EXTERNAL FEATURE DOOR 2040MM HIGH x 820MM WIDE	1	each	$454.55	**$454.55**	2	1
3792	DURACOTE EXTERNAL DOOR 820X2040MM	1	each	$109.00	**$109.00**	2	1
3800	PRE-PRIMED TREATED PINE 140X32 JAMBS	10.2	lin m	$8.01	**$81.70**	2	1
3801	TREATED PINE 32X12 STOPS	10.2	lin m	$0.96	**$9.79**	2	1
3805	DELIVERY	1	each	$95.00	**$95.00**	2	1
3840	HIRLINE HINGE 100MM	2	each	$1.00	**$2.00**	2	1
38410	HIRLINE HINGE 100X75X1.6mm	2	each	$3.00	**$6.00**	2	1
386410	HUMES DOOR 2040 HIGH	1	each	$48.60	**$48.60**	2	1
3911	92X19MM FJP DAR	5.4	lin m	$3.16	**$17.06**	2	1
3916	32X12MM FJP DAR	5.4	lin m	$0.97	**$5.24**	2	1
	Total 365 EXTERNAL DOORS / FRAMES				**$828.95**		

400 CABINETMAKER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3521	FLOOR CUPBOARDS	4.7	lin.m	$641.00	**$3,012.70**	2	1
3522	LEVEL BAR 800MM	1.5	lin.m	$662.00	**$993.00**	2	1
3526	FRIDGE GABLE	1	each	$126.00	**$126.00**	2	1
3527	MICROWAVE CUPBOARD	1	each	$504.00	**$504.00**	2	1
3529	UNDERBENCH OVEN PROVISION	1	each	$189.00	**$189.00**	2	1
3530	1 DOOR PANTRY TO 600 WIDE	1	each	$693.00	**$693.00**	2	1
3533	OVERHEAD CUPBOARDS	2.4	lin.m	$378.00	**$907.20**	2	1
3537	RANGEHOOD CUTOUT	1	each	$126.00	**$126.00**	2	1
3540	VANITY OFF FLOOR CUPBOARDS	1.8	lin.m	$672.00	**$1,209.60**	2	1
3541	SET OF DRAWERS TO VANITY	2	each	$231.00	**$462.00**	2	1
3551	STANDARD EXTRAS OVER BASE KITCHEN	1	each	$1,166.00	**$1,166.00**	2	1
3556	20MM ENGINEERED (LOW END) STONE BENCHTOP-EXTRA OVER LAMINATE	4.8	m2 stone	$395.00	**$1,896.00**	2	1
	Total 400 CABINETMAKER				**$11,284.50**		

405 TILE SUPPLY

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3601	ALLOWANCE - BATHROOM WALL TILES	8.4	m2	$27.27	**$229.07**	2	1
3602	ALLOWANCE - ENSUITE WALL TILES	8.4	m2	$27.27	**$229.07**	2	1
3603	ALLOWANCE - BATHROOM SPASHBACK TILES	00.28	m2	$27.27	**$7.64**	2	1
3604	ALLOWANCE - ENSUITE SPASHBACK TILES	00.28	m2	$27.27	**$7.64**	2	1
3605	ALLOWANCE - KITCHEN SPASHBACK TILES	2.92	m2	$27.27	**$79.63**	2	1
3606	ALLOWANCE - LAUNDRY SPASHBACK TILES	00.36	m2	$27.27	**$9.82**	2	1
3607	ALLOWANCE - BATHROOM SKIRTING TILES	00.44	m2	$27.27	**$12.00**	2	1
3608	ALLOWANCE - ENSUITE SKIRTING TILES	00.64	m2	$27.27	**$17.45**	2	1
3611	ALLOWANCE - BATHROOM FLOOR TILES	3.84	m2	$27.27	**$104.72**	2	1
3612	ALLOWANCE - ENSUITE FLOOR TILES	5.8	m2	$27.27	**$158.17**	2	1
3616	ALLOWANCE - MAIN FLOOR TILES	44.6	m2	$27.27	**$1,216.24**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

405 TILE SUPPLY

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3620	ALLOWANCE - PATIO FLOOR TILES	24.6	m2	$27.27	**$670.84**	2	1
3628	ALUMINIUM ANGLE	15	each	$18.50	**$277.50**	2	3
3636	FEATURE TILE ALLOWANCE	1	each	$545.45	**$545.45**	2	1
3650	TILE DELIVERY	2	each	$65.00	**$130.00**	2	2
		Total 405 TILE SUPPLY			**$3,695.22**		

410 WARDROBES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
36642	SLIDING ROBE - 2400X1200 VINYL-INSTALLED	1	each	$274.76	**$274.76**	2	1
36651	SLIDING ROBE - 2400X1500 MIRROR PANELS-INSTALLED	1	each	$410.98	**$410.98**	2	1
36652	SLIDING ROBE - 2400X1500 VINYL-INSTALLED	1	each	$366.35	**$366.35**	2	1
36661	SLIDING ROBE - 2400X1800 MIRROR PANELS-INSTALLED	1	each	$439.96	**$439.96**	2	1
		Total 410 WARDROBES			**$1,492.05**		

415 FLOORCOVERINGS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3684	CARPET ALLOWANCE (A)	10.8	lin.m	$150.00	**$1,620.00**	2	1
		Total 415 FLOORCOVERINGS			**$1,620.00**		

417 WALL/CEILING INSULATION

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
27211	SUPPLY AND INSTALL R1.5 BATTS TO EXTERNAL WALLS~	12.96	m2	$5.20	**$67.39**	2	1
		Total 417 WALL/CEILING INSULATION			**$67.39**		

424 PLASTERBOARD CONTRACTOR

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3752	10MM PLASTERBOARD TO CEILINGS NETT RATE	134.28	m2	$15.00	**$2,014.20**	2	1
3752003	10MM WR BOARD TO CEILINGS NETT RATE	22.36	m2	$18.25	**$408.07**	2	1
3753	10MM PLASTERBOARD TO PARTITIONS NETT RATE	221.92	m2	$14.00	**$3,106.88**	2	1
3754	PLASTERBOARD LINING TO CMB NETT RATE	91.28	m2	$14.00	**$1,277.92**	2	1
3755	EXTRA FOR 6MM VILLABOARD LINING NETT RATE	54	m2	$3.95	**$213.30**	2	1
37592	CONCERTO CORNICE	173.1	lin m	$12.10	**$2,094.51**	2	1
3760	PREPAINT	1	each	$215.00	**$215.00**	2	1
3763	MANHOLE	1	each	$50.00	**$50.00**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

424 PLASTERBOARD CONTRACTOR

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
376780	RETURN TO FIX CORNICE TO KITCHEN	1	each	$165.00	$165.00	2	1
376781	RETURN TO FIX CORNICE TO WET AREA	1	each	$75.00	$75.00	2	2

Total 424 PLASTERBOARD CONTRACTOR **$9,619.88**

425 DOOR LOCKS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3816	TRILOCK ENTRANCE LEVER SET	1	each	$173.95	$173.95	2	1
3820	REAR/ GARAGE ENTRANCE SET	2	each	$70.00	$140.00	2	1
3829	INTERNAL DOOR PASSAGE SETS	2	each	$38.10	$76.20	2	1
3831	INTERNAL PRIVACY SET	2	each	$54.58	$109.16	2	1
3833	CAVITY SLIDING DOOR PRIVACY SET	1	each	$31.29	$31.29	2	1
3834	CAVITY SLIDING DOOR PASSAGE SET	1	each	$18.71	$18.71	2	1
38403	HIRLINE HINGE 100MM-STAINLESS STEEL	6	each	$4.20	$25.20	2	1
38405	LIFT OFF HINGE 100MM -STAINLESS STEEL	2	each	$4.50	$9.00	2	1
38410	HIRLINE HINGE 100X75X1.6mm	3	each	$3.00	$9.00	2	1
3844	MAGNETIC DOOR STOP / CATCH	7	each	$9.80	$68.60	2	1
3848	RP4 STORM SEAL 915mm	2	each	$17.15	$34.30	2	1
38488	RP60 DOOR SEAL 915mm	1	each	$16.83	$16.83	2	1
3849	DELIVERY DOOR LOCKS	1	each	$20.00	$20.00	2	1

Total 425 DOOR LOCKS **$732.24**

430 INTERNAL DOORS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
38641	HUMES ACCENT DOOR 2040 HIGH	6	each	$53.30	$319.80	2	1
3890	DELIVERY INTERNAL DOORS	1	each	$95.00	$95.00	2	1

Total 430 INTERNAL DOORS **$414.80**

435 FINISHING TIMBER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3900	68 X 12MM FJP SKIRT/ARCHITRAVE	286.2	lin m	$1.54	$440.75	2	1
3910	116X19MM FJP DAR	10.8	lin m	$4.35	$46.98	2	1
3911	92X19MM FJP DAR	64.8	lin m	$3.16	$204.77	2	1
3912	68X19MM FJP DAR	59.4	lin m	$2.46	$146.12	2	1
3913	42X19MM FJP DAR	48.6	lin m	$1.65	$80.19	2	1
3916	32X12MM FJP DAR	21.6	lin m	$0.97	$20.95	2	1
3956	P/BOARD EDGE LIP SHELVING 2400 X 450 X 16MM	4	each	$21.33	$85.32	2	1
3957	P/BOARD EDGE LIP SHELVING 3600 X 450 X 16MM	8	each	$31.99	$255.92	2	1
3960	DELIVERY FINISHING TIMBER	1	each	$95.00	$95.00	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

Total 435 FINISHING TIMBER	**$1,376.00**

440 FINISHING HARDWARE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
4101	19MM S/S CURTAIN ROD	9	lin.m	$5.00	**$45.00**	2	1
4102	19MM DIA PILLAR ENDS (PAIR)	5	pair	$2.10	**$10.50**	2	1
4103	19MM DIA PILLAR CENTRE	5	each	$1.10	**$5.50**	2	1
				Total 440 FINISHING HARDWARE	**$61.00**		

445 FINISHING CARPENTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2647	FIT LAUNDRY TUB	1	each	$27.50	**$27.50**	2	1
2663	FIT INTERNAL DOORS INCL JAMBS, STOPS ARCS & HARDWARE	4	each	$71.50	**$286.00**	2	1
2665	FIT INTERNAL SLIDING DOORS INCL JAMBS, ARCS & HARDWARE	2	each	$88.00	**$176.00**	2	1
2666	FIX SKIRTING	85.4	lin.m	$3.10	**$264.74**	2	1
2667	EXTRA FOR TIMBER REVEALS TO WINDOWS	8	each	$60.50	**$484.00**	2	1
26685	FIT ARCHITRAVES TO WINDOWS/ SGDS	3	each	$33.00	**$99.00**	2	1
2674	JAMB & ARC ROBE OPENING	4	each	$33.00	**$132.00**	2	1
2675	FITOUT ROBES WITH SHELF & HANGING RAIL	5	each	$66.00	**$330.00**	2	1
2676	EXTRA FOR NEST OF SHELVES IN ROBE	4	each	$99.00	**$396.00**	2	1
2677	FITOUT LINEN INCL 4 SHELVES AND BROOM SPACE	1	each	$176.00	**$176.00**	2	1
2678	FITOUT PANTRY INCL 4 SHELVES	1	each	$165.00	**$165.00**	2	1
2679	FIT CANOPY RANGEHOOD INCL FLEXIDUCT INTO ROOF SPACE	1	each	$132.00	**$132.00**	2	1
				Total 445 FINISHING CARPENTER	**$2,668.24**		

465 WATERPROOFING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5155	WATERPROOF FLASHING	9	lin m	$15.50	**$139.50**	2	1
5178	WATERPROOF SHOWER 900 X 1500 TILED BASE	2	each	$198.50	**$397.00**	2	1
5182	SUPPLY & INSTALL WATERSTOP ANGLE	4	lin.m	$17.00	**$68.00**	2	1
5184	SHOWER WASTES -SUPPLY INSTALL AND WATERPROOF	2	each	$30.00	**$60.00**	2	1
5221	SUPPLY & INSTALL CHROME FLOOR WASTE GRATE/ PUDDLE FLANGE	1	each	$25.00	**$25.00**	2	1
				Total 465 WATERPROOFING	**$689.50**		

470 CERAMIC TILING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5205	FIX WALL TILING INCL GLUE & GROUT	14	m2	$38.00	**$532.00**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

470 CERAMIC TILING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5207	FIX FLOOR TILING INCL GLUE & GROUT	8.04	m2	$36.00	**$289.44**	2	1
5209	FIX SPLASHBACK WALL TILING INCL GLUE & GROUT	3.2	m2	$38.00	**$121.60**	2	1
5211	FIX SKIRTING TILING INCL GLUE & GROUT	9	lin m	$15.00	**$135.00**	2	1
5218	BED RECESSED FLOOR PRIOR TO TILING	2.8	m2	$75.00	**$210.00**	2	1
5224	INSTALL SMART TILE FLOOR WASTE	4	each	$30.00	**$120.00**	2	1
5225	FIX LARGE FLOOR AREAS INCL GLUE & GROUT	40.56	m2	$36.00	**$1,460.16**	2	1
5227	FIX PATIO FLOOR AREAS INCL GLUE & GROUT	22.36	m2	$36.00	**$804.96**	2	1
5233	SILICONE INTERNAL ANGLES -SINGLE BATHROOM ALLOWANCE	1	item	$80.00	**$80.00**	2	1
52335	SILICONE INTERNAL ANGLES -EXTRA BATHROOM ALLOWANCE	1	each	$60.00	**$60.00**	2	1
5235	MITRE EXTERNAL ANGLES	3	lin m	$18.00	**$54.00**	2	1
5237	DOOR THRESHOLD/ ALUMINIUM ANGLE	4	each	$15.00	**$60.00**	2	1
5238	TILE NICHE	2	each	$65.00	**$130.00**	2	1
5239	EXPANSION JOINT IN TILE FLOORING	15.3	lin m	$7.00	**$107.10**	2	1
		Total 470 CERAMIC TILING			**$4,164.26**		

475 SHOWER SCREENS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5354	SEMI FRAMELESS 2000 X 1400MM PIVOT SHOWER SCREEN SUPPLIED & INSTALLED	2	each	$1,056.86	**$2,113.72**	2	1
5380	SHOWER SCREEN DELIVERY	1	each	$31.50	**$31.50**	2	1
		Total 475 SHOWER SCREENS			**$2,145.22**		

480 MIRRORS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5431	900 X 900 POLISHED EDGE MIRROR SUPPLIED & INSTALLED	2	each	$170.00	**$340.00**	2	1
		Total 480 MIRRORS			**$340.00**		

483 PLUMBING - FLOOR WASTE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
3626	SUPPLY SMART TILE FLOOR WASTE	4	each	$61.60	**$246.40**	2	1
		Total 483 PLUMBING - FLOOR WASTE			**$246.40**		

486 PLUMBING - HWS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

486 PLUMBING - HWS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
561448	APRICUS 315 LITRE ELECTRIC HOT WATER SYSTEM (SOLAR READY)	1	each	$995.00	**$995.00**	2	1
				Total 486 PLUMBING - HWS	**$995.00**		

505 PLUMBING - PC ITEMS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5514	MINI CISTERN COCK Q/T WITH NON RETURN VALVE	2	each	$7.18	**$14.36**	2	1
55140	WASHING MACHINE COCK (1 ONLY) C/D WITH NON RETURN VALVE	1	each	$5.90	**$5.90**	2	1
5515	HOSE COCK BALL WITH LEVER HANDLE 15MM	2	each	$9.26	**$18.52**	2	1
5516	BACK FLOW PREVENTION DEVICE DUAL CHECK	1	each	$34.68	**$34.68**	2	1
5520	BUSH BRS 20 X 15MM	1	each	$4.36	**$4.36**	2	1
5603	PLUMBING PC ITEMS AS QUOTED	1	each	$0.00	**$0.00**	2	1
5625	NUGLEAM SUPREME 45L S/S TUB & PVC CABINET	1	each	$227.53	**$227.53**	2	1
5669	WC SUITE	2	each	$175.20	**$350.40**	2	1
5680	DOUBLE TOWEL RAIL	2	each	$49.70	**$99.40**	2	1
5684	TOILET ROLL HOLDER	2	each	$18.99	**$37.98**	2	1
5751	DELIVERY SINKS/ BASINS	1	each	$15.00	**$15.00**	2	1
5752	DELIVERY PLUMBING BATHS	1	each	$15.00	**$15.00**	2	1
5753	DELIVERY PLUMBING PC ITEMS	1	each	$16.00	**$16.00**	2	1
5805	BASIN SET	2	each	$75.02	**$150.04**	2	1
5807	SHOWER SET	2	each	$186.69	**$373.38**	2	1
5808	LAUNDRY SET	1	each	$82.73	**$82.73**	2	1
5809	WASHING MACHINE TAPS	1	each	$11.80	**$11.80**	2	1
5820	SINK SET	1	each	$82.73	**$82.73**	2	1
				Total 505 PLUMBING - PC ITEMS	**$1,539.81**		

510 PAINTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
5960	LIVING/ GARAGE AREA PAINTERS RATE	134.28	m2	$40.00	**$5,371.20**	2	1
5965	CARPORT/ PATIO AREA PAINTERS RATE	22.36	m2	$40.00	**$894.40**	2	1
5974	PAINT INTERNAL WALLS	89.4	m2	$25.00	**$2,235.00**	2	1
5980	EXTRA TO PAINT EXTERNAL CLADDING BOARDS TO GABLES	11.68	m2	$15.00	**$175.20**	2	1
59806	EXTRA TO PAINT RAISED GABLE ENDS	2	each	$100.00	**$200.00**	2	1
59808	EXTRA TO PAINT EXTERNAL CLADDING BOARDS TO WALLS	8.4	m2	$5.00	**$42.00**	2	1
5981	EXTRA TO PAINT EXTERNAL FC CLADDING SHEETS TO RAISED AREAS	11.12	m2	$10.00	**$111.20**	2	1
6059	STAIN ENTRY DOOR	1	each	$200.00	**$200.00**	2	1
6061	PAINT MASONARY/ HEBEL LETTERBOX	1	each	$80.00	**$80.00**	2	1
6062	ALLOWANCE FOR FEATURE WALL	2	each	$300.00	**$600.00**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

	Total 510 PAINTER	**$9,909.00**

515 PLUMBER - FIT-OFF

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
1179	STANDARD FITOUT	1	each	$1,700.00	**$1,700.00**	2	1
1180	FITOUT FOR ENSUITE	1	each	$400.00	**$400.00**	2	1
1181	EXTRA FITOUT PER FIXTURE	-1	each	$110.00	**-$110.00**	2	1
1183	EXTRA FOR HOSE TAP WITH VACUUM BREAKER	1	each	$200.00	**$200.00**	2	1
11832	EXTRA FOR FITTING FRIDGE CONNECTED TO COLD WATER	1	each	$200.00	**$200.00**	2	1
				Total 515 PLUMBER - FIT-OFF	**$2,390.00**		

520 APPLIANCES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6121	COOKTOP (A)	1	each	$525.00	**$525.00**	2	1
6131	OVEN (A)	1	each	$1,045.45	**$1,045.45**	2	1
6151	RANGEHOOD (A)	1	each	$417.27	**$417.27**	2	1
6156	DISHWASHER	1	each	$820.00	**$820.00**	2	1
6157	DUCTING FOR RANGEHOOD	1	each	$160.00	**$160.00**	2	2
6159	DELIVERY	1	each	$40.00	**$40.00**	2	2
				Total 520 APPLIANCES	**$3,007.72**		

530 ELECTRICAL FITTINGS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6197	LIGHT FITTING PC PER FITTING	26	each	$27.27	**$709.02**	2	1
6212	48" WHITE CEILING FAN	6	each	$65.00	**$390.00**	2	1
6213	290MM SQUARE WHITE EXHAUST FAN	2	each	$60.91	**$121.82**	2	1
				Total 530 ELECTRICAL FITTINGS	**$1,220.84**		

545 FINAL CARPENTER

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
2681	FIT ACCESSORIES	6	each	$12.00	**$72.00**	2	1
2682	FINAL FITOUT	1	each	$330.00	**$330.00**	2	1
				Total 545 FINAL CARPENTER	**$402.00**		

550 A.C & SPECIAL APPLIANCES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
63100	INVERTER SPLIT UNIT 9,000 BTU -2.5kW	3	each	$599.00	**$1,797.00**	2	1

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

550 A.C & SPECIAL APPLIANCES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
63162	INVERTER SPLIT UNIT 28,000 BTU - 8.0kW	1	each	$2,037.00	**$2,037.00**	2	1
	Total 550 A.C & SPECIAL APPLIANCES				**$3,834.00**		

552 INSTALL A.C & SPECIAL APPLIANCES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
631700	AIRCONDITIONING SPECIFICATION	1	item	$0.00	**$0.00**	2	1
6318	SPLIT SYSTEM A.C INSTALLATION 7000-12000	3	each	$600.00	**$1,800.00**	2	1
6319	SPLIT SYSTEM A.C INSTALLATION 21000-30000	1	each	$600.00	**$600.00**	2	1
	Total 552 INSTALL A.C & SPECIAL APPLIANCES				**$2,400.00**		

570 SCREENS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
328055	SL 06-12 XO SECURITY SCREENS	2	each	$49.03	**$98.06**	2	1
328095	SL 06-18 XO SECURITY SCREENS	5	each	$63.57	**$317.85**	2	1
328135	SL 06-24 OXXO SECURITY SCREENS	1	each	$91.58	**$91.58**	2	1
328605	S1218 XO SECURITY SCREENS	1	each	$94.27	**$94.27**	2	1
329260	S1818 OX/OX SECURITY SCREENS	1	each	$165.38	**$165.38**	2	1
331155	S2330 OXXO SGD SECURITY SCREENS	1	each	$436.41	**$436.41**	2	1
331890	HINGED DOOR 820 X 2040MM SECURITY SCREEN	1	each	$291.38	**$291.38**	2	1
331915	DELIVERY SCREENS	1	each	$0.00	**$0.00**	2	1
	Total 570 SCREENS				**$1,494.93**		

590 GARAGE DOORS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6924	PANEL LIFT DOOR 2400X5200	1	each	$1,680.00	**$1,680.00**	2	1
69301	REMOTE CONTROL TO PANELIFT DOOR	1	each	$390.00	**$390.00**	2	1
	Total 590 GARAGE DOORS				**$2,070.00**		

595 HOUSE CLEAN

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6912	INTERNAL HOUSE CLEAN	134.28	m2	$2.50	**$335.70**	2	1
6913	HOUSE CLEAN -PATIOS & CARPORTS	22.36	m2	$2.50	**$55.90**	2	1
	Total 595 HOUSE CLEAN				**$391.60**		

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

625 EXTERNAL CONCRETING

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6557	SUPPLY & INSTALL EXPOSED AGGREGATE DRIVEWAY	65	m2	$76.00	**$4,940.00**	2	1
65574	90MM PIPE CONDUIT UNDER DRIVEWAY	1	each	$45.00	**$45.00**	2	1
6563	LAUNDRY STEP	1	each	$150.00	**$150.00**	2	1
6566	FORM, PLACE & FINISH HOT WATER SYSTEM SLAB	1	each	$150.00	**$150.00**	2	1
	Total 625 EXTERNAL CONCRETING				**$5,285.00**		

640 CLOTHESLINES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
659110	HILLS EVERYDAY SINGLE WALL MOUNTED CLOTHESLINE	1	each	$240.91	**$240.91**	2	1
65930	INSTALL WALL MOUNTED CLOTHESLINE	1	each	$0.00	**$0.00**	2	1
	Total 640 CLOTHESLINES				**$240.91**		

645 LETTERBOXES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
65955	STANDARD RENDERED HEBEL LETTERBOX - COMPLETE	1	each	$370.00	**$370.00**	2	1
	Total 645 LETTERBOXES				**$370.00**		

665 SITE CLEAN

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6931	PROVISIONAL ALLOWANCE FOR TWO SITE CLEANS. INC. TIP FEES	1	each	$500.00	**$500.00**	2	1
6932	SITE CLEAN AREA ALLOWANCE	156.6	m2	$2.50	**$391.50**	2	1
	Total 665 SITE CLEAN				**$891.50**		

670 SKIP HIRE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
6955	SKIP HIRE	3	each	$420.00	**$1,260.00**	2	1
	Total 670 SKIP HIRE				**$1,260.00**		

700 MISCELLANEOUS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld

ERP2021
Bill of Quantities

23 May 2021

Job 000 EXAMPLE ESTIMATE

700 MISCELLANEOUS

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
7301	MISCELLANEOUS HARDWARE	1	each	$200.00	**$200.00**	2	1
7305	MISCELLANEOUS LABOUR	1	hour	$50.00	**$50.00**	2	1
7310	MISCELLANEOUS MATERIALS	1	each	$200.00	**$200.00**	2	1
	Total 700 MISCELLANEOUS				**$450.00**		

705 TEMPORARY SERVICES

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
7352	ALLOWANCE FOR TEMPORARY POWER	1	each	$100.00	**$100.00**	2	1
	Total 705 TEMPORARY SERVICES				**$100.00**		

710 CONTINGENCY

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
7453	CONTINGENCY	156.6	m2	$5.00	**$783.00**	2	1
	Total 710 CONTINGENCY				**$783.00**		

715 MAINTENANCE

Item	Descrip ion	Quantity	Units	Rate	Amount	Lvl	Ld
7481	MAINTENANCE PER JOB	1	each	$250.00	**$250.00**	2	1
	Total 715 MAINTENANCE				**$250.00**		

Total 000 EXAMPLE ESTIMATE **$173,582.44**

Appendix T – Example cost summary

Please see following pages for this appendix document.

ERP2021 - Sample Data
Bill Summary

6 September 2021

000 **EXAMPLE ESTIMATE**

	Cost Centre	Amount	
005	PREL MINARIES	$120.00	.1%
015	CONSULTANCY FEES	$400.00	.2%
030	SOIL TEST	$375.00	.2%
035	ENGINEER	$730.00	.4%
045	ENERGY EFFICIENCY	$120.00	.1%
055	WORKPLACE HEALTH & SAFETY	$227.27	.1%
070	CERTIFICATION AND COUNCIL FEES	$1,895.00	1.1%
075	COUNCIL FEES - HYDRAULICS	$2,003.00	1.2%
	1 PRELIMINARIES	**$5,870.27**	**3%**
100	SURVEYOR	$227.28	.1%
105	EQUIPMENT HIRE	$1,060.00	.6%
115	EARTHWORKS	$313.20	.2%
130	PLANT MACHINE HIRE	$1,254.75	.7%
135	CONCRETE PUMP FOOTING	$712.60	.4%
140	FOOTING / SLAB REINFORCING	$3,128.36	1.8%
145	FOOTING CONCRETE	$1,860.00	1.1%
160	PLUMBER - DRAINS	$2,910.00	1.7%
165	TERMITE TREATMENT	$2,436.75	1.4%
170	SAND AND GRAVEL	$1,815.60	1.0%
180	SLAB FINISHER	$4,594.80	2.6%
185	SLAB CONCRETE	$6,360.00	3.7%
190	CONCRETE PUMP SLAB	$1,387.60	.8%
	2 BASE	**$28,060.94**	**16%**
200	BLOCK LAYER	$7,492.90	4.3%
202	CONCRETE MASONARY	$4,965.20	2.9%
205	BOND BEAM STEEL	$1,034.94	.6%
212	TRUSS TIE DOWNS	$139.40	.1%
216	BOND BEAM PUMP	$680.80	.4%
218	BOND BEAM CONCRETE	$1,166.40	.7%
223	ELECTRICIAN	$7,565.00	4.4%
230	RENDER AND APPLIED FINISHES	$3,183.60	1.8%
235	SCAFFOLDING	$311.30	.2%
255	CRANE HIRE	$633.75	.4%
260	TRUSSES	$4,264.78	2.5%
270	NON-STRUCTURAL FRAMING TIMBER	$1,453.37	.8%
275	STRUCTURAL FRAMING TIMBER	$1,624.44	.9%
285	FC SHEETING / CLADDING	$1,702.49	1.0%
290	FRAME HARDWARE	$770.19	.4%
298	EXTERNAL FRAME CARPENTER	$2,204.26	1.3%
	3 FRAME	**$39,192.82**	**23%**
300	INTERNAL FRAME CARPENTER	$1,183.94	.7%

ERP2021 - Sample Data
Bill Summary

6 September 2021

000 **EXAMPLE ESTIMATE**

	Cost Centre	Amount	
320	ROOF SUNDRIES	$762.71	.4%
325	ROOF CONTRACTOR	$10,254.71	5.9%
335	PLUMBER - ROUGH IN	$1,990.00	1.1%
355	WINDOWS	$3,507.35	2.0%
360	LOCK-UP CARPENTER	$2,028.74	1.2%
365	EXTERNAL DOORS / FRAMES	$828.95	.5%
	4 ENCLOSED	**$20,556.40**	**12%**
400	CABINETMAKER	$11,284.50	6.5%
405	TILE SUPPLY	$3,695.22	2.1%
410	WARDROBES	$1,492.05	.9%
415	FLOORCOVERINGS	$1,620.00	.9%
417	WALL/CEILING INSULATION	$67.39	.0%
424	PLASTERBOARD CONTRACTOR	$9,619.88	5.5%
425	DOOR LOCKS	$732.24	.4%
430	INTERNAL DOORS	$414.80	.2%
435	FINISHING TIMBER	$1,376.00	.8%
440	FINISHING HARDWARE	$61.00	.0%
445	FINISHING CARPENTER	$2,668.24	1.5%
465	WATERPROOFING	$689.50	.4%
470	CERAMIC TILING	$4,164.26	2.4%
475	SHOWER SCREENS	$2,145.22	1.2%
480	MIRRORS	$340.00	.2%
483	PLUMBING - FLOOR WASTE	$246.40	.1%
486	PLUMBING - HWS	$995.00	.6%
	5 FIXING	**$41,611.71**	**24%**
505	PLUMBING - PC ITEMS	$1,539.81	.9%
510	PAINTER	$9,909.00	5.7%
515	PLUMBER - FIT-OFF	$2,390.00	1.4%
520	APPLIANCES	$3,007.72	1.7%
530	ELECTRICAL FITTINGS	$1,220.84	.7%
545	FINAL CARPENTER	$402.00	.2%
550	A.C & SPECIAL APPLIANCES	$3,834.00	2.2%
552	INSTALL A.C & SPECIAL APPLIANCES	$2,400.00	1.4%
570	SCREENS	$1,494.93	.9%
590	GARAGE DOORS	$2,070.00	1.2%
595	HOUSE CLEAN	$391.60	.2%
625	EXTERNAL CONCRETING	$5,285.00	3.0%
640	CLOTHESLINES	$240.91	.1%
645	LETTERBOXES	$370.00	.2%
665	SITE CLEAN	$891.50	.5%
670	SKIP HIRE	$1,260.00	.7%
700	MISCELLANEOUS	$450.00	.3%

ERP2021 - Sample Data
Bill Summary

6 September 2021

000 **EXAMPLE ESTIMATE**

	Cost Centre	Amount	
705	TEMPORARY SERVICES	$100.00	.1%
710	CONTINGENCY	$783.00	.5%
715	MAINTENANCE	$250.00	.1%
	6 PRACTICAL COMPLETION	**$38,290.31**	**22%**
	Total	**$173,582.44**	
	Plus **10.00%** GST	**$17,358.24**	
	Total	**$190,940.68**	