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Developing a predictive model for quantity estimation of tie columns and lintel beams in residential construction

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Abstract

Accurate construction cost estimation is at the root of any effective project planning, yet it often requires extensive expertise and time-consuming calculations. This paper discusses a predictive equation for estimating the quantity of tie columns and lintel beams in a two-story residential building. In this study, multiple linear regression analysis was employed to identify the significant variables that impact the quantity of those structural elements using 75 sets of residential drawings, all of which featured conventional two-story brick masonry construction with reinforced concrete frames. The formulated equation, where Y represents the total linear meters of tie columns and lintel beams combined, is expressed as Y = 1.834 + 1.243 (brick wall area in m²) - 0.639 (open space area in m²). The equation was checked against fifteen residential designs with detailed estimates. The percentage error was observed to be between -3.58% and 5.37%, which is considered within an acceptable limit for preliminary estimates. This equation could provide a useful tool for cost estimators, offering a much-simplified approach yet yielding reasonable accuracy for preliminary assessments of the structural quantities of buildings. This research highlights the equation's potential for improving efficiency in project planning and cost estimation within its defined scope, with further validation across a wider range of designs recommended to broaden its applicability.

Keywords: Construction cost estimation, Tie column-lintel beam, Multiple Linear Regression, Residential buildings, Predictive modeling

1. Introduction

Construction cost estimation is considered a crucial factor for project success [1-5]. Cost estimation involves assessing and predicting the possible costs of a project based on available data [6]. It is a vital initial step before proceeding with any construction [7].Quick and accurate cost estimation facilitates various decision-making processes in project planning [8]. It serves as an indicator of success for contractors or project owners. Inaccurate or misguided cost estimations can lead to project losses or budget misalignments that do not reflect actual construction costs [9]. Erroneous cost estimations may result in project failure. Cost estimation, therefore, is a primary factor in avoiding project failures [10, 11]. Conversely, accurate cost estimation is a key to a project success [12].

The purpose of cost estimation varies. For example, it can be used to establish project budgets [13]; evaluate project benefits for investment suitability; control project budgets; and establish project baseline prices for consideration of designers during the construction process [14]. Additionally, it helps control construction costs to determine work values for payment requests during the construction [15]. Existing several cost estimation methods are generally divided into two categories: rough estimation and detailed estimation. Rough estimation involving multiplying unit prices by the area of the building is suitable for preliminary budgeting for new projects. Despite the advantage of speed, it may indulge high margins of error due to lack of accurate data or experience which could lead to potential project losses. Detailed estimation, on the other hand, is performed after having construction plans and specifications. It is typically done by construction contractors to prepare bids and control expenses during the construction phase. Alternatively, it may be done by project owners to establish baseline prices or control progress payments from contractors. Therefore, the detailed estimation requires experienced professionals and significant time investment [9, 13, 16, 17].

The detailed construction cost estimation consists of several steps as follows: (1) studying construction drawings, component lists, and specifications; (2) conducting site visits and receiving design clarifications; (3) quantity takeoff; (4) analyzing material and labor costs; (5) analyzing operational costs, taxes, profits, and interest; and (6) summarizing construction costs. Material costs typically account for 60 to 70% of the total construction costs. Accurate estimation of material costs helps alleviate various issues [18-21]. The quantity takeoff is a complex process that requires experienced estimators [22]. Accurate quantity takeoff is crucial for construction projects to closely match actual material usage. The accuracy of material quantity estimation is essential for construction cost estimation

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[23, 24]. Therefore, user-friendly tools that require minimal experience, for accountants or economists, can facilitate material quantity estimation or verification [25]. These tools could also assist government committees in establishing standard construction prices to quickly and conveniently verify material quantities without extensive time investment. Regression analysis is another technique commonly used in construction cost estimation. By establishing models based on the relationship between two or more variables, researchers aim to develop simple equations for estimating construction costs. In this respect, development of straightforward equations to estimate material quantities in two-story residential construction projects can provide a convenient, fast, accurate, and reliable means of verifying construction material quantities and closely approximating actual construction costs. For this study, a sample of 75 two-story residential construction drawings was analyzed. The aspects investigated included building area, brick wall area, open space area, height of brick walls, and the quantity of tie columns and lintel beams. The data obtained were analyzed using Statistical Package for the Social Sciences (SPSS) for Windows. The analysis aimed to identify independent variables that influence the dependent variables through linear regression. Subsequently, the analyzed data were used to create an equation for determining the quantity of tie columns and lintel beams.

2. Literature review

Research on the application of regression analysis techniques for construction cost estimation has been diverse. For example, in a study aimed at developing models to predict construction costs in Nigeria, it was found that factors influencing construction costs include (1) adequacy of equipment on the construction site; (2) contractor experience; (3) change orders; (4) team communication; and (5) difficulty level of the construction tasks [26]. In a study comparing construction cost estimations using multiple linear regression analysis and artificial neural networks in a primary school construction project, it was revealed that both methods have their own advantages [27]. The development of a labor productivity estimation model in the installation of lightweight floor tiles using multiple linear regression (MLR) showed promising results, with an average accuracy of 96.30% [28]. The use of parametric cost estimation, employing a combination of regression analysis and bootstrapping techniques to predict construction costs, has also been explored [29]. Additionally, regression analysis techniques have been employed to create equations for estimating construction costs in sandy coastal areas [30]. Developing regression analysis models to predict labor productivity in bricklaying construction projects in Iraq revealed that a multifactor linear regression model could predict labor productivity well with an accuracy level of 92.50% [31].

In another study, the development of mathematical models using multiple linear regression analysis was conducted to predict the costs of constructing communication towers in Iraq. It was found that the multifactor linear regression method accurately predicted construction costs with an accuracy level of 90.10%, an average percentage error of 9.89%, and a correlation coefficient (R) of 98.60% [32]. Furthermore, models were developed to forecast costs and project durations based on past data from similar projects. Statistical regression models were developed using real construction project data to predict construction costs and project durations using linear regression methods [33]. Applying linear regression techniques to predict construction costs in the Pune region of India, models achieved prediction accuracies ranging from 91 to 97% [34]. Similarly, predictive models were built to estimate the costs of construction projects in Iraq using multiple linear regression (MLR) with Weighted Least Square (WLS). It was found that MLR and WLS had the ability to predict construction costs with an accuracy level of 98.97% and the lowest absolute percentage error of 1.03% [35]. Developing mathematical models for predicting road construction durations in the West Bank area of Palestine using regression techniques revealed that the coefficient of determination (R^2) of the developed models ranged from 0.88 to 0.93, confirming a strong relationship between the dependent and independent variables. The mean absolute percentage error (MAPE) of the developed regression models ranged from 19.10 to 31.40% [36]. Creating multivariable linear regression models to predict house prices found that models such as Lasso, Lasso CV, Ridge, Ridge CV, and Multivariable Linear Regression worked best, achieving an accuracy of 84.50% [37]. Constructing polynomial multivariable linear regression models for predicting residential property prices concluded that these models could effectively predict and analyze residential property prices with high efficiency [38]. In developing regression models to estimate project cost budgets, the reliability of the model was tested through usage analysis. It was revealed that the maximum budget variance rate was 4.80% which falls within a 10% variance. Therefore, this model can be considered an efficient tool for analyzing construction project costs [39]. Creating preliminary parametric cost estimation models for tunnels, roads, and railways in project planning stages, utilizing multiple regression analysis, resulted in a high coefficient of determination (R^2) of 0.968. Additionally, the developed model was compared to actual construction costs, showing an accuracy in cost estimation of over 75%, indicating its suitability [40]. Predicting house prices accurately is conducive to government policies in appropriate regulation. It assists investors in devising accurate investment strategies and serves as a guideline for long-term real estate market development. By creating multiple linear regression models to predict and analyze the real estate market, research findings revealed that the maximum error rate of the house price prediction model does not exceed 8% indicating high accuracy and efficiency [41]. Developing preliminary cost estimation models for road construction projects using multiple regression analysis in the West Bank, Palestine, yielded results comparable to previous research standards [42]. As construction costs for buildings, influenced by material prices, human resources, and other cost-related factors, fluctuate significantly yearly, these could pose challenges in estimating construction expenses for the following year. Therefore, research was conducted to derive a formula for predicting residential development costs and creating a construction cost model using linear regression. The formula obtained for predicting construction costs for residential development is $y = 1{,}169{,}813.19+(334{,}729{,}758)x$ [43]. A preliminary parameter estimation model for road tunnels was developed utilizing multiple regression analysis [44]. Construction costs estimation and price escalation prediction are also crucial steps for project owners, estimators, and contractors. Construction costs often fluctuate, with tendencies to increase in the long term, making pricing a challenging process. The construction cost index (CCI) is widely used in project cost forecasting. However, the challenge lies in the absence of any organization providing estimates for this critical index. Artificial neural networks, linear regression, and autoregressive time series models have been employed to predict construction cost indices in Egypt [45]. Developing models to predict groundwater levels in Australia involved three methods: linear regression (LR), multilayer perceptron (MLP), and long short-term memory (LSTM) models [46]. Developing linear regression models to predict construction costs in the United Kingdom, the best-performing regression model, recorded a coefficient of determination (R^2) of 0.66 and an average mean absolute percentage error (MAPE) of 19.30 percent outperforming previous research [47]. Presenting guidelines for predicting the CCI of building materials in Pakistan, three techniques namely artificial neural networks (ANN), autoregressive time series, and linear regression were employed to forecast and predict the

CCI. The developed model can assist contractors, project managers, and owners by providing accurate estimates through CCI prediction, aiding in the accurate assessment of project budgets according to material prices [48]. Utilizing regression analysis techniques to formulate equations for estimating the quantity of small residential brick wall construction, the resulting equations are accurate and acceptable, facilitating convenient use and reducing work time [23]. Regression models and artificial neural networks have been developed to predict costs and project durations for the reconstruction of severely damaged schools in Taiwan due to earthquakes. The predictive performance of regression models varies depending on the contracting organization. Projects contracted by central government agencies yield predictions with a mean error rate of less than 10%. However, for projects contracted by local governments and the private sector, the average error rate increases to around 15% [49]. The development of a cost estimation model for sports stadium construction projects in Kenya using regression analysis techniques [50].

3. Methodology

To develop a practical and accurate equation for estimating the quantity of tie columns and lintel beams in two-story residential buildings, the research methodology was structured into three main phases: sample selection, data collection, and data analysis. Each phase consists of specific steps to ensure consistency and reliability of the results. The overall research workflow is as illustrated in Figure 1.

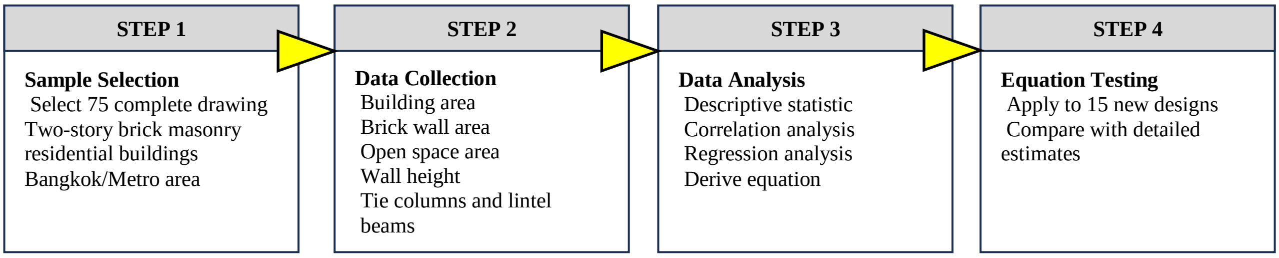

Figure 1 Workflow of the Research Methodology.

3.1 Sample selection

As the most constructed in Thailand, the two-story residential buildings were, therefore, the target of this research. In this regard, 75 construction drawings were selected as samples of the study. The criteria for the selection were:

3.1.1 Geographical setting

All dwellings were situated either in Bangkok and the metropolitan area of Thailand, thereby offering a uniform background with respect to construction practices and the availability of materials.

3.1.2 Building design

The sample included only two-story residential buildings that used conventional design and construction methods on a reinforced concrete frame with masonry walls using bricks. There was some uniformity in design, and hence comparable variables under study for the selected cases.

3.1.3 Drawing completeness

The chosen construction drawings used in this study were complete, depicting details of architectural, structural, electrical, and sanitary plans. This ensured the performance of a proper quantity takeoff in that all design variables of relevance could be measured with accuracy while no approximation of design features during data collection would be allowed.

3.2 Data collection

The data collection was done through an extensive analysis of the selected construction drawings in order to get the relevant variables. The following were identified as the key variables to be analyzed for this study:

3.2.1 Building area (m^2)

This refers to the gross floor area of the building including both floors. This variable is a surrogate for the general size of the structure and will likely affect the quantities of tie columns and lintel beams. It does not include any covered area used for parking, balconies, terraces, attics, or outside steps, as indicated in Figure 2.

3.2.2 Brick wall area (m^2)

The total area of brick masonry walls in the building. This variable was calculated by measuring the length and height of all brick walls in construction drawings. The brick wall area is directly related to some of the structural elements, like tie columns and lintel beams, used to support these walls. Measured quantity of brick wall construction in square meters was in accordance with the guidelines for measuring the quantity of brick wall of the Engineering Institute of Thailand under H.M. the King's Patronage [51], as illustrated in Figure 3(a).

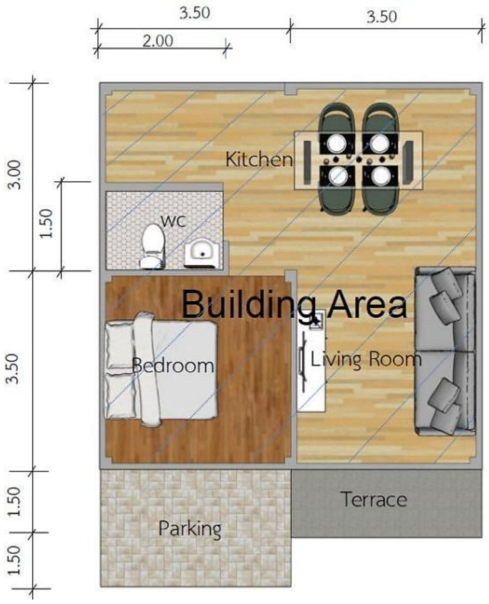

Figure 2 Guidelines for Measuring Building Area

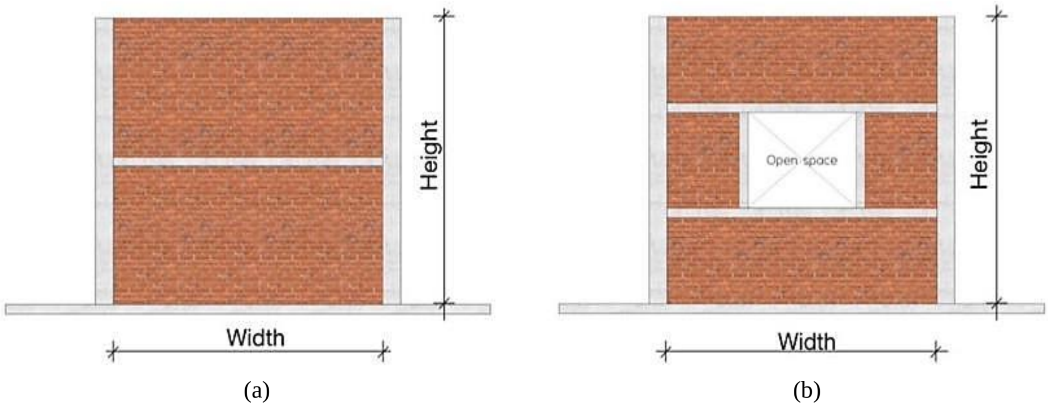

Figure 3 Guidelines for Measuring the Quantity of Brick Wall

3.2.3 Open space area (m²)

The area of open spaces in the building, which includes windows, doors, and other openings. This was calculated by deducting open space areas from the total wall area since open spaces are a requisite for structural support and are likely to impact the quantities of tie columns and lintel beams, as shown in Figure 3(b). Furthermore, the calculated area of the brick wall does not make any deduction for quantities arising from items in the following list: (1) openings with an area not exceeding 0.10 square meters; (2) joints; (3) other objects passing through or embedded in the brick wall having a cross-sectional area not exceeding 0.01 square meters; (4) tie column-lintel beam; and (5) grooves, corbels, and other surface features having an area not exceeding 0.05 square meters [51].

3.2.4 Height of brick walls (m)

The average height of the brick walls in the building. This variable was included to take into account any variation in wall height differences. Hence, the structural design implications which, in turn, will impact the count of items such as tie columns and lintel beams, as illustrated in Figure 3(a)-3(b).

3.2.5 Quantity of tie columns and lintel beams (m)

The total length consumed by tie columns and lintel beams. The tie column and lintel beam provide anchorage between the brick walls and the structure of the building, thus giving the necessary strength to both the wall and the building structure. They act as subsidiary supports to every principal structural element of the building [52]. This variable was derived from the structural drawings and was used as the dependent variable for regression analysis. Guidelines for tie column and lintel beam [51] are represented in Figure 4.

3.3 Data analysis

The data collected were analyzed with the aid of the SPSS for Windows software, an appropriately applied statistics tool, in the following steps:

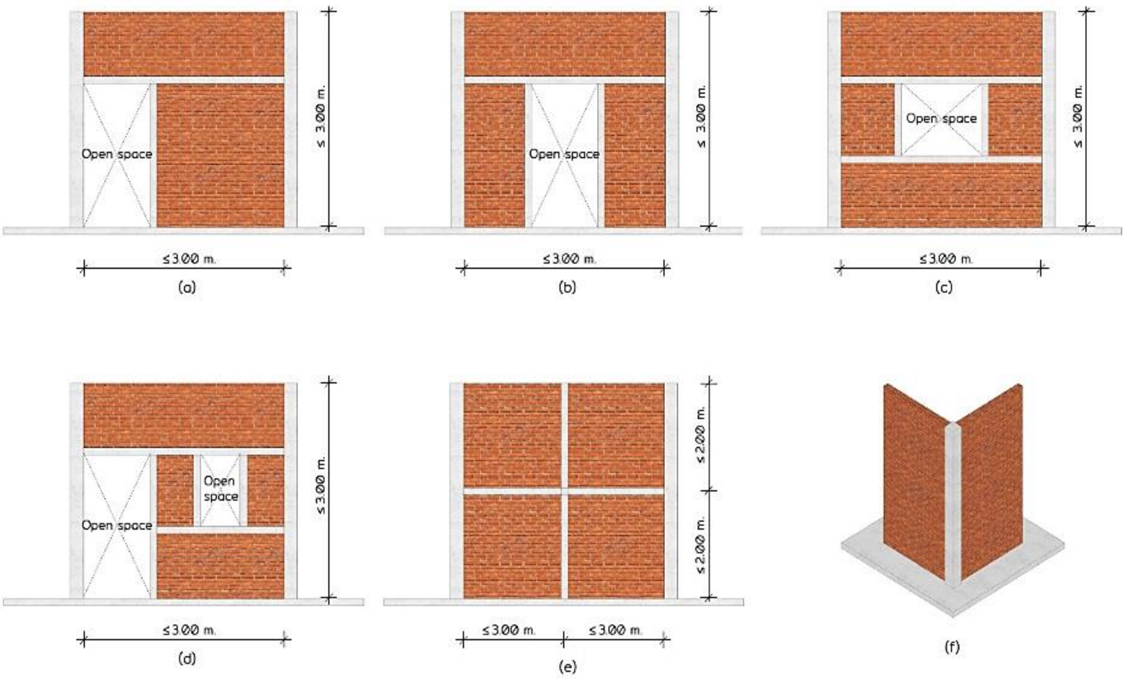

Figure 4 Standards for Tie Column and Lintel Beam

3.3.1 Descriptive statistics

First of all, the descriptive statistics were computed for all variables. This was done with the operation of summarizing the data to eventually point out the anomalies that were likely to exist. The computation of measures of central tendency, dispersion, and range gave an overview of the dispersion.

3.3.2 Correlation analysis

First, correlation analysis was done to establish the relationship between the building area, brick wall area, open space area, height of the brick walls, and the dependent variable or quantity of tie columns and lintel beams. The strength of the relationship would be established by the coefficient of Pearson's correlation and its direction.

3.3.3 Multiple Linear Regression Analysis

Linear Regression analysis is a statistical method used to study the relationship between independent variables and a dependent variable. It examines linearity wherein if the relationship between one independent variable and one dependent variable is studied, it is called Simple Linear Regression analysis. If there are multiple independent variables with one dependent variable, it is called Multiple Linear Regression analysis. The purpose of regression analysis is to study the relationship between independent and dependent variables. For example, the study of the relationship between age and cholesterol level and the predictive factors of independent variables together to forecast the dependent variable such as factors affecting blood sugar levels in diabetic patients [53]. The framework of multiple linear regression analysis concepts is as shown in Figure 5.

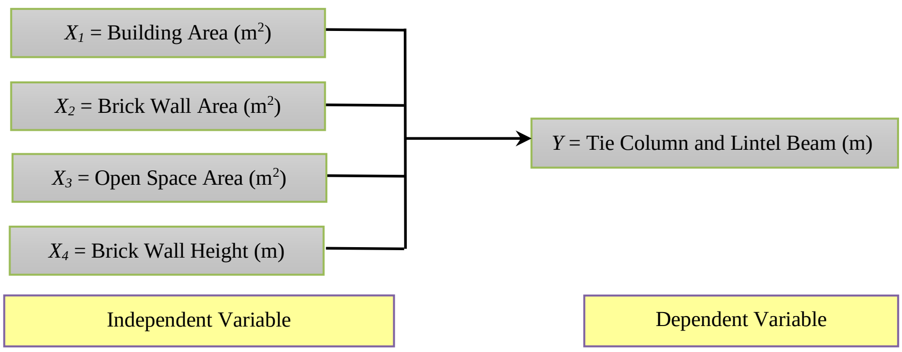

Figure 5 Framework of Multiple Linear Regression Analysis Concept

A multiple linear regression analysis was conducted to develop an equation that could predict the quantity of tie columns and lintel beams based on the identified independent variables. The general form of the regression model is as follows (Equation 1):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \epsilon \quad (1)$$

Where:
- Y is the quantity of tie columns and lintel beams (m);
- X_1 is the building area (m^2);
- X_2 is the brick wall area (m^2);
- X_3 is the open space area (m^2);
- X_4 is the brick wall height (m);
- β_0 is the intercept;
- $\beta_1, \beta_2, \beta_3, \beta_4$ are the coefficients for each independent variable; and
- ϵ is the error term.

The regression analysis aimed to identify the most significant predictors of tie column and lintel beam quantities. Variables with high p-values were considered statistically insignificant and were excluded from the final model to improve its predictive accuracy.

3.3.4 Equation testing

The regression equation was tested on fifteen additional drawings for two-story residential buildings, not included in the sample. All test cases were selected in view of their similarity to the analyzed designs in the study and therefore allowed the testing of the equation in a relevant environment. In this regard, in each case, the estimated column and lintel beam quantities in the tie have been worked out using both the derived equation and a detailed estimation method based on traditional quantity surveying techniques. The results were compared to check the accuracy of the equation.

4. Results of the study

4.1 Descriptive statistics

The construction designs examined in this study consisted of 75 two-story residential drawings. The details are as follows: the foundation type is dry-bored pile, reinforced concrete structural floors, tiled interior floors, brick walls with smooth plaster and paint finish, and some walls coated with tiles. The analysis of the data from these construction designs is summarized in Table 1. The analysis of the overall residential drawings revealed that the construction cost ranged from 39,244.5 US dollars to 88,223.18 US dollars, with an average cost of 63,656.89 US dollars. The building area varied between 102.00 and 229.30 m^2, averaging 165.45 m^2. The brick wall area ranged from 157.58 to 386.78 m^2, with an average of 246.91 m^2. The open space area within these buildings spanned from 41.45 to 113.01 m^2, with an average of 66.26 m^2. The height of the brick walls ranged from 2.70 to 3.10 m, averaging 2.81 m. The quantity of tie columns and lintel beams varied significantly, with a minimum of 161.34 m, a maximum of 451.22 m, and an average of 266.39 m. The ratio of tie column-lintel beam quantity to brick wall area was found to range from 1.00 to 1.21 m/m^2, with an average ratio of 1.07 m/m^2.

Table 1 Data of Two-Story Residential Drawing under Study

Parameter	Minimum	Maximum	Average
Construction Cost (US dollar)	39,244.50	88,223.18	63,656.89
Building Area (m^2)	102.00	229.30	165.45
Brick Wall Area (m^2)	157.58	386.78	246.91
Open Space Area (m^2)	41.45	113.01	66.26
Brick Wall Height (m)	2.70	3.10	2.81
The Quantity of Tie Column-Lintel Beam (m)	161.34	451.22	266.39
Ratio of Tie Column-Lintel Beam/Brick Wall Area (m/m^2)	1.00	1.21	1.07

The above results provide important insight into typical parameters and relations associated with two-story residential buildings in Thailand. On the other hand, there is a large variation in construction cost due to differences in design complexity, material quality, and labor cost between samples. The large range in building area and brick wall area suggests that residential designs are very varied in this study which obviously affects the requirements for tie columns and lintel beams. Of special note is the ratio of the quantity of tie columns and lintel beams to brick wall area since it is a normalized measure for structural demand in relation to wall area. The average ratio of 1.07 meters per square meter indicated that an average little over one meter of tie column and lintel beam was required for every square meter of brick wall. This ratio may be a good benchmark to use in making preliminary estimates for similar construction in the future. These data also point out the relationship between brick wall height and the length of tie columns and lintel beams. With the increasing height of walls, the structural demands for supporting and reinforcing walls increase, hence increasing quantities of tie columns and lintel beams. This relationship brings out the fact that wall height is an important consideration in structural design and material estimation.

4.2 Multiple Linear Regression Analysis

In the stepwise multiple linear regression analysis, it shows that only brick wall area and open space area are the significant independent variables affecting the number of tie columns and lintel beams. It was analyzed using SPSS for Windows set at 0.05 significance level. Table 2 presents the results using only the brick wall area as a predictor variable, which returns an R value of 0.971, an R^2 of 0.943, and an adjusted R^2 of 0.942, with a standard error of the estimate at 13.60464. It means that the brick wall area alone explains 94.3 percent of the variation in the number of tie columns and lintel beams. Introducing the open space area as the second predictor improved the model with an R value of 0.978, R^2 of 0.956, and adjusted R^2 of 0.954. The standard error of the estimate is now better at 12.10521. It is evident that adding the open space area as an independent variable increased the model's explanatory power since these two variables account for 95.6 percent of the variance in the dependent variable.

Table 2 Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.971[a]	0.943	0.942	13.60464
2	0.978[b]	0.956	0.954	12.10521

a. Predictors: (Constant), Brick wall area
b. Predictors: (Constant), Brick wall area, open space area

The results of the regression analysis established excellence in predictive ability with respect to the brick wall area and open space area variables in estimating the quantity of tie columns and lintel beams for two-story residential buildings. The high R^2 values in both models indicated that these explanatory variables were very effective in explaining the variation of the quantity of structural elements with the least error. The R^2 for the initial model was 0.943, thus putting a premium on the brick wall area which makes sense as one would think that larger wall areas require additional structural support. This value improves considerably with the addition of an open space area, which indicated that it was accounting for openings, like windows and doors, to increase the nuance in understanding structural needs. Open spaces reduce the quantum of wall area that has to be supported, thereby impacting the overall quantity of tie columns and lintel beams.

The adjusted R^2 values, very close to the respective R^2 values of both models, serve as an indicator that the models are well-fitted without overfitting. This indicates that including another variable meaningfully adds to the explanatory power of the model. A further reduction in the standard error of the estimate in the second model confirms the improvement of precision in the prediction upon consideration of both brick wall area and open space area. These findings therefore stipulate that the brick wall area and open space area should be considered when properly estimating the quantity of tie column and lintel beam. With this insight, much accuracy can be brought into preliminary cost estimate activities in residential construction projects, hence a more efficient and reliable process for estimators.

Table 3 Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-5.803	7.978		-0.727	0.469
	Brick wall area	1.102	0.032	0.971	34.799	0.000
2	(Constant)	1.834	7.299		0.251	0.802
	Brick wall area	1.243	0.042	1.095	29.525	0.000
	Open space area	-0.639	0.142	-0.167	-4.495	0.000

a. Dependent Variable: Quantity of Tie Column and Lintel Beam

The results from the regression coefficients in Model 2, as shown in Table 3, provide further details about the relationship of independent variables to the quantity of tie columns and lintel beams. In both variables, it is highly significant with Sig. = 0.000, which confirms that brick wall area and open space area are two major factors in determining the quantity of these structural elements. The positive coefficient for brick wall area, B = 1.243, suggests that if the brick wall area increases, then so will the quantity of tie columns and lintel beams. This makes sense since larger wall areas require more structural support. In contrast, the negative open space area coefficient occurred with greater open space area, for example, from windows and doors. This indicates lesser need for tie columns and lintel beams, since these open spaces decrease the total wall area that has to be supported. It is apparent that the B value for the brick wall area is higher compared to the open space area. This clearly shows that the brick wall area is of greater influence on the structural requirement. It means that even if the open spaces do reduce the requirement in terms of structural elements, the overall size of the brick wall area is what accounts predominantly for the quantity of the tie column and the lintel beam.

Table 4 Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	Building area	-0.125[b]	-1.707	0.092	-0.197	0.142
	Open space area	-0.167[b]	-4.495	0.000	-0.468	0.448
	Brick wall height	-0.011[b]	-0.380	0.705	-0.045	0.996
2	Building area	-0.031[c]	-0.444	0.658	-0.053	0.127
	Brick wall height	-0.024[c]	-0.943	0.349	-0.111	0.983

a. Dependent variable: quantity of tie column and lintel beam;
b. Predictors in the model: (constant), brick wall area; and
c. Predictors in the model: (constant), brick wall area, open space area.

From Table 4, the results show that building area and brick wall height are not significant regarding their power to predict the quantity of tie columns and lintel beams. The rather high significance values, with Sig. = 0.658 for building area and Sig. = 0.349 for brick wall height, prove that such variables have little contribution to variation in the dependent variable. Such outcome suggests that, although intuitively relevant to structural requirements, building area and brick wall height do not provide any extra predictive power above and beyond what is already captured by the brick wall area and open space area. This finding is further supported by the low partial correlations and collinearity statistics, indicating that the variables are of no additional help in enhancing the model's accuracy. This now simplifies the estimation process to include only major influencing factors: brick wall area and open space area. This reduces model complexity and makes the model more efficient to use in practical applications for construction cost estimating. This eliminates insignificant predictors, thus avoiding possible complicating effects on the model and allowing the produced estimates to be accurate yet accessible to most users without an in-depth understanding of all variables that could be included.

The data from Tables 2 to 4 were used to create the scatter plot for Multiple Linear Regression Modeling, as shown in Figure 6.

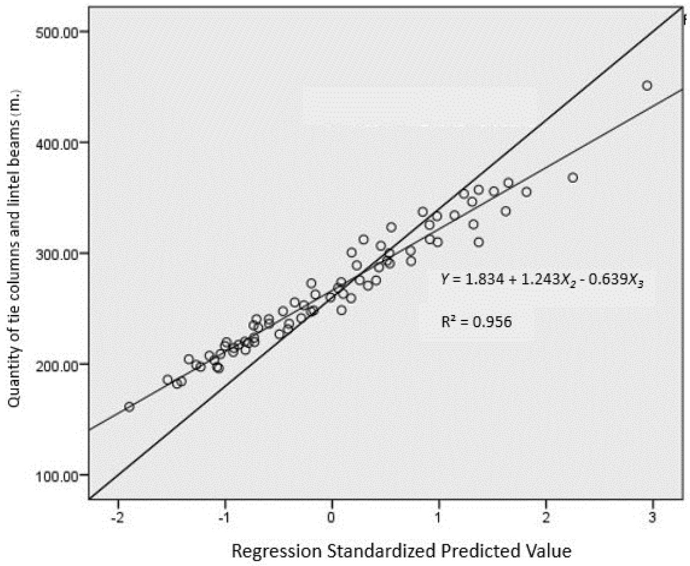

Figure 6 Multiple Linear Regression Modeling

Using the data obtained from the analysis, the equation for determining the quantity of tie columns and lintel beams was derived based on the coefficients presented in Table 3. The resulting equation is (Equation 2):

$$Y = 1.834 + 1.243X_2 - 0.639X_3 \quad (2)$$

Where:

- Y is the quantity of tie columns and lintel beams;
- X_2 is the brick wall area; and
- X_3 is the open space area.

The equation formulated in this work serves as a practical tool in the estimation of the quantity of tie columns and lintel beams in a two-story residential building. The equation indicates that brick wall area is a major contributor to the structural requirement, with a coefficient of 1.243 meaning that with each increase of one square meter in brick wall area, the quantity of tie columns and lintel beams will increase by approximately 1.243 m. The coefficient for the open space area is -0.639, which accounts for those features that include windows and doors. Basically, it would mean that if the open space area increases, then the requirement of tie columns and lintel beams would decrease, reflecting a decrease of structural support required for non-wall areas.

The constant term of 1.834 in the equation provides the baseline quantity of tie columns and lintel beams when both brick wall area and open space area are zero. This baseline return considers the minimum structural elements that shall be included to hold the building together. This equation is especially useful for preliminary cost estimation and material planning. It allows one to make quick and relatively accurate predictions without detailed measurements or a great deal of experience. It basically simplifies the process of estimation by focusing only on the most influential factors so that it can give both reliable and easy-to-apply estimates in practice. Thus, this equation can offer tremendous help to construction professionals at the primary stages of planning a project and estimating its cost.

4.3 Model validation

The validations of the derived formula were through its use in calculating the building areas, brick walls areas, and open space areas, together with the height of brick walls, the number of tie columns and lintel beams of fifteen residential two-story designs with similar design parameters by detailed estimation, as summarized in Table 5. These were sized using one of the fifteen residential types, B1 to B15, and had different structural elements and sizes.

Residential type B5, the smallest of the selected designs, with a building area of 114.64 m^2, brick wall area reaching 225.69 m^2, and open space at 42.75 m^2 has an estimated quantity of tie columns and lintel beams amounting to 241.36 m. Residential type B15 had the biggest building area of 229.30 m^2. From the area, the corresponding brick wall and open space areas are 335.55 m^2 and 81.14 m^2 respectively. Lintel beams and tie columns were estimated at 355.25 m.

Detailed estimates for fifteen selected residential types: The applicability of the derived equation to real-world scenarios is shown through the detailed estimates prepared for fifteen selected residential types. This clearly explains the variation in the quantity of tie columns and lintel beams with respect to different residential types due to differences in areas of brick walls and open spaces, again proving the accuracy of the equation in its predictions. As expected from the positive coefficient for brick wall area in the equation, it is always the case that the larger brick wall areas produced more tie columns and lintel beams. At the same time, the smaller open space areas of residential types B3, B4 and B5 correlate with a reduced required quantity of the tie column and lintel beam elements, consistent with the negative coefficient for open space area. It confirms that the equation does not only capture the primary influences on the structural requirement but also correctly reflects the impact of variations in design.

Comparisons of the detailed estimation with equation-based estimation for the number of tie columns and lintel beams according to each of the fifteen residential types are shown in Table 6.

Table 5 Two-Story Residential Estimate by Detailed Estimation Method

Residential Type	Description				
	Building Area (m^2)	Brick Wall Area (m^2)	Open Space Area (m^2)	Brick Wall Height (m)	Tie Column and Lintel Beam (m)
B1	182.00	372.32	74.91	2.80	396.90
B2	150.00	332.27	72.11	2.80	358.15
B3	133.08	258.39	48.57	2.80	280.06
B4	124.50	245.06	46.17	2.80	263.07
B5	114.64	225.69	42.75	2.80	241.36
B6	183.60	293.76	71.90	2.80	309.95
B7	202.48	325.99	89.00	2.85	355.72
B8	180.00	288.00	67.00	2.70	312.51
B9	199.50	321.19	92.00	2.80	357.20
B10	205.54	344.39	113.01	2.80	363.52
B11	209.35	386.78	83.00	2.85	451.22
B12	186.15	297.35	57.55	2.80	353.55
B13	210.54	303.76	77.67	2.80	334.14
B14	208.47	278.31	80.65	2.70	290.67
B15	229.30	335.55	81.14	2.85	355.25

Table 6 The Comparison between the Detailed Estimation Method and the Equation-Based Estimation.

Residential type	Tie columns and lintel beam (m.)		Difference (%)
	Detailed estimation	Equation-based	
B1	396.90	416.76	4.77 (+)
B2	358.15	368.80	2.89 (+)
B3	280.06	291.97	4.08 (+)
B4	263.07	276.94	5.01 (+)
B5	241.36	255.05	5.37 (+)
B6	321.03	309.95	3.58 (-)
B7	350.17	355.72	1.56 (+)
B8	317.01	312.51	1.44 (-)
B9	342.29	357.20	4.18 (+)
B10	357.70	363.52	1.60 (+)
B11	429.56	451.22	4.80 (+)
B12	334.67	353.55	5.34 (+)
B13	329.78	334.14	1.30 (+)
B14	296.24	290.67	1.92 (-)
B15	367.07	355.25	3.33 (-)

Comparisons of the results indicate that the values arrived at from the developed equation for estimating the quantity of tie columns and lintel beams are slightly higher and more consistent than those obtained through the detailed estimation method by differences ranging from -3.58% to 5.37%. This variation falls within an acceptable margin of error for preliminary estimates, confirming the reliability and robustness of the equation. The relatively small differences indicate that the formula is dependable and produce accurate results providing a close approximation of the required quantities of tie columns and lintel beams. This makes it particularly useful during the early stages of project planning. The highest difference observed was +5.37% in residential type B5, while the lowest was -3.58% in residential type B6, indicating consistency across various building sizes and layout variations. To describe the linear relationship between the quantities of columns and lintel beams obtained from the detailed cost estimation and the values derived using the developed equation, the coefficient of determination was found to be 0.9569, as shown in Figure 7. This range of values indicates that the quantities calculated using the equation are highly consistent with those obtained through the detailed estimation methods.

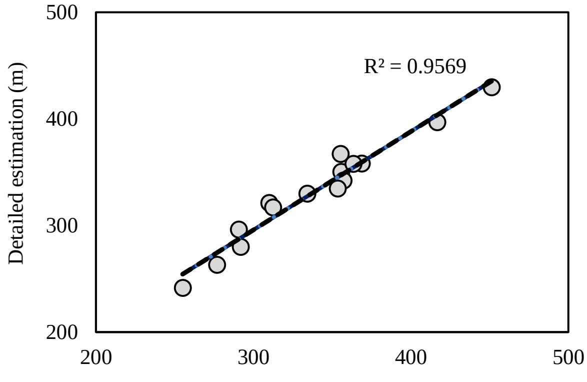

Figure 7 Comparison of the Quantity of Tie Columns and Lintel Beams

5. Discussion

Tie columns and lintel beams are important structural members that play a great role in making masonry walls strong and durable. They allow for vertical and horizontal wall alignment while reducing cracking and overall wall strength [54, 55], with ties preventing column buckling and mitigating lateral loads, while lintels distribute loads over openings, thus preventing localized failure [56]. From cost perspective, these elements are highly significant as they directly affect structural performance and material quantities, warranting their inclusion in predictive modeling.

The formula derived for the estimation of the quantity of tie columns and lintel beams in a residential building project has many practical advantages, especially at the initial stage of a project plan. It brings down the estimation to parameters that are vital for speedy and accurate budgeting and resource allocation. According to several studies, there is a whole need for cost estimation in the early phases of construction. This aligns with the findings of Alkhuadhan and Naimi [57], who emphasized influential factors in hybrid cost estimation models. Similarly, Yang et al. [58] developed a BIM-based model that considers parameters beyond floor area to enhance the accuracy of estimation and reduce errors inherent in traditional methods. This is thus in line with the approach of the derived equation, which makes use of specific variables to simplify the process of estimation. Additionally, the adoption of machine learning techniques, as explained by a study on deep learning frameworks, demonstrates that technology can enhance estimation accuracy by learning from historical data and duplicating the information onto similar projects [59]. Such technological advancement aids the practical application of the derived equation by providing a data-driven justification for its application [60].

However, it is important to clarify that the equation is not universally conservative: validation across fifteen test designs produced a mix of slight over- and under-estimations, with individual percentage errors ranging from -3.58 to +5.37%. Nonetheless, most cases fell within a ±5% margin, which is acceptable for preliminary estimates, and the mean error was slightly positive. This nuanced performance reflects both strengths and limitations when compared to previous studies that reported accuracy rates exceeding 90% [28-35], indicating that while our model performs well, there is still room for refinement. Although innovative estimation tools are emerging, their adoption remains limited due to challenges such as data availability, user training, and integration into conventional workflows. Therefore, enhancing their practicality like this equation requires continuous improvement to meet industry standards. The derived equation is a streamlined early-stage cost estimation tool that, once periodically updated to reflect evolving industry data, could substantially improve budgeting and resource planning.

A principal advantage of the equation is its accessibility for less-experienced estimators, democratizing the estimation process and reducing reliance on specialized structural knowledge. Its outputs, which sometimes slightly exceed detailed estimates, provide a practical buffer for material planning. Nonetheless, it should be noted that underestimations did occur in some cases. The model's flexibility across various residential designs was demonstrated by consistent accuracy across validation cases with differing floor areas and layouts, confirming its practical utility. This flexibility makes it a valuable tool for cost estimators managing multiple diverse projects. Moreover, the speed of the model facilitates timely decision-making during design adjustments, budget reviews, or procurement planning, improving overall project efficiency and enabling faster project initiation with smoother team coordination. These benefits align with findings from studies on early-stage cost modeling [27, 58]. Looking ahead, this equation can serve as a foundation for more advanced, automated estimation systems particularly when integrated with BIM or cost software platforms.

6. Conclusion

In this research, multiple linear regression analysis was used to develop and validate an equation for estimating the quantity of tie columns and lintel beams for two-story residential buildings. The total linear meters of tie columns and lintel beams combined (Y) = 1.834 + 1.243 (brick wall area in m²) - 0.639 (open space area in m²), was developed from analysis of 75 sets of residential drawings and validated against detailed estimates for fifteen different residential types. Results indicate that the equation can provide a reasonably accurate method for preliminary estimation, with differences between the equation-based estimates and detailed estimates ranging from –3.58% to 5.37%. These differences are considered to be within acceptable limits for preliminary estimation and suggest that the model may be effectively used as a simplified alternative to more detailed quantity takeoff methods.

The practical implications of this equation are noteworthy for construction cost estimators. It simplifies the estimation process by focusing on two major variables: brick wall area and open space area, making it accessible to less-experienced users and reducing the time required for calculations. Although the equation produced both slight underestimations and overestimations, the overall error range indicates that it generally provides a close approximation of actual quantities, which may help in planning material procurement with a reasonable margin. The equation has demonstrated consistent performance across 15 residential designs within the same typology (two-story residential buildings in Thailand), supporting its applicability within this scope. It offers a helpful tool for improving early-stage project planning and cost management, contributing to better decision-making and greater efficiency in the estimation process.

7. Recommendations and limitations

• The model proposed is particularly for two-storey residential buildings with typical design typology in the Thai environment. These buildings generally feature reinforced concrete frames with infill brick masonry walls, standard story heights (around 2.81 meters), and conventional floor plans with regular spatial layouts. Its application to other buildings of different typology, size, or in other locations must therefore be approached with caution.

• It is based on the linearity assumption between variables, which might not be enough to capture complex structural relationships. The next research could explore more advanced techniques such as nonlinear regression, artificial neural networks (ANN), or support vector machines (SVM) to improve predictive ability and universality.

• The model employed only a limited number of predictors. To enhance model robustness and generalizability, future studies should consider incorporating other influential factors, especially those expected to have more significant effects, such as wall thickness, number and size of door and window openings, and story height. Additional secondary variables, such as material type, building height, and architectural complexity, may also contribute to improved prediction accuracy.

• Cross-validation of the model across different architectural and geographical conditions is required to establish its generalizability and ensure valid usage in different construction settings.

• Application of the model in real-world settings through Building Information Modeling (BIM) applications or computer-based cost estimation software, in collaboration with design professionals and contractors, can enable its usage in practical settings, especially in early-stage design and planning.

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