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Development of Linear Regression Model for Tile Waste Generation in Malaysian Construction Industry

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ABSTRACT

The effect of unmanageable construction waste is an unstable land settlement and groundwater pollution. In addition to environmental pollution, construction waste could incur construction cost. The most construction waste is the material used at sites and tile is also a part of the waste generated in construction. The objectives of this study are to determine the tile waste generated in construction stages and linear regression analysis for the amount of tile waste generated. The method used in this study was the Linear Regression Model. The regression model established in the sample data reported an R^2 value of 0.793; therefore, the model can predict approximately 79.3% of the factor (area) of tile waste generation. The linear regressions can be applied as tools to predict the tile waste generated at construction sites and help the contractor to track the sources of missing waste.

Keywords: *construction waste; tile waste; linear regression model*

1. INTRODUCTION

Construction waste (CW) is an economic burden in the construction industry. Tile used in construction sites is one of the waste generators in this industry. Quantifying the tile waste generated at sites is the most crucial step in recording and predicting the waste data [1]. Previous study stated that the unreliable quantification method often leads to increase wastage up to between 15 and 20 times compared to the original estimation during the construction process [2]. However, most of the data related to construction waste are based mostly on assumptions. The collection of valid data is important in order to be able to establish treatment solutions for construction waste that will be based on reliable data on the quantities of construction waste [3].

Hence, an accurate quantification strategy for CW is needed to address these issues. Development of waste quantification model such as the linear regression model is found to be the future strategy for accurate tile waste estimation. The linear regression predicts the amount of tile waste generated per unit/built area. Regression analysis is a statistical technique to investigate and model the relationship between variables [4]. The study of the

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regression analysis techniques will also provide certain insights on how to plan the data collected [5]. The approach can be utilised by decision-makers in a pro-active manner with the objective to predict the amount of construction waste and establish a benchmark to reduce waste generation, the key and can be considered as the most effective step in waste management.

2. METHODOLOGY

The project analysed was based on a case study at the construction site located at Taman Ilmu, Taman Seri Akasia and Seri Putera in Pulau Pinang. All of the covered areas were development of residential houses during the construction stage. Multiple Linear Regression (MLR) was adopted to analyse the data obtained in this study and it required several assumptions to be satisfied in order to obtain the best model with efficient, unbiased and consistent estimation. The four main assumptions for residual (error term) are;

a. Mean of residual is zero
b. The variance of residual is constant
c. Residual follow a normal distribution
d. Residuals are uncorrelated with the independent variables

Further study was reported that to establish an MLR model, a few stages are required. In Stage 1, 80% of the data for each variable was randomly selected with MATLAB R2014a software [6].

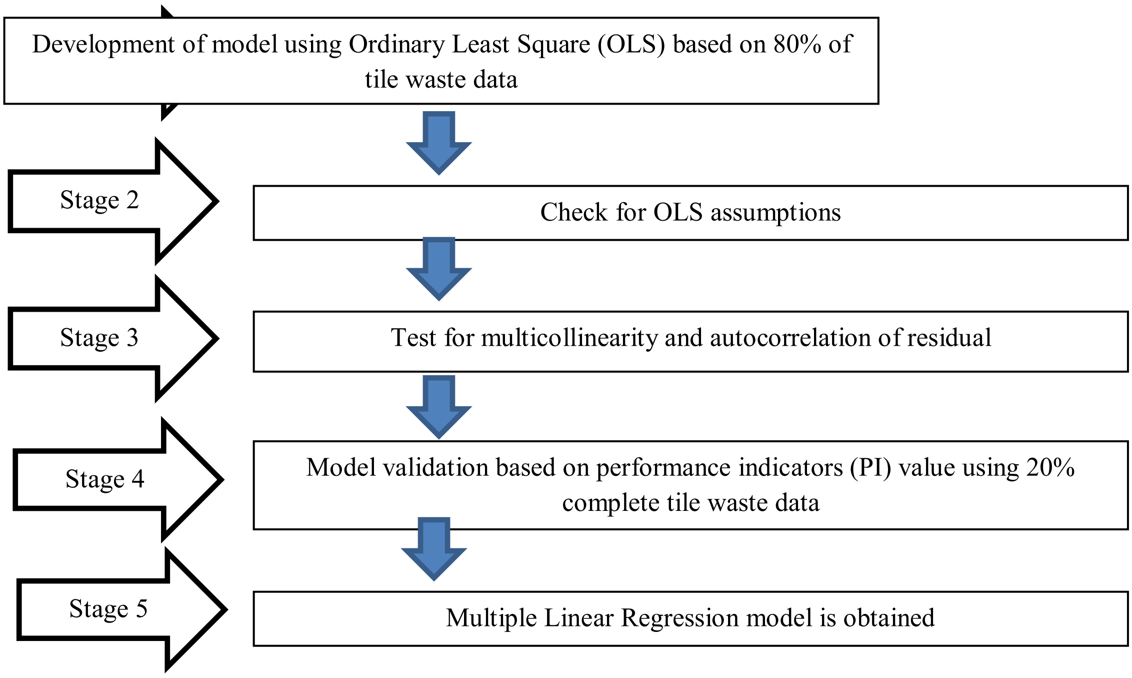

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Figure 1: Stages of Linear Regression Models Development

In Stage 2, the classification as depicted in Table 1 was used to interpret the obtained correlation coefficient values. The most important variables were derived with IBM SPSS Statistic 23.

Table 1: Interpretation of the strength of correlation results [7]

Correlation coefficient range	Strength of correlation
0.00-0.30	Weak
0.31-0.50	Moderate
0.31-0.50	Strong
0.81-1.00	Very strong

In Stage 3, the Variance Inflation Factor (VIF) was used to measure the effect of multicollinearity on the variance of estimated regression coefficients. When the VIF for one or more independent variables is large, then it has a multicollinearity problem. Field (2005) suggests VIF of 10 as a critical threshold.

Another test for MLR is Durbin Watson (D-W) statistical test. This test is for lag-one autocorrelation of residual. Stage 4 is for model validation based on Performance Indicators (PI) value using 20% complete data sampling. Ordinary Least Squares (OLS) assumptions were checked in Stage 4 (Table 2); then, the models were validated by a performance indicator (NAE, PA, IA, and R^2) in accordance with a 20% sampling data. The MLR model was obtained in Stage 5.

Table 2: Ordinary least square assumption [8]

Assumption	Checked by
Residuals follow a normal distribution	Normal P-P plot
Residual has constant variance	Scatter plot (the spread of point)
Residuals are uncorrelated with the Independent variables	Durbin Watson test statistics (no \ autocorrelation)

To evaluate the performance models for predictions, performance indicators are used [9]. The performance models (Table 3) consist of accuracy measures (PA, IA and R^2) and error measures (NAE).

Table 3: Performance Indicators [10]

Performance Indicator (PI)	Notes
Normalized Absolute Error (NAE)	Close to 0, model is appropriate
Index of Agreement (IA)	Close to 1, model is appropriate
Prediction Accuracy (PA)	Close to 1, model is appropriate
Coefficient of determination (R^2)	Close to 1, model is appropriate

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3. RESULTS AND DISCUSSION

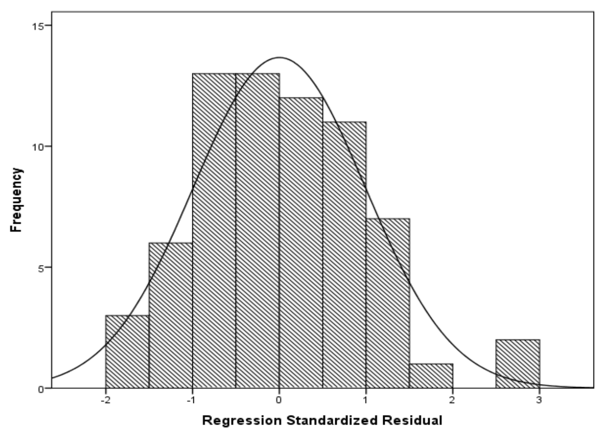
Linear regressions have been developed from sites sampling data (Site Taman Ilmu, Seri Akasia and Seri Putera) using IBM SPSS Statistics 23. The Durbin-Watson test statistic tests for auto-correlations between errors. It tests whether adjacent residual is correlated because one of the assumptions of residual is that it should be independent. From Table 4, the values of Durbin-Watson are closer to two, indicating that the assumption is satisfied. The models do not have any auto correlation problem.

Table 4: Result for Durbin-Watson Test

Sites	Linear Regression Models	Durbin-Watson
Taman Ilmu	MW = 10.174+ 0.664A-1.238S	1.885
Seri Aksia	MW = 2.665 + 0.538A	1.832
Seri Putera	MW = 3.361 + 0.544A	2.059

MW=Tile Waste, A=Area, S=Skill Workers

The plot of the residuals shown in Figure 2 fits the expected pattern well enough to support the conclusion that these residuals are normally distributed with zero means.



(a) Site Taman Ilmu

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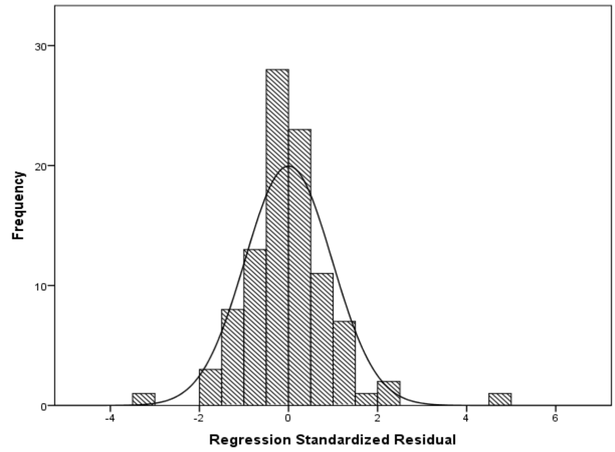
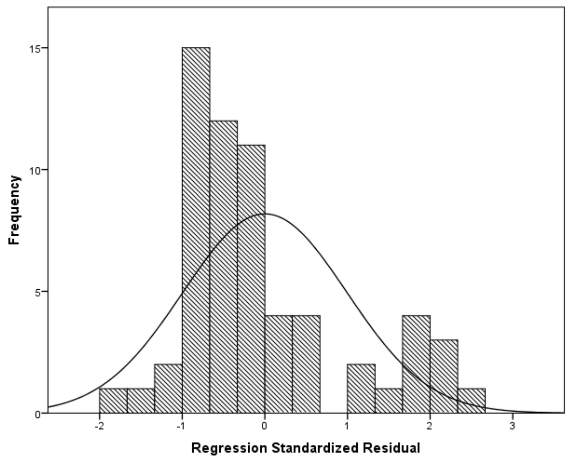


(b) Site Seri Akasia



(c) Site Seri Putera

Figure 2: Histogram of tile waste residual

This residual plot exhibits a random scatter; as such, no obvious pattern can be observed in Figure 2. The assumption that the residual displays a constant variance is satisfied when the scatter plot exhibits an equal spread and approach to the regression line (homoscedacity). Moreover, the assumption that the residuals are uncorrelated with the independent variable is satisfied because the Durbin–Watson value (2.2) is close to 2. In summary, the analysis described above verifies that the developed model can be used to predict the tile waste generated by housing construction projects.

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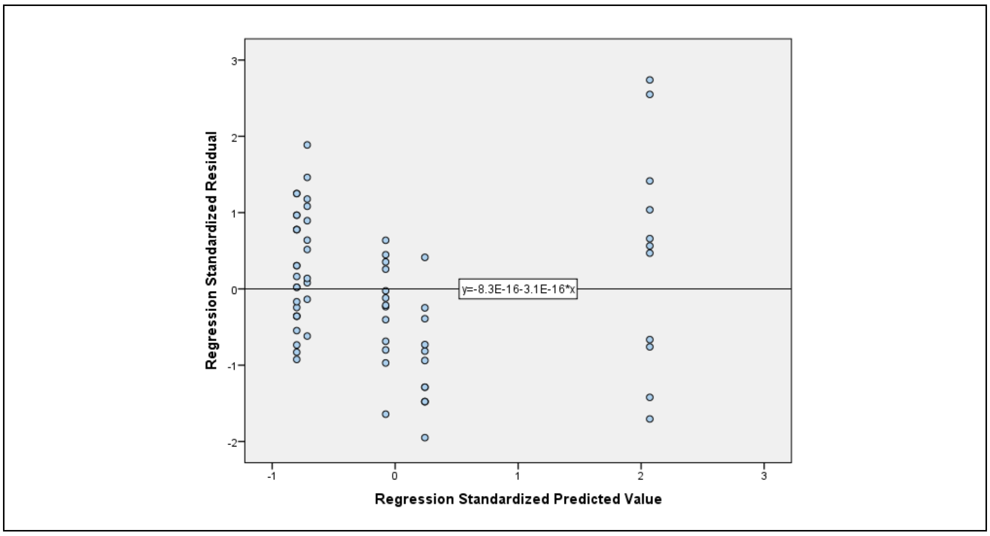
The plot of the residuals shown in Figure 3.2 fits the expected pattern well enough to support the conclusion that these residuals are normally distributed with zero means. This residual plot exhibits a random scatter; as such, no obvious pattern can be observed in Figure 3. The assumption that the residual displays a constant variance is satisfied when the scatter plot exhibits an equal spread and approach to the regression line (homoscedacity). Moreover, the assumption that the residuals are uncorrelated with the independent variable is satisfied because the Durbin–Watson value (2.2) is close to 2. In summary, the analysis described above verifies that the developed model can be used to predict the tile waste generated by housing construction projects.

Performance indicators were used to measure the accuracy such as Prediction Accuracy (PA), Coefficient of Determination (R^2) and Index of Agreement (IA) and error Normalised Absolute Error (NAE) for linear regression models. Table 5 shows the performance indicators for brick waste. The results show that Site Taman Ilmu and Seri Putera prediction is more accurate for predicting the tile waste generated. Accuracy measure for Site Seri Putera and Taman Ilmu model (PA, IA and R^2) is greater than 0.7, indicating that predicted values are a highly representative model.

Table 5: Linear Regression and Performance Indicator

Sites	Linear Regression Models	NAE	IA	PA	R^2
Taman Ilmu	MW = 10.174+ 0.664A-1.238S	0.2008	0.9530	0.9135	0.8345
Seri Akasia	MW = 2.665 + 0.538A	0.3634	0.8632	0.7800	0.6086
Seri Putera	MW = 3.361 + 0.544A	0.2223	0.9747	0.9516	0.9055

MW = Tile waste, A = Area, S= Skill Workers, Prediction Accuracy =PA, Coefficient of Determination =R^2, Index of Agreement =IA, Normalised Absolute Error =NAE



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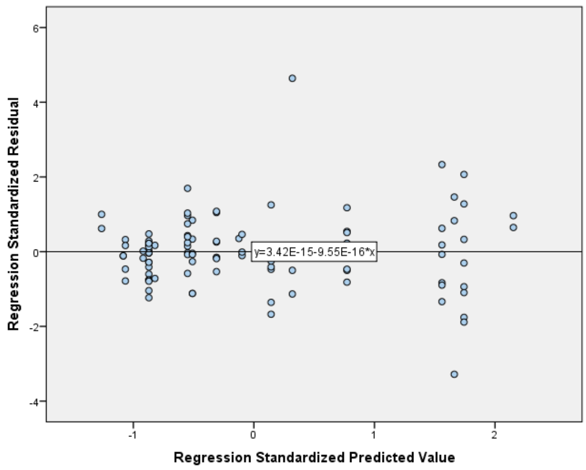
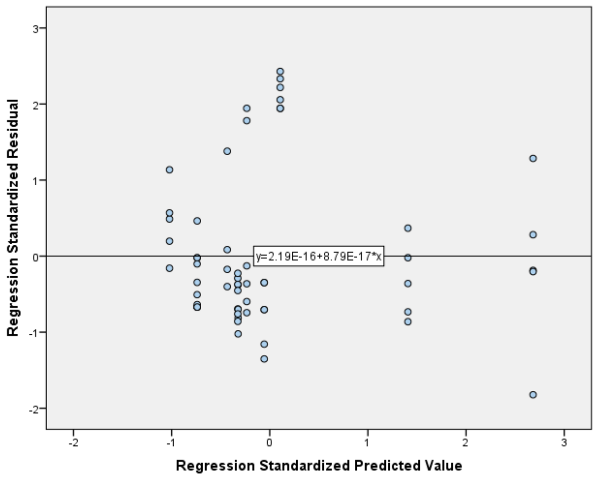
(a) Site Taman Ilmu



(b) Site Seri Akasia



(c) Site Seri Putera

Figure 3: Scatter plot of residual versus fitted values

A previous research was conducted using multiple linear regression and found the set of these variables was able to predict approximately up to 69% of the factors involved in waste generation in high-rise residential buildings of the sample, since the statistical model presented coefficient of determination (R^2) = 0.784 and the adjusted coefficient of determination (adjusted R^2) 0.694 [11]. This sampling involved 18 buildings with a different company.

A study on estimation of construction and demolition waste generation in Lisbon Metropolitan Area, Portugal found that population density, building density and percentage

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of urban [12]. These explained the waste generation as the factors contribute to high correlation coefficients with 0.82, 0.68, and 0.79, respectively. Apart from that, in China a model was developed to integrate the mass balance principle, break-down the work structure, take-off of material quantity, conversion ratios between different waste measurement units and the wastage levels of various materials used in different work packages [13]. The proposed model can predict the quantities of various kinds of construction waste from a building project, to track the origin of construction waste (i.e., from which work package is a particular kind of waste generated and how much) and to help contractors investigate the potential improvements for waste management.

A quantification model of waste generated in high-rise building construction in Brazil using statistical multiple produced dependent (i.e. the amount of waste generated) and independent variables associated with the design and the production system used [14]. The best regression model obtained from the sample data resulted in an adjusted R^2 value of 0.694, which means that it predicts approximately 69% of the factors involved in the generation of waste in similar constructions. Most independent variables show a low determination coefficient when assessed in isolation, which emphasises the importance of assessing their joint influence on the response (dependent) variable.

3.1 Validation and Verification of Models

The next stage after training and validating is to verify the models. Table 6 shows the comparison of performance indicator between validation and verification at the three sites for the tile waste. The validation is to verify the models either it is significant to the study or not. The details for the verification data show the comparison of performance indicator between validation and verification at the three sites for the tile waste.

Table 6: Comparing performance indicator between validation and verification at the Site Taman Ilmu, Seri Akasia and Seri Putera for tile waste

Tile Waste	**NAE**		**RMSE**		**IA**	
Site	Validate	Verify	Validate	Verify	Validate	Verify
Taman Ilmu	0.3074	0.4072	14.127	17.757	0.9593	0.7163
Seri Akasia	0.1722	0.5099	3.1021	22.366	0.9627	0.6428
Seri Putera	0.2940	0.4886	4.143	21.630	0.9602	0.6507

3.2 Framework Development

The construction waste minimization plan for the tile wastes generated at the selected housing construction site was developed at the end of this study as shown in Figure 4. This framework was divided into two factors, i.e. management and workers with management in the middle of the framework. This framework focused on minimising the waste on tile by giving guidelines to the supervisor and workers how to minimise waste and towards the end how many predicted waste could be produced based on the working area.

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3.2.1 Project Planning

During this project planning stage, the company managing the construction site must provide a proper implementation of the material management plan, which includes management and quality planning. For the efficient strategy to be recommended and determined, the nature and sources of each material must be identified [15].

At the design stage, the waste can be reduced if the designs are standardized and coherent. In construction, standardization of design is executed to develop better buildability and to avoid over-design and under-design. According to [15], standardization is a method in design as it is evidenced to decrease the generation of construction waste. Consultants should be concerned about the design planning hence design management is capable of managing the entire design stage to attain project cost funds and control waste material at a construction site.

3.2.2 Site Organization

The main contractor ensures accountability for the control of construction waste. The site supervisor holds the main role as a supervisor to supervise all the workers at the site. If the role of a supervisor at the site is not played efficiently, it will lead to waste contribution because supposedly the supervisor is the waste solver at the sites [16]. The site supervisor can also monitor site waste data as a clear strategy to reduce waste. According to [16], the use of unskilled workers is one of the factors of waste generation in construction projects. This is because any improvement in labour productivity will give high impact to the entire performance in the construction industry such as cost, time and quality of the project. For example, when the worker has experience and high productivity, they can complete all the task given as planning and follow the correct requirement of the project. Any mistake also can be reduced when using skilled workers because they are fully trained as an expert in their working scope. Thus, the waste generated coming from mistakes of unskilled workers, and unproductivity of workers such as cutting error of timber will be reduced.

For organizing the material storage, the appointed contractors are responsible for housekeeping and clean-up in their areas of responsibilities. Delivery of materials shall be closely coordinated with the Quality Assurance and Quality Control Engineer (QA QC Engineer) to assure proper storage locations and safe accessibility. Designated storage areas also shall be set at locations that will be predetermined and will not present hazards to traffic, workers and actual construction.

3.2.3 Site Controlling

Well managed site management with contracts and contractual clauses can help to control waste by punishing those with poor waste management performance. Government or regulatory bodies can also provide incentives or rewards to contractors applying the 3R method as their construction waste management. This approach has successfully been adopted by the Hong Kong government where they implemented the Construction Waste

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Disposal Charging Scheme (CWDCS) to provide financial incentives for those who reduce construction and demolition waste and promote reuse and recycling [17]. Regulatory bodies can introduce education programs related to raising awareness in minimizing waste and measures related to design and construction practices in order to reduce waste. Through such educational programs, the clients will be aware that their role is important to contribute to a sustainable environment as a stakeholder.

3.3.4 Implementation

According to the Construction Industry Development Board (CIDB), Industrialized Building System (IBS) is an alternative innovation on the construction site which applies the construction techniques where components are manufactured, transported, positioned and assembled into structures with minimal additional work. The benefit of this is that it can minimise work at the site, reduce of construction materials to be used, thus, reducing the percentage of waste generated. Furthermore, the IBS method is a safe, clean and organized condition of the site which can simultaneously reduce the number of employees at a site [18]. Moreover, IBS implementation in construction industry needs to be continuously improved in quality, productivity, labour, safety invention and inferior working condition. Improvement of the mentioned parameters will help to reduce the negative perceptions of IBS and subsequently increase the willingness to adopt IBS in the construction industry [19].

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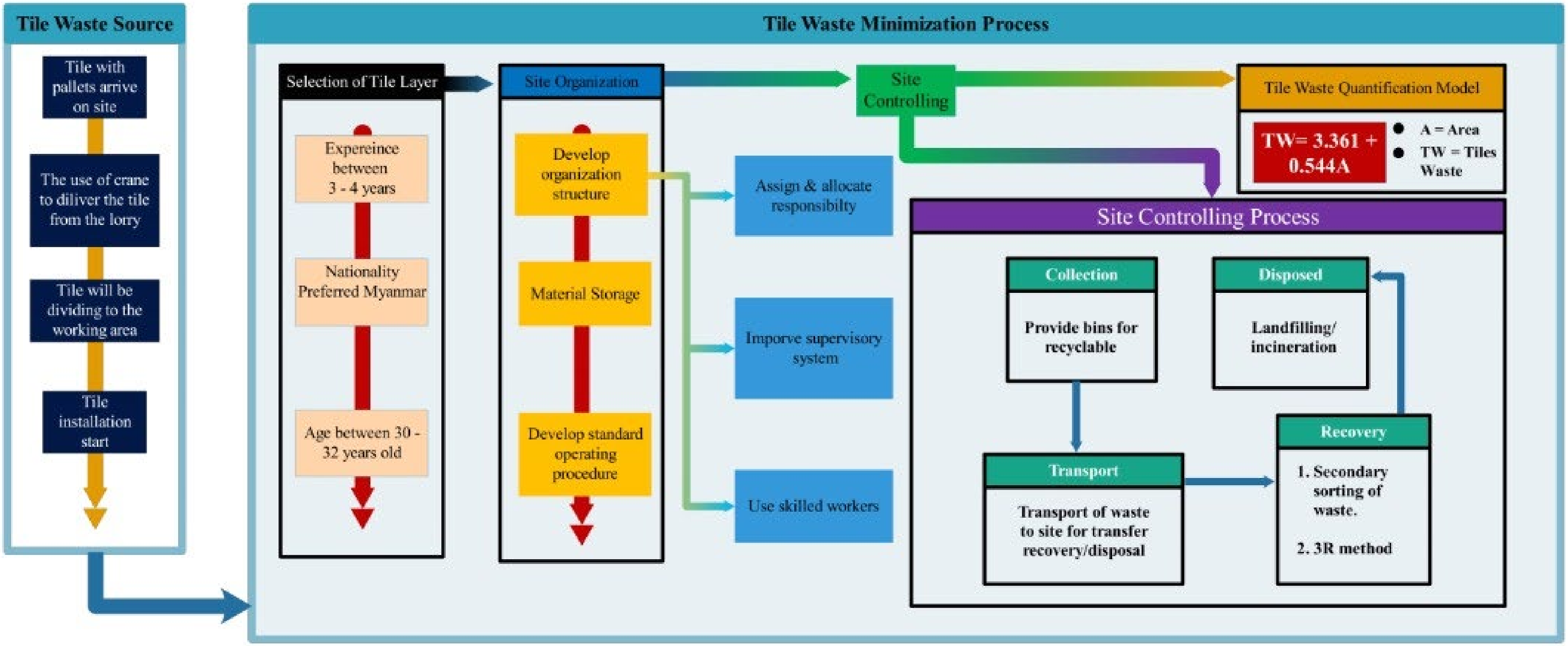

Figure 4: Framework of Tile Waste Minimization

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4. CONCLUSION

This study recommends the use of linear regressions to investigate the amount of tile waste generated from tile installation activities in housing construction sites. The analyses were only conducted from the construction stages. The projected amount may be utilized for future improvement in tile activities. The most common tile waste producers are the unskilled workers who had been assigned to do the skill work. Because educational work (to become the skill one) is a process, waste may come from many areas within this process. The site manager is the person responsible for controlling the amount of waste produces at sites.

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