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Material Based Penalty-Cost Quantification Model for Construction Projects Influencing Waste Management

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The Construction and demolition (C and D) waste generation is a critical issue for the construction industry, which negatively affects the economy, environment, and society. This study estimates the penalty-cost based on the produced C&D wastes in steel and concrete skeleton projects. Field survey and the BOQ data were collected from five concrete and four steel skeleton projects. The difference of materials used and wastes generated between concrete and steel skeleton projects were evaluated statistically (ANOVA and Welch and Brown-Forsythe). A financial analysis was implemented for estimating the penalty cost. The study outcomes demonstrate that the amount of waste that construction managers estimated is significantly lower than the actual amount generated. Furthermore, 0.055% of the total project cost of a penalty was estimated based on the waste produced at construction sites. In the end, the estimated penalty was validated by comparing it with the six recent completed projects. The penalty calculated in this study could save the project cost and reduce the C&D waste. As a result, imposing the estimated cost as a penalty would force construction managers to think thoroughly about the generated C&D waste problems. This study also has a novelty and will add to the body of knowledge by using penalty-cost quantification model to save project-cost of construction material-based-waste, and it can be further explored by adopting more quality data and engaging different construction materials.

Keywords: estimation of waste, construction projects, construction materials, penalty, cost quantification, waste management

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INTRODUCTION

In recent years, heavy construction has led to significant environmental destruction and excessive consumption of natural resources globally. The immense amounts of energy required for the transformation of C&D waste into construction goods (Maués et al., 2020). The impact generated by the dumping of untreated C&D waste into illegal landfills has resulted in landscape degradation and in environmental pollution, which remains difficult to resolve (Chi et al., 2020; Lu et al., 2021). The increase in produced waste, especially C&D, has attracted considerable attention in the last few decades (Lauritzen, 1998; De Melo et al., 2011). While construction activities play an essential role in the growth of towns and cities as the environment is adversely affected by construction activities. The harmful effects of heavy construction include the absence of adequate space for the filling of wasteland, energy over-consumption, high water use, dust, and gases released into the atmosphere (Lu and Yuan, 2011).

Construction waste consists of unused parts directly generated by the construction projects. The remaining unwanted materials from the removal of a building structure are demolition waste (Jia et al., 2017; Li et al., 2015; Long et al., 2020). Consequently, any construction waste method should be considered to minimize the harmful impact of waste generated in construction projects (Ding et al., 2018). While construction activity has since declined due to the shift in the economic cycle, the constant concern should remain for problems caused by such waste, or preferably by its management (Ma et al., 2020; Ahmed and Zhang, 2021). Waste management has become one of the world's critical environmental issues in developed and developing countries (Agamuthu, 2008; Ghaffar et al., 2020). Approximately 40% of material resources and worldwide energy are used under existing design and construction activities. The building industry produces 35% of industrial waste worldwide (F. Hendriks, 2000). In 2006, 81% of all waste generated by economic activities was accounted for by the industry and construction sectors (Xu et al., 2020).

According to Lu and Yuan (2011), developing countries produce about 50% of municipal solid waste, decreasing to 35% for developed countries. According to Maués et al. (2020), C&D waste generation in Brazil increased to 45 million tons in 2015. Besides, Kabirifar et al. (2020) argue that it is not only the issue of today's lifestyle to take care of risky C&D waste but also needs to be disposed of to avoid harmful environmental effects. In the European Union, 40% of the total use of natural resources is used to produce building materials alone, and 40% of the waste is produced by the construction of buildings (Wu et al., 2017). In 2008, Europe produced approximately 890 million tons of C&D waste while the degree of material recovery was only 25% (Sáez et al., 2011). The Statistics in China show that approximately one billion tons of C&W has been produced annually, but the overall recycling rate is only 5% (Yang et al., 2020).

Due to the large amount of C&D waste production, the quantity of various building project waste can be measured by many methods (Kabirifar et al., 2020; Maués et al., 2020; Lu et al., 2021). In recent years, the estimation methods have been assessed by some researchers to improve them by providing measurement tools and software (Wang et al., 2004; Cheng and Ma, 2013; Santos et al., 2019). It also created indicators and parameters that define the waste produced by construction activities (Hsiao et al., 2002; Fatta et al., 2003; Yuan and Shen, 2011). However, these methods are not sufficiently effective to estimate and reduce the C&D waste but may increase awareness among construction managers. The problem needs to be tackled through the management process, both in terms of the C&D waste produced and the origin of the trash. It is essential to introduce new procedures to prevent waste generation at construction sites (Chi et al., 2020; Kabirifar et al., 2020; Ma et al., 2020). For efficient waste management, the quantification of C&D waste is essential and the analyzed results will provide practitioners with fundamental data to determine the debris actual size and make the right decisions on its minimization and sustainable management (Ma et al., 2020).

The main objectives of this study are to investigate and test a quantification model for calculating a penalty for construction managers. This study also addresses the financial concerns, including the cost estimation of the recycling or disposal of hazardous waste for different projects. Moreover, the difference of materials used and wastes generated between concrete and steel skeleton projects were evaluated by ANOVA and Welch and Brown-Forsythe. A financial analysis was implemented for estimating the penalty cost. The quantification model has been developed to estimate the C&D waste for commonly produced wastes such as concrete, cement, aggregate, steel etc. As a result, the projected cost allocation as a penalty would force construction managers to consider it and accept the responsibility to control the generation of C&D waste.

LITERATURE REVIEW

Waste is characterized as a redundant degradation of ordinary materials (Negash et al., 2021), and advanced waste management techniques may dispense with additional costs and environmental dilapidation (Ding et al., 2018). Akinade et al. (2018) described waste as any loss caused by activities that produce direct or indirect costs but do not add any value to the product from the customer perspective. Liu et al. (2020) stated that any non-value addition performed at any time in any working system could be described as waste. Furthermore, Ajayi et al. (2015) described waste as unwanted materials entirely arising from human activities discarded in the environment. Lu et al. (2017) defined the concept of waste as unwanted or unusable materials that originate from numerous sources from industry, agriculture, construction businesses or depending on their location and concentration as it can be liquid, solid or gaseous, and hazardous or non-hazardous. Akinade et al. (2018) referred the waste management as the collection, transport, treatment and disposal of waste after site care. The principle of waste management is stated by Lu et al. (2015) to reduce waste generation, maximize waste recycling, to ensure safe and environmentally sound disposal of waste. Based on Huang et al. (2018) principle, the management of waste should be discussed in terms of the entire material cycle, including manufacturing, distribution, usage, collection, and disposal of waste. As an essential mechanism for the environment, waste recycling and removal should be treated fairly (Wu et al., 2019).

The C and D wastes generation generally occur due to a lack of awareness and skills among construction workers at various stages of the construction process. Nikmehr et al. (2015) and Khaleel and Al-Zubaidy (2018) reported that the lack of performance among construction workers and awareness of waste generation was significantly correlated. A large amount of C&D waste had a negative impact on the economy and exploiting natural resources and causing irreparable environmental harm. Lu et al. (2015) suggest that a picture of the current effects of C&D waste on the atmosphere can be drawn from precise measurements. Approximately 40–50% of the world's energy is generated by C&D waste, up to 50% of which would be correlated with CO_2 emissions (Ding et al., 2018; Ahmed and Zhang, 2021). Furthermore, if the transport of these waste materials is also considered, this view will increase to 75%. The Authors further revealed that 40% of the approximately 7.5 billion tons of raw materials are disposed of as waste per year, equivalent to approximately 3 billion tons a year. Nonetheless, the C&D waste produced is expected to account for 16% of global water eliminations. According to Edwards (2014), the environmental effects of C&D waste in 2050 will be four times of the todays environmental effects.

There are many methods, strategies and software tools available to estimate the C&D produced waste, in addition limited authors has work on the cost-penalty influencing waste management in construction sectors. Penteado and Rosado (2016) proposed a C&D waste management life cycle evaluation method to assess the environmental impacts of C&D-induced waste. Paz and Lafayette (2016) developed software-based analysis and strategies to build waste management. They argued that the outcome illustrates a beneficial method that can be used for building projects and significantly increases the efficiency of the waste management process. A dynamic model was introduced by Tam et al. (2014) to investigate the complexity of C&D waste in China. They concluded that C&D waste could be effectively managed by implementing the systematic and strategic landfilling and illegal waste dumping policy. According to the analysis of Yeheyis et al. (2013), 27% of C&D waste in Canada is disposed of by landfilling, while residential values are 70% of the waste produced. Butera et al. (2015) demonstrated that the velocity of C&D waste generation has recently caused many concerns in China due to urbanization. Dahlbo et al. (2015) introduced Reduce, Recycle and Reuse (3-R's) as three essential waste reduction strategies to reduce the environmental effects of C&D waste. Liu et al. (2021) stated that waste reduction strategies positively decrease the C&D waste problems based on the concept of cause and effect relationship. Hasan and Jha (2013) explore the safety incentives and penalty-provisions concerning the construction contracts to improve safety performance, similarly Maria (2018) discussed about the decision-making process in green construction projects. The authors further added about the waste demolition and its recycling by adopting the game theory penalty-mechanism. Arashpour et al. (2020) demonstrated about the off-site construction development and penalty-based optimization cycle for cost-effective solutions for the quality problems. Li et al. (2021) introduced a theory of (nowhere to dump) in which they discussed about the penalty charges and construction subsidy-mechanism for the C&D waste. Manowong (2012) followed a study mechanism based on the penalty cost for the parallel machine scheduling problems, and Meng et al. (2021) introduced a penalty strategies and reward system for green building incentives for environmental sustainability. They discussed about the dynamic and static reward and penalty system in construction projects.

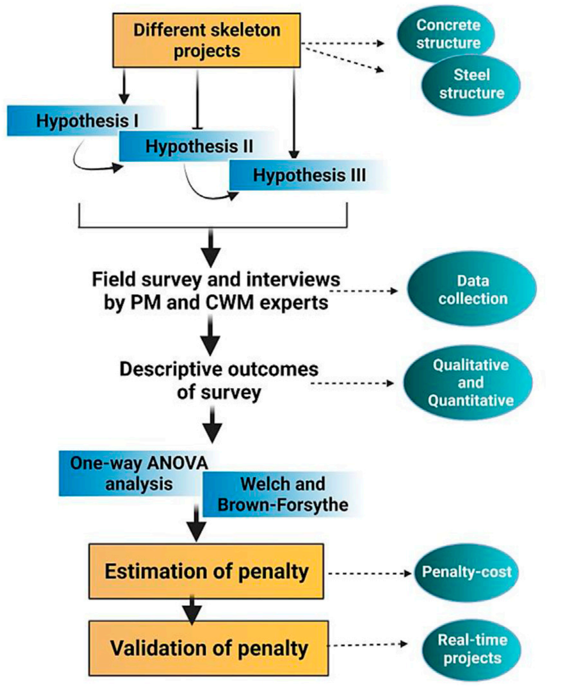

FIGURE 1 | The layout of the study.

The C&D waste can be minimized through proper awareness among worker and profit margin will increased significantly. Ajayi et al. (2015) proved that 25% of the waste produced on construction sites could be easily minimized, increasing profits by up to 2%. Most of the building projects are in a competitive market, and the marginal gains are therefore minimal. Due to wastage being reduced significantly, roughly average disposal costs using waste minimization measures accounted for 0.3% of the project value (Jin et al., 2019). In certain places, the waste level was as low as 1/3 of the normal rate of the waste. A waste minimization policy can achieve savings of 1%, and the building projects generally included four percent as a C&D waste allowance in the total project budget (Huang et al., 2018). Begum et al. (2006) found that recycling and reuse could raise the financial funding of building projects by 2.5%. By the quality of resources based on reduction, reuse and recycling (Udawatta et al., 2015), the costs will decrease, and the environmental performance of businesses will be increased. It must be recognized that any move towards the reduction, reuse and recycling of C&D waste will not only produce a healthier climate (Dahlbo et al., 2015), but also be financially profitable for those who are working in the direction of these types of project strategies (Wu et al., 2017).

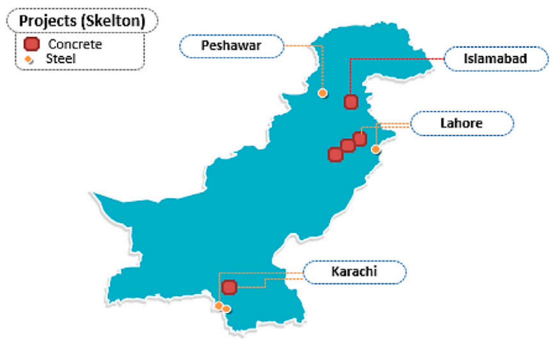

FIGURE 2 | The Location of construction projects in a map of Pakistan (city-wise).

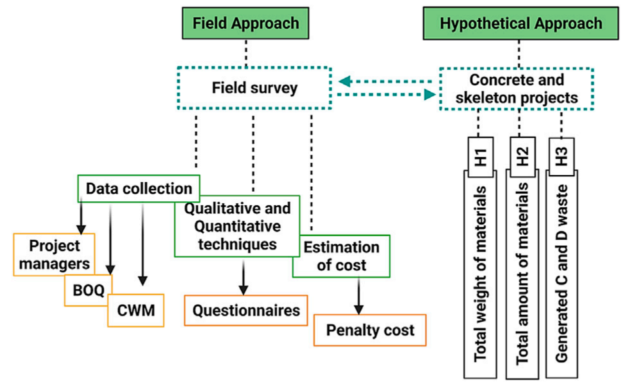

FIGURE 3 | Hypothetical and field approach.

METHODOLOGY

The research methodology represents the whole plan for incorporating different study components rationally and logically to address the research problem in an organized way. It provides a framework for data collection, calculation, and interpretation. Various research designs, such as interviews, descriptive and case studies, are used depending on the research objectives (Nawaz et al., 2019). In the present study, a case design was chosen to achieve the study's goal. A case study, also known as an in-depth field study (Huo et al., 2021), is ideal for determining whether a model, formula or other pieces of information applies to a phenomenon to achieve suitable results. (Rozenes et al., 2006; Creswell and Creswell, 2018). The methodology framework is shown in **Figure 1**.

Characteristics of Sample Projects

There were nine projects selected from four major cities (Lahore, Islamabad, Karachi, Peshawar) for this study. Two different skeleton-structure projects were selected as a case study, i.e., five concrete and four steel. Each project has different areas and costs. It is important to note that all of these nine projects were constructed by nine different construction companies. There were five projects (3-concrete and 1-steel skeleton) selected from the province Punjab (city-Lahore); three projects (1-concrete and 2-steel skeleton) were selected from province Sindh (city-Karachi). One project was selected from province Khyber Pakhtunkhwa (city-Peshawar), and one was chosen from Islamabad, the capital city of Pakistan, as shown in **Figure 2**. A non-probability technique was used to select these projects as non-probability (convenient sampling) is the best sampling technique to collect the data when having a budget and time constraints (Nawaz et al., 2020). It would not have been possible to collect the critical data if the probability technique had been used for choosing these projects, where every variable has a chance of being randomly included in the sample (Avotra et al., 2021). The statistical comparison between these two types of skeleton-projects is then evaluated and hypothesis are formed with respect to construction materials. The characteristics of these projects, including skeleton type, project location, area, and project cost are shown in **Table 2**.

Hypothesis Development

There are three hypothesis that was formed and then tested using statistical methods.

HI: The weight of materials used in one square meter (1 m^2) of the concrete and steel skeleton projects vary significantly.

To analyze the 3-R approaches (reduce, recycle, and reuse), this argument may be a tool to understand what will be the most produced waste in the C&D projects (Ahmed and Zhang, 2021). The approach was to list the primary materials based on the behavior of the dependent and independent variables and use a mean comparison test. A glimpse of hypothetical approach and filed approach can be seen in **Figure 3**.

H II: The total amount of used materials in one square meter (1 m^2) of concrete and steel skeleton projects chosen for this study differs significantly.
H III: There is a major difference in the generated C&D waste from concrete and steel skeleton structure projects.

ANOVA is a numerical approach for assessing variations in a dependent and independent variable based on scale using a nominal-level variable reflecting two or more groups (An et al., 2021). In a one-way ANOVA, there is just one independent variable, and in a two-way ANOVA there are two independent variables. One-way ANOVA is a valid approach for testing the hypothesis. One-way ANOVA has one assumption that the dependent variable must be normally distributed and randomly chosen (Nawaz et al., 2021). In this study, the dependent variables are hypothesis II and III, which are numeric with ton/m^2.

Questionnaire Survey

A questionnaire is a method for evaluating a series of questions intended to collect data from a targeted population. In this study a questionnaire was presented to be filled in by project

TABLE 1 | Profiles of the respondents.

Sr. NO.	Role	Experience
1	PM of a local construction company	>7 years
2	PM of another local construction company	>5 years
3	PM and CWM expert, Lahore Development Authority	>15 years
4	PM and Engineer	>8 years
5	Deputy PM of a local construction company	>9 years
6	Site Manager of a construction and demolition site	>10 years
7	CWM expert and Scholar from a local university	>12 years
8	CWM expert and Scholar from a local university	>16 years
9	PM and former Government official	>25 years

Note: PM, project manager; CWM, construction waste management.

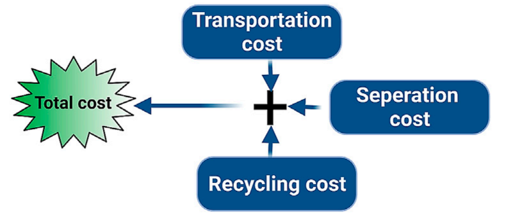

FIGURE 4 | Cost estimation.

TABLE 2 | Description of construction projects.

Projects	Description	Location	Skeleton structure	Area (m^2)	Cost (PKR, Millions)
P-1	Shopping Mall	Karachi	Concrete	18,300	1,202.0
P-2	Residential	Lahore	Concrete	7,370	398.51
P-3	Police Office	Lahore	Concrete	5,933	291.72
P-4	School	Lahore	Concrete	6,378	441.71
P-5	Resturant	Islamabad	Concrete	3,500	179.85
P-6	3-Subway Stations	Lahore	Steel	2,700	1,083.6
P-7	University Hostel	Karachi	Steel	11,365	712.81
P-8	Hospital	Peshawar	Steel	27,560	3,546.4
P-9	Warehouse	Karachi	Steel	7,245	677.22

managers. The questionnaire was completed during face-to-face interviews. The managers were asked to list the most valuable and commonly produced waste materials in their projects based on project quantity. Moreover, the amount of generated waste mentioned by project managers in the questionnaire for each material was also calculated in (ton). The cost of the specified generated waste was estimated, including its dumping cost. **Table 1** shows the profiles of the interviews. All the respondents hold at least 5 years of construction waste management (CWM) relevant experience.

Data Collection

All the data was collected from the bill of quantities (BOQ) associated with each selected project, as shown in **Table 3**. The amount of material used and waste produced was estimated based on collected data. The data in BOQs were not sorted as necessary and the material units are reported according to the local-traditional way. Most units were classified as m^2, m^3, and kg. The aim is to centralize the units' weight and then split them into the project area to provide the ton/m^2 unit in this study. Most of the third dimensions related to the unit of m^2 have been specified in the material name, such as mortar (2 cm), gypsum (1 cm), wood flat (4 ml), and glass (10 mm). The weight of the material used was determined by multiplying the area (A), density (ρ), and volume (V) of the same materials. If the unit is in m^3, the total weight of used material in the project was determined by multiplying the mass and volume of total quantity purchased. Consequently, the weight of the products in kilograms was determined by dividing the weights by 1,000. The ton/m^2 target unit was then achieved by dividing the weight of materials by the project area. The essential information for each of the selected projects is shown in **Table 2**.

Cost Estimation

To determine the fare penalty for the purpose of cost-estimation, it is appropriate to measure the cost of separating, transporting, and recycling/disposing of waste. This section illustrates the following methods for estimating the costs of three groups as shown in **Figure 4**.

- *C&D Waste Separation Cost*: All of the generated C&D wastes were mixed at the construction site. A skilled worker was hired to separate the mixed waste into a required individual category of the material. The time (hours) was noted for the separation of one-ton material, and then the worker's hourly wage was estimated.
- *Transportation Cost:* Various transport methods are available for this purpose, based on the weight of waste produced at construction sites. The estimated transportation cost was collected from several construction transportation firms by telephonic interviews. The average price from all the transportation firms was calculated and used in this study.
- *Recycling Cost:* It is not expensive to set up a recycling plant for the construction managers; as there are many companies (Modern Construction Company (MCC), Lahore Waste Management Company (LWMC) available in Pakistan

that run their business on recycling and disposal of building waste. Several telephone calls with the managers of these companies were arranged.

Consequently, the cost of 1 ton of each generated waste material (concrete, steel, Ceramic, wood, paper, stone, plastic, and plaster) was estimated.

Estimation of Penalty

A penalty is a punishment that someone is given to do something against a law or contract. A well designed policy by the government for reducing C&D waste can encourage project managers to reduce waste production. The construction employers will realize that it is more beneficial for them to reduce waste through recycling or reusing if the government establishes a penalty equal to the amount of generated C&D waste by each project. As a result, the companies will be able to buy new goods by reducing waste generation or recycling. Penalty was estimated by **Eq. 1**.

$$\text{Penality} = \sum_{i=1}^{n} Q_{ri} \times \text{Area} \times \text{Cost} \tag{1}$$

Where Q_{ri} is the amount of waste for "i" case study (ton/m^2); n is the number of waste produced in the project, Area is the total area of each project (m^2); Cost is the estimated cost (PKR) including the cost of separation, transportation, and recycling of all the waste materials.

Waste Estimation

The amount of generated waste was calculated based on the BOQ data of each selected project. There are nine (9) projects that have been selected to assess the basic components of the materials wasted in different construction activities. The waste produced during transportation, packaging or the material used in construction but wasted as the result of packaging was also considered in this study. The amount of C&D waste was calculated by **Eq. 2**.

$$Q_r = \phi(Q_m) = Q_m\,(CR\ x\ CT\ x\ CC) \tag{2}$$

Q_r denotes the construction waste; Q_m refers the overall construction material used on project site; CR is the coefficient applied for basic elements (BE) measurement; CC shows per unit's conversion coefficient for each quantity; and CT reflects standard assessment of targeted material item to standard measurement as a conversion coefficient.

As of adding the first and the afore-mentioned equation, CC = 1 (having a same measurement of ton/m^2); Similarly, CT = 1 (alteration of kg/m^2 turned into ton/m^2). Therefore, let **Eq. 2** be:

$$Q_r = \phi(Q_m) = Q_m\,(CR) \tag{3}$$

RESULTS AND DISCUSSION

The descriptive table for numeric variables and frequency table for categorical variables are demonstrated using the Statistical and Graphical tools (SPSS, JASP, and Origin Lab). Instrument findings such as upper boundary and lower boundary of 95% confidence interval for each numeric variable and mean standard deviation (SD) were calculated. Additionally, a number of questionnaire (N), median, maximum, and minimum for each categorical variable are also extracted. All the project managers had preferred the four groups of materials (Steel, Concrete, Aggregates, and Ceramic) as the most significant wastes generated in their projects. The complete descriptive details of all targeted construction projects extracted from population are estimated as amount of waste illustrated in **Table 3**.

Figure 5 demonstrates the total weight of used materials and produced waste (ton/m^2) in each project based on the BOQs of nine projects.

Hypothesis Results

There are three hypothesis developed based on the waste-materials from the nine projects (five concrete, four steel skeleton) selected as a case study. The Analysis of Variances (ANOVA) is applicable to evaluate hypothesis I, if the dependent variable (ton/m^2) is in numeric-state and the classified materials employees for independent variable in term of categorical-state. The dependent variable must be normally distributed and randomly chosen, corresponding to one of ANOVA's assumptions (Sthle and Wold, 1989). The other assumption is that each level's variances are equal, which can be evaluated using the Levene method. The Levene test is a statistical-technique that adds to determine the normality of the data between two or more groups. It is used to test the hypothesis if the population variances are identical. Suppose the corresponding *p*-value of Levene's test is smaller than the threshold value (0.05 in this study). In that case, the selection method in sample differences are unlikely to have arisen as a function of random sampling from an equivalent variance population. As a consequence, the hypothesis of equivalent variances would be rejected, indicating that there is a gap in the population's variances (Gastwirth et al., 2009; Derrick et al., 2018).

In this study, the assumptions of Levane test was not fulfilled for hypothesis I, because the *p*-value was less than 0.05. Therefore, the welch and Brown-Forsythe test was used, which do not require such assumption and the outcomes are shown in **SupplementaryTable SA2** (see **Supplementary Materials**). Regarding the second hypothesis of this research that the total amount of used materials in one square meter (1 m^2) of concrete and steel skeleton projects chosen for this study differs significantly. Therefore, one-way ANOVA was used for the second hypothesis and the results are demonstrated in **SupplementaryTable SA1** (see **Supplementary Materials**). For the equality of variances assumption same as the first hypothesis, the results indicate that dependent variables Mortar & Brick and Aggregates have a significantly unequal variance; therefore, instead of ANOVA, Welch and Brown-Forsyth were used. There is no restriction regarding the rest of the variables and the method of the test method is ANOVA. **SupplementaryTable SA2** shows the results of Welch and Brown-Forsythe tests for hypothesis II.

TABLE 3 | Descriptive outcome of questionnaire.

Materials	N	Mean	SD	L. Boundary	U. Boundary	Min.	Max.
				95% confidence interval			
Concrete	9	1710.2	1,197	812.6	2,490	360	3,650
Aggregates	9	610.11	345.7	382.7	865.4	146	1,250
steel	9	112.22	83.66	54.29	167.8	18.1	305.1
Plastic	9	2.4401	0.881	1.512	3.212	2.11	5.224
Ceramic	9	13.161	8.952	6.340	20.25	1.00	32.10
Wood	9	5.2123	2.255	1.724	7.620	1.00	8.121
Paper	9	5.4811	1.856	3.843	7.231	3.00	10.25
Gypsum	9	6.1312	1.487	1.567	6.187	1.15	7.518
Bricks	9	10.125	1.897	2.368	9.654	2.254	11.25

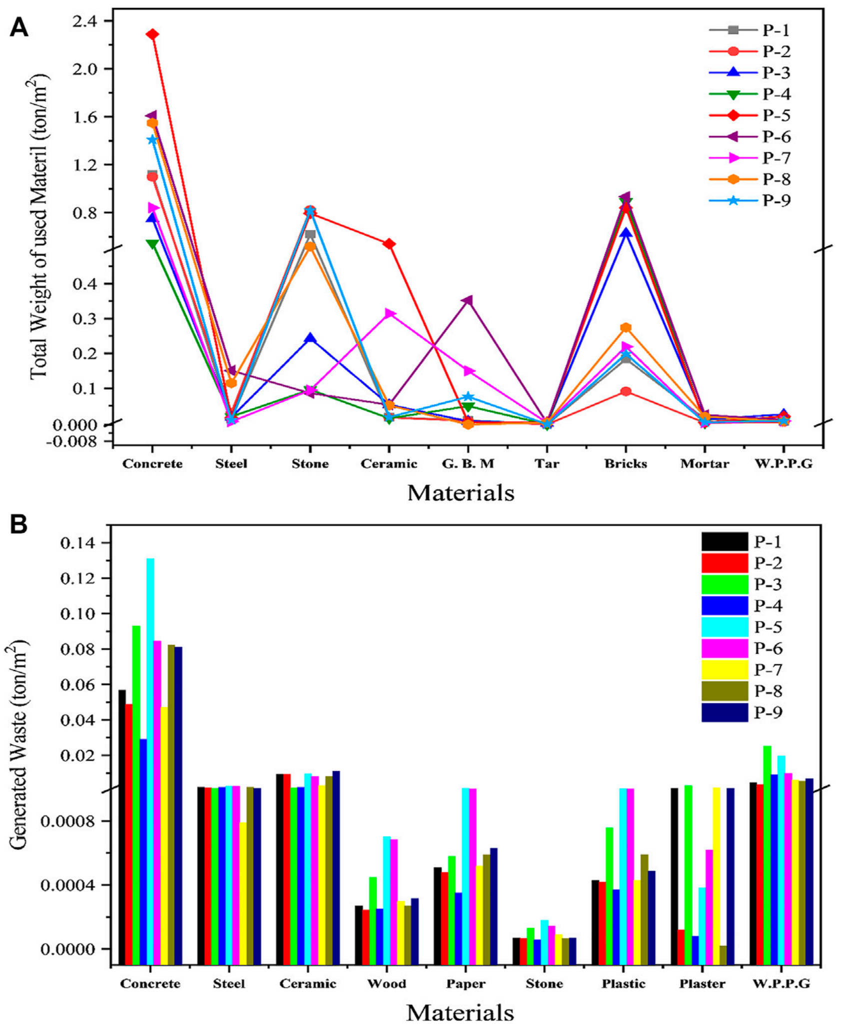

FIGURE 5 | Weight of selected projects. **(A)** Total used weight. **(B)** Total generated weight.

The amount of concrete used is substantially different according to the One Way ANOVA analysis performed on the required materials. In **Figure 5**, it is clarified that the amount of concrete usage is much higher in the concrete skeleton structure. There may not be enough data to suggest a substantial weight difference between the components and the skeleton structure for the others. There is little evidence to suggest that the amount of Mortar, Brick and Aggregates used in both structures differs significantly. Finally, hypothesis III claims that the produced wastes in

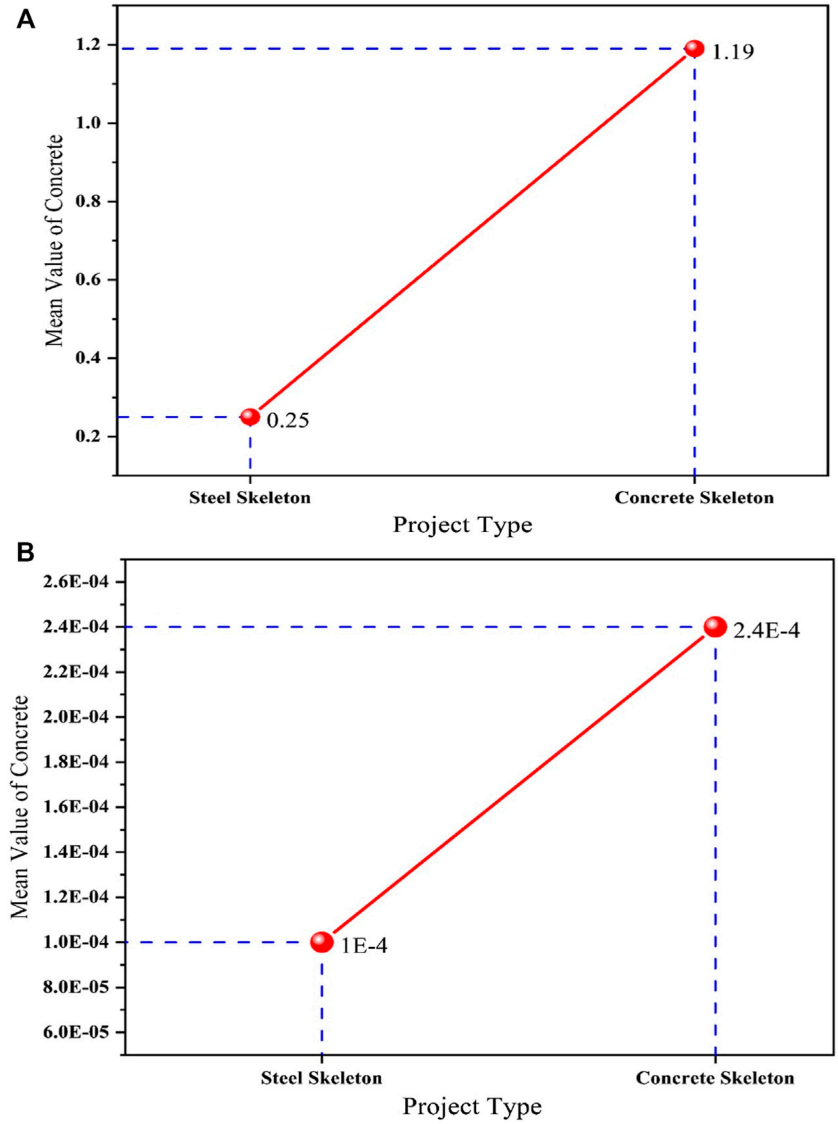

FIGURE 6 | Mean Plot. **(A)** Total used material. **(B)** Total generated waste.

concrete and steel skeleton structures are significantly different. ANOVA was used to test the last hypothesis, just as it tested the first two hypothesis. The results for hypothesis III is shown in **SupplementaryTable SA3** (see **Supplementary Materials**). The test results show a significant difference of variances only for "other" category among independent variables. The results of Welch and Brown-Forsythe results for hypothesis I, II, and III are given in **SupplementaryTable SA2**.

The descriptive outcomes for hypothesis II and III are shown in **SupplementaryTable SA3**. The mean plot of hypothesis I and II are (see **Figure 6**) based on the questionnaire's descriptive results (**SupplementaryTable SA3**). The mean value of the amount of concrete used in the concrete skeleton is 1.19 and the steel skeleton was only 0.25. The amount of concrete used in concrete skeleton projects is significantly higher than steel skeleton projects. Similar to the first hypothesis outcomes, the amount of generated waste in concrete skeleton projects was higher than in steel skeleton projects. The concrete's mean value as a generated waste for concrete and steel skeleton was 0.00024 (2.4E-4) and 0.0001 (1E-4), respectively. It is reflected from the mean plot (**Figure 6**) that concrete is the majorly used material and is commonly produced as a waste for both types of skeleton projects.

Separation, Transportation and Recycling Cost

The amount of waste that must be transported, regardless of distance, has a significant impact on transportation costs. During a telephone interview with several construction

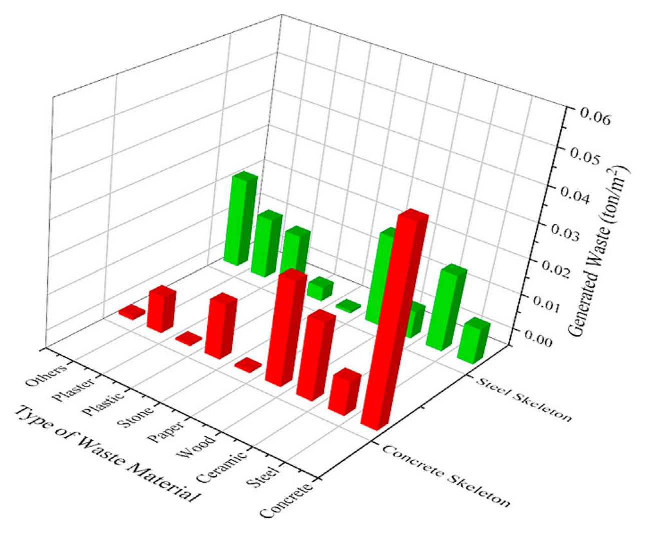

FIGURE 7 | Generated waste of concrete and skeleton projects in ton/m^2.

transportation firms, an average transport price was gathered and summarized in **SupplementaryTable SA4** (see **Supplementary Materials**). In the light of **SupplementaryTable SA4**, it can be observed that the average cost of transportation for each ton of waste is approximately 1712 PKR. It is important to remember that the products' quality has no impact on the prices as long as they are solid.

To cover the cost of separation, one worker separated 1-ton wastes in four projects from multiple mixed and the time being spent was reported as follows; 1) plastic, aggregates, mortar, concrete, paper, ceramic, and mosaic were separated in 4.2 h; 2) plastic, tar, steel, and brick were separated in 3.7 h; 3) In 5.2 h (concrete, aggregate, wood, glass, and plastic) and in 4 h (gypsum, base material, concrete, separate stone, and other insulation materials) were separated.

Based on the average timing of these four collected times, it took 4.3 working hours to separate each pile of produced waste into the various waste classifications mentioned in **Figure 3B**. Furthermore, the expense of hiring a worker for this job is 1920

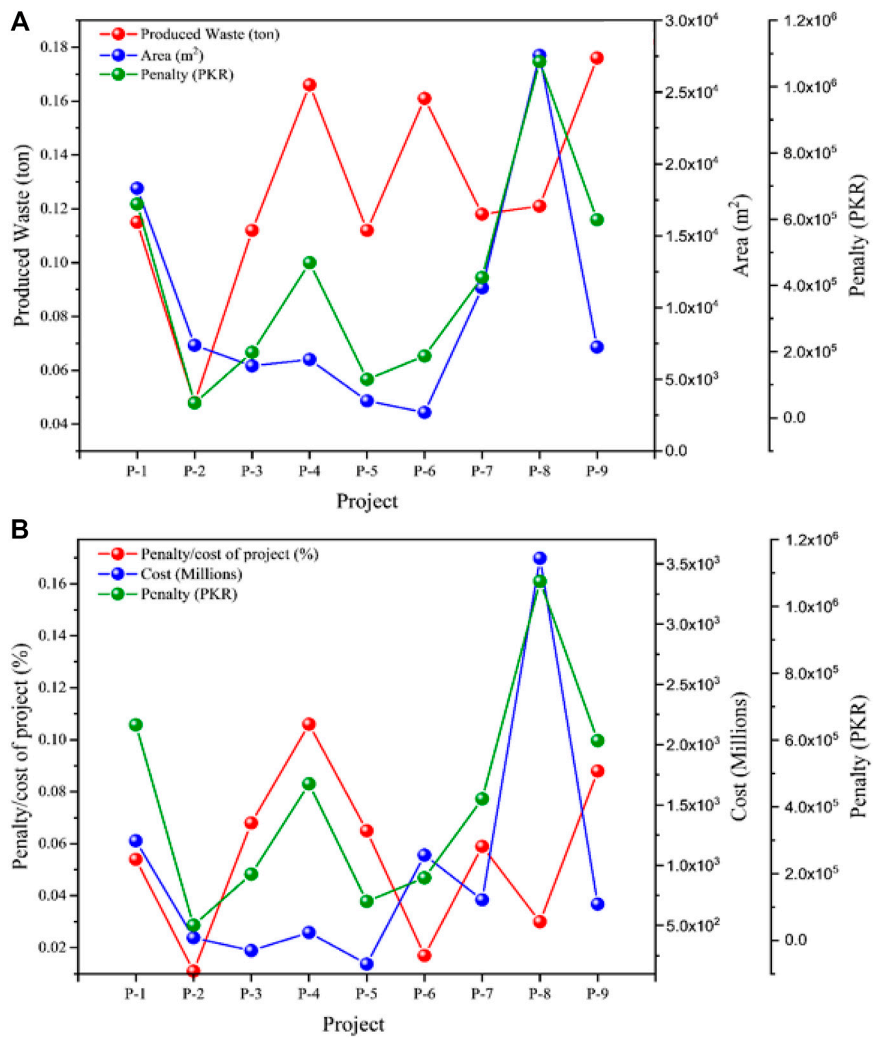

FIGURE 8 | Penalty estimation **(A)** Produced waste (tons) **(B)** Penalty/cost of project (%).

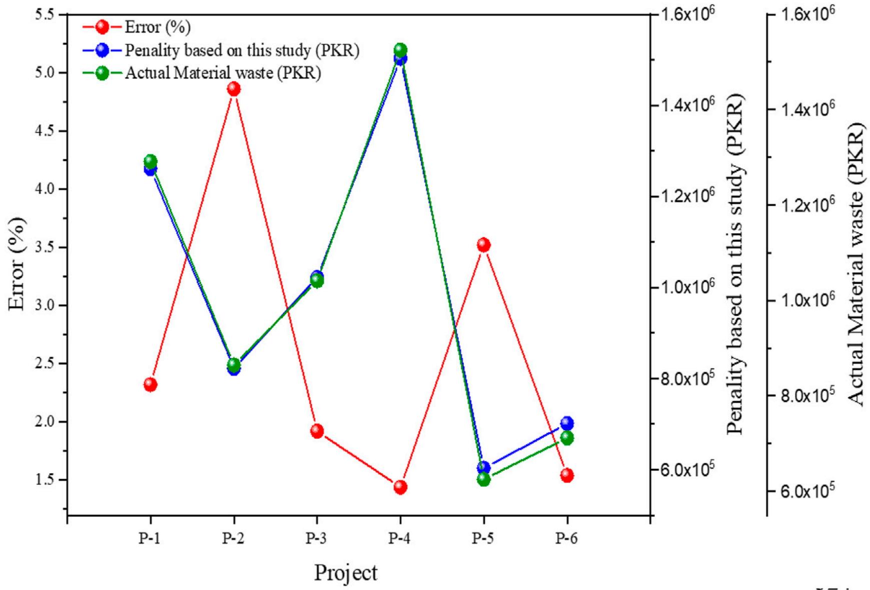

FIGURE 9 | Penalty error (%), actual material waste and calculated penalty (PKR).

PKR per day for 8 h of work or 240 PKR per hour. As a result, the cost of splitting one tone of waste into various waste materials will be about 960 PKR.

Penalty Calculations

The amount of concrete used in steel skeleton and concrete skeleton projects differed significantly; two models for both structures were demonstrated. The average amount of C&D waste produced per square meter of concrete and steel skeleton projects is calculated separately by **Eqs. 2, 3** and presented in **SupplementaryTable SA5**(see **Supplementary Materials**) and **Figure 7**.

All of the information needed to determine the penalty has been collected, the penalties for each case study are calculated using equation one and shown in **SupplementaryTable SA6** (see **Supplementary Materials**) and **Figure 8**. Consequently, the penalty estimated for each project contains approximately 0.055% of the cost of that project. The cost of recycling the C&D waste materials on the construction site is lower than the cost of separation and transportation of C&D waste at the end of the project. As a result, the employer is encouraged to recycle and save new materials than paying the penalty at the same rate. Furthermore, the government has some benefits in projects where the employers are willing to pay the penalty rather than tackle the project wastes. The revenue generated by these types of projects will be used to fund waste recycling research and development. Then small companies can grow to recycle the same wastes and allowing them to sell the recycled materials to contractors for future projects.

Penalty Validation

The estimated penalty in this study was compared with six real time-projects completed in recent years. Three steel and three concrete skeleton projects were selected for the validation of the penalty. The selected projects were completed by six construction companies (contractors) and located in different cities of Pakistan. The face-to-face interviews with project managers have been taken regarding the generated waste in their projects, and results are shown in **SupplementaryTable SA7** (see **Supplementary Materials**) and **Figure 9**. The data collected during the interviews includes waste produced (ton), price of generated wastes (PKR), total cost (PKR) and area of projects (m^2). The penalty cost was calculated based on **Eq. 1** by using the data collected by the project managers. As a result, penalty cost was compared with the material waste price and error between penalty and actual price of produced waste was calculated. It can be seen that their loss due to produced waste is approximately equal to the estimated penalty in this study. Therefore, it is a valued need for project managers to use penalty calculation before starting the project to save the project's cost.

CONCLUSION AND RECOMMENDATIONS

In this presented work, the investigation of the total amount of materials used and generated C&D waste in concrete and steel skeleton structure projects were studied. For this purpose, a total of nine skeleton structure projects were selected as a case study, including five concrete and four steel skeleton structure projects from four major cities of Pakistan. Three hypothesis was developed, and the questionnaire were filled by the project managers of five concrete and four steel skeleton projects to collect the data. BOQ were also a major source to collect the data. A descriptive analysis of the questionnaire data was performed.

One-way ANOVA, Levene, and Welch and Brown-Forsythe tests were used to test and validate the hypothesis. Furthermore, the penalty-model was developed to estimate the penalty in the construction industry based on the cost of the project. The key findings of this study are followings:

1) The results of the questionnaire demonstrate that the amount of C&D waste that project managers estimate is significantly lower than the actual amount of generated waste. The lack of awareness may cause harmful damages to the environment and could be a reason for financial losses in their projects.

2) Regarding the difference of used materials in nine projects, results demonstrate that the amount of concrete used in the concrete skeleton structure is significantly higher than steel skeleton structure projects. However, there is no strong evidence of a significant difference for material used in both skeleton projects (p-value > 0.05). The total amount of used materials in the concrete skeleton project was five time greater then the steel skeleton structure projects.

3) The amount of concrete generated as waste in steel skeleton structures is significantly less than in concrete skeleton structure projects. The mean value of concrete as a generated waste for concrete and steel skeleton was 2.4E-4 and 1.0E-4, respectively.
4) A penalty-cost was estimated at approximately 0.055% of the total project costs, which the manager of the project would ignore the generated waste. The estimated penalty cost was compared and validated with six real time-projects completed in the last 3 years. The cost of recycling the C&D waste materials at the construction site is lower than the cost of separation and transportation of C&D waste. Consequently, the employer would need to choose to recycle the C&D waste materials rather than paying the penalty at the same rate.

The construction managers need to use the penalty-cost estimated in this study to calculate the cost of generated waste. As a result, incorporating this research in for the first time could bring a new debate about improving the culture of recycling waste, especially in relation to construction projects for developing countries, i.e., Pakistan. The government must update almost all of the costs that have been estimated for the penalty on a yearly or even monthly basis because of high inflation rate in developing countries. Otherwise, this penalty will be unnecessary for project managers to be charged instead of taking care of wastes created in their project. Since there is a lack of understanding about C&D waste generation and recycling in country, the majority of waste generated is disposed rather than recycled. However, there are more companies with more advanced technology for recycling the C&D waste materials in developed countries.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

AN: Conceptualization, writing the draft, methodology, XS: supervision, JC: resources and funding acquisition, HZ: data collection and editing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.807359/full#supplementary-material

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