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Influence of Design Quality on Material Waste in Residential Building Projects

Influencia de la calidad del diseño en el desperdicio de materiales en proyectos de edificación residencial

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Abstract.
This study aims at identifying the main factors affecting design quality, identifying the main factors affecting material waste and addressing the relationship between design quality and waste on construction sites in residential building projects in Palestine. To identify the main factors of deign quality and material waste, a questionnaire survey is conducted. Fifteen (factors of design quality and 15 factors of material waste are identified from literature review and feedback from local experts. A questionnaire is designed to include these factors. Targeted population included contractors and consultants who have experience in residential projects. Forty-five contractors and 35 consultants rank the identified factors according to their importance. The study reveals that the top factors of design quality are: lack of staff experience, inadequate time given for design, payments delay for design services, owners award bids for lowest price designer and copying and modifying from previous designs. It also indicates the significant factors of material waste). Include: design mistakes, late design changes, rework, lack of labor experience and purchasing materials not complying with specifications. Based on data collected from 33 building projects, a predictive model is established. The model indicates a good relation between material waste and design quality.
Keywords: *residential, buildings, material waste, design quality, design mistakes.*

Resumen
Este estudio tiene como objetivo identificar los principales factores que afectan la calidad del diseño, identificar los principales factores que afectan el desperdicio de materiales y abordar la relación entre la calidad del diseño y el desperdicio en los sitios de construcción en proyectos de edificación residencial en Palestina. Para identificar los principales factores de la calidad del diseño y el desperdicio de materiales, se realiza una encuesta. Quince (factores de calidad de diseño y 15 factores de desperdicio de materiales se identifican a partir de la revisión de la literatura y la retroalimentación de expertos locales. Se diseñó un cuestionario para incluir estos factores. La población objetivo incluyó contratistas y consultores que tienen experiencia en proyectos residenciales. Cuarenta y cinco contratistas y 35 consultores clasificaron los factores identificados según su importancia. El estudio revela que los principales factores de la calidad del diseño son: falta de experiencia del personal, tiempo inadecuado para el diseño, demora en los pagos por los servicios de diseño, licitaciones de adjudicación de los propietarios para el diseñador de bajo costo. Incluyen: errores de diseño, cambios tardíos en el diseño, reelaboración, falta de experiencia laboral y compra de materiales que no cumplen con las especificaciones. Datos recopilados de 33 proyectos de construcción, se establece un modelo predictivo que indica una buena relación entre el desperdicio de material y la calidad del diseño.
Palabras Claves: residencial; edificaciones; desperdicios de material; calidad de diseño, errores de diseño

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1. Introduction

Construction sector is one of the main economic sectors in any country. It helps in providing people with homes and infrastructure. Moreover, it helps in absorbing labors. In spite of its high importance, construction industry is full with risks that lead to projects failure (Mahamid, 2021). Material waste is one of the main risks in construction projects (Saidu and Shakantu, 2016a); (Mahamid, 2021). Previous studies concluded that about 15% of building materials delivered to construction sites end up as wastage (Bekr, 2014); (Ameh and Itodo, 2013); (Mahamid, 2020). Some previous studies linked between material waste on sites and cost overrun (Saidu and Shakantu, 2016b); Mahamid, 2020). Others linked between it and project delay (Mahamid, 2021). Mahamid (2020) concluded a strong relation between material waste and change orders in building projects. (Ameh and Itodo, 2013) suggested that construction parties should pay attention to material waste on site as it is a significant factor of poor performance in construction projects.

On the other hand, design quality plays a great role in project success or failure; such that well-prepared design documents lead to project success and design defects and mistakes lead to project failure (Couto, 2012); (Williams and Johnson, 2013). Some previous studies found a link between design quality and project failure in terms of delay and cost increase (Mahamid and Bruland, 2012); (Durdyev et al., 2010); (Kpamma and Adjei-Kumi, 2011). (Pandit, 2015) and (Gopang et al., 2020) concluded that poor design quality leads to frequent design changes during project construction. (Mahamid , 2021) concluded that poor design quality has high impact on rework and interrupts the whole project performance. In his study, (Mahamid, 2021) recommended construction parties to pay attention for the problem of design quality in construction projects to improve projects performance. He suggested giving designers enough time for design and review to improve produced design documents.

Literature review reveals the followings: 1) many studies conducted to investigate material waste causes in construction projects, 2) little studies conducted to study design quality factors, 3) very little or no studies conducted to investigate the impact of design quality on material waste in building projects. Therefore, this study is highly important because it highlights the relationship between design quality and material waste in residential building projects. It aims at: (Abdelaziz,2009).) investigating design quality factors, (Agyekum et al., 2013),) identifying factors of construction material waste on site, (Al-Hajj and Hamani, 2011).) developing predictive models that describe the impact of design quality on construction material waste in building projects.

2. Previous studies

2.1 Factors affecting design quality in building projects

(Tilley et al., 1997) defined design quality as "the ability to provide the contractor with all the information needed to enable construction to be carried out as required, efficiently and without hindrance". The quality of design affects the performance of the project. (Lopez and Love, 2012) studied 139 construction projects. They found that design mistakes contribute to about 7% of project cost increase. (Couto, 2012) indicated that design mistakes and errors lead to claims and disputes between construction parties. (Mahamid and Bruland, 2011) concluded that "design deficiencies" is a main factor causing cost overrun in public and private projects.(Abdelaziz, 2009) revealed that the poor quality of design leads to bad performance in building projects. (Love et al., 2006) found that problems in design contribute to large proportion of rework cost in construction projects. (Li and Taylor, 2014) stated that "design mistakes" is a main factor that affects rework which influences the smoothness of project progress. They recommended improvement of design quality to minimize rework in construction projects. (Ali et al., 2012) indicated that design mistakes and omissions lead to cost increase, delay and poor-quality deviations in construction projects.

(Pandit, 2015) conducted a questionnaire survey to identify the major factors affecting design quality in construction projects. He concluded that the main factors include: soil tests, surveying works, parameters of structural and architectural design, and quality control. (Abdelaziz, 2009) found that the most important factors affecting design quality in construction projects are: lack of consultant skills, tight schedule for design and review, lack of experience, lack of managerial skills. The study also concluded that the most frequent factors affecting design quality are: selection of designers with lowest fees, late changes by the client, low design fees, working of designers on many projects at the same time. (Durdyev et al., 2010) found that inadequate site investigations and late design changes are the top factors affecting design quality in construction projects. (Sweis's, 2013) indicated that design deficiencies and

problems with the use of design parameters are main factors contributing to time overrun in construction projects. (Mahamid, 2021) concluded that the top design quality factors are: payments delay from owners to designers, staff working on more than one project at the same time, copying from previous projects and lack of time available for design and review. In his study, he found a strong link between design quality and rework in building projects.

2.2 Factors affecting material waste in building projects

(Ikau et al., 2016) defined waste as "unwanted materials". Material waste in construction projects has major effects on cost increase (Rawshan et al., 2009); (Mahamdi and Badawi, 2014); (Mahmaid, 2020). Many previous studies concluded that the value of construction material waste is about 30% in construction projects (Mahamid, 2020); (Bekr, 2014). (Mahamid , 2020) found a significant relationship between rework and material waste in building construction projects. (Ameh and Itodo, 2013) found that material waste in building projects contributes to 30% of cost increase. "Careless handling" is found to be one of the major factors leading to waste in tiles, ceramics, and plastering materials (Poon, 2007). (Swinburne et al., 2010) concluded that the main factors affecting material waste in construction projects include: improper storage, improper handling, poor site conditions, materials overordering, and material damage.

(Nagapan et al., 2011) performed a study to identify the main factors contributing to material waste on construction sites. They concluded that the top material waste factors are: late design changes, poor storage, lack of workforce skills, change orders and bad weather. (Al-Hajj and Hamani, 2011) conducted a questionnaire survey to find out the main factors affecting material waste on construction sites in UAE. They indicated that the top factors include: problems in design, change orders, and rework. (Agyekum et al., 2013) found that the major factors of material waste in building projects are: improper storage, late changes, poor material management on site, and using materials that do not comply with specifications. Recycling and using of surplus materials is recommended by them to reduce waste on sites. Through a questionnaire survey, (Ameh and Itodo, 2013) identified the main factors affecting material waste in building projects, namely: improper handling, rework and shortage in supervisors. On the other hand, (Ikau et al., 2016) found that the top material waste factors on construction sites are: lack of experience, bad storage, rework, and using materials that do not comply with specifications.

(Arshad et al., 2017) conducted a questionnaire survey to rank the factors affecting construction waste. They found that the top factors are: lack of skilled labors, lack of supervision, and improper management on site. (Ahmad et al., 2018) concluded that financial conditions, variations, poor communications between participants, improper planning and poor handling are the top factors contributing to material waste in building projects. (Luangcharoenrat et al., 2019) conducted a study to investigate the material waste causes in construction projects. They found that late design changes, improper storage and poor planning are the most factors affecting material waste. (Mahamid, 2020) identified the main factors of material waste, namely: lack of labors experience, late changes, bidding policy, rework, and design mistakes.

In summary, literature review reveals that: very little studies addressed the problem of design quality in construction projects; numerous studies addressed the construction material waste, very little or no studies conducted to investigate the relationship between design quality and material waste on site. This study is conducted to fill this gap, it addresses the impact of design quality on material waste. Results of this study would be helpful for academics and construction professionals in terms of: identifying the main factors affecting design quality, identifying the main factors affecting material waste, and addressing the relationship between design quality and waste on construction sites.

3. Research Methods

In this study, the following methods are used to achieve the study objectives:

(1) A questionnaire survey is conducted to address the followings:
   (a) Major factors affecting design quality in building projects (objective 1)
   (b) Major factors affecting material waste in building projects (objective 2)

(2) Developing predictive models to investigate the relationship between design quality and material waste (objective 3).

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3.1 Questionnaire survey

The questionnaire is designed to contain 3 sections. Section 1 is designed to collect general information about the participants (i.e name of organization, education level, occupation, experience). Section 2 addresses the factors that might affect design quality in building projects. Fifteen factors believed to affect design quality are identified from related literature and listed in this section. Section 3 contains the factors that might affect material waste on sites. Fifteen (Lopez and Love, 2012) factors that might affect material waste in building project are identified from related literature and listed in this section. In section2 and section 3, participants are asked to identify the importance of each factor using an ordinal five-point scale as follow: very high, high, moderate, little and very little.

Before sending the questionnaire to the participants, a draft questionnaire is sent to 3 local experts in building projects to check the validity of the questionnaire and to ensure that it will help in achieving the study objectives. Positive response is received from them.

Two populations are targeted in this study: contractors of grade 1 and grade 2 who have experience in residential buildings and valid registration in the Palestinian Contractors Union (PCU), and first-class consultants who are specialized in building projects and have valid membership in the engineering association. The questionnaire is distributed randomly to 50 contractors and 40 consultants. The following ways are used to distribute and collect the questionnaire: direct by hand, by email, and by fax. Forty-five filled by contractors (response rate of 90%) and 35 completed questionnaires received from consultants (response rate of 87%). The participants include: project managers, construction managers, design engineers, office engineers, site engineers and others (Figure 1). Their average experience is greater than 10 years in construction industry.

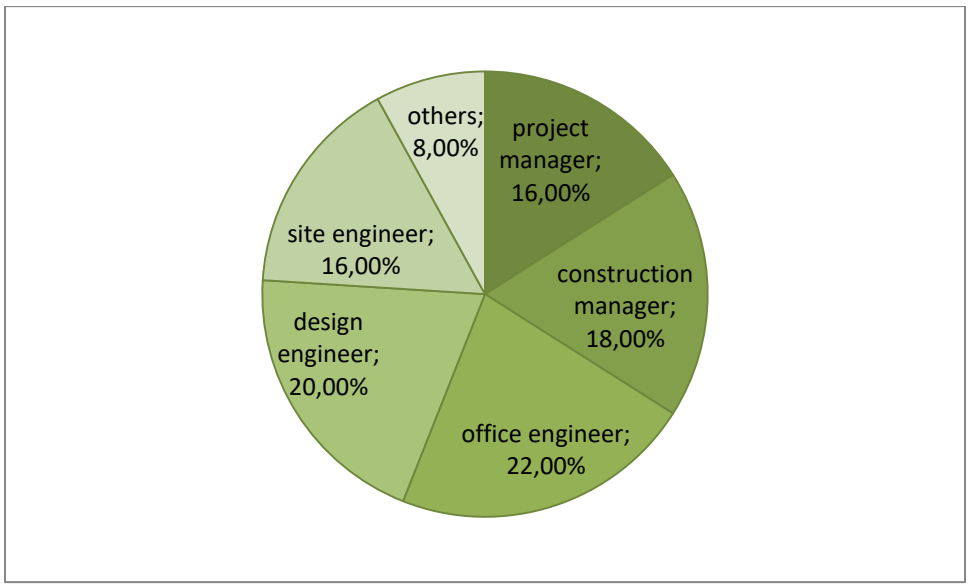

Figure 1. *Respondents positions*

The responses are analyzed statically, and the identified factors are ranked according to their arithmetic mean.

3.2 Regression analysis

One of the study objectives is to establish predictive models that describe the relation between design quality and material waste in building projects. Regression analysis is decided to be used in this study since it is considered as a "powerful tool that helps the researcher to learn more about the relationships between variables and to find the linear combination of independent variables which best correlates with dependent variables" (Mahamid, 2011). Regression equation is expressed as shown in (Equation 1):

$$Y = C + bX \qquad (1)$$

Where;

Y: dependent variable.
C: regression constant.
b: regression estimates.
X: independent variable.

In this study, a regression model is established using design mistakes as independent variable and material waste as dependent variables. The model is developed using data from 33 residential building projects implemented in the West Bank in Palestine (more details are shown in section 4.4).

3.3 Spearman rank correlation

The correlation between the responses of participants (contractors and consultants) is measured using Spearman rank correlation test. The value of Spearman rank correlation (r_s) is calculated using (Equation 2) (Harnett and Murphy, 1975). Values of (r_s) close to (+1) indicate good positive correlations.

$$r_s = 1 - [6 * \sum d^2/(n^3 - n)] \qquad (2)$$

Where; r_s = Spearman rank correlation coefficient (the agreement between contractors and consultants)
d = difference between ranks on one variable and ranks on the other variable
n = number of factors

4. Results and Discussion

4.1 Ranking of design quality factors

(Table 1) shows 15 factors that affect design quality in residential projects. These factors are identified through related literatures and opinions of local experts. Contractors' perception indicates that the top 5 design quality factors include: lack of staff experience, inadequate time given for design, owners award bids for lowest price designer, payments delay for design services and lack of designers' familiarity with techniques and materials available in the market. Consultants indicate that the top five factors are: lack of staff experience, owners award bids for lowest price designer, inadequate time given for design, payments delay for design services and copying and modifying from previous designs. Overall ranking of design quality factors shows that the top five factors are: lack of staff experience, inadequate time given for design, payments delay for design services, owners award bids for lowest price designer and copying and modifying from previous designs.

"Lack of staff experience" is ranked in the 1st position. Lack of experience means less productivity, more mistakes and poor design documents. This case leads to late changes, reworks and conflicts between parties that affects the overall performance. "Inadequate time given for design" is the 2nd ranked factor with overall mean = 4.10. "lack of available time" leads to mistakes and less coordination between designers from different specializations which affect the quality of design. This result is concluded by (Mahamid, 2021). "Payments delay for design services" ranked in position 3 with mean value of = 4.05. This factor is concluded by (Mahamid, 2021) and (Abdelaziz, 2009) as a critical factor affecting design quality. Delay of payments affects ability of design office to pay for their staff which affects the moral of staff and their motivation for work. "Owners award bids for lowest price designer" ranked in position 4. In general, the designer with lowest price is the designer with low qualifications such as lack of experience, lack of staff | parameters play a critical role in the quality of produced design. Thus, the owners are recommended to check the designer qualifications before awarding the design bid. This result is the same as in study of (Abdelaziz, 2009). "Copying and modifying from previous designs" is ranked in the 5th position with mean = 3.83. Lack of time available for design and review pushes designers to copy from previous projects to save time. This might lead to mistakes and bad design quality. This result is in line with (Mahamid, 2021) and (Abdelaziz, 2009).

Table 1. *Ranking of design quality factors*

Factors	***Contractor***		***Consultant***		***Overall***	
	Mean	***Rank***	*Mean*	***Rank***	***Mean***	***Rank***
lack of staff experience	*4.23*	*1*	*4.24*	*1*	*4.23*	*1*
inadequate time given for design	*4.12*	*2*	*4.08*	*3*	*4.10*	***2***
payments delay for design services	*3.98*	*4*	*4.15*	*2*	*4.05*	*3*
owners award bids for lowest price designer	*4.02*	*3*	*4.03*	*4*	*4.02*	*4*
copying and modifying from previous designs	*3.84*	*6*	*3.82*	*5*	*3.83*	*5*
lack of designers familiarity with techniques and materials available in the market	*3.92*	*5*	*3.52*	*8*	*3.75*	*6*
low design fees	*3.7*	*8*	*3.74*	*6*	*3.72*	*7*
late changes by clients	*3.71*	*7*	*3.44*	*9*	*3.59*	*8*
inadequate time for reviewing design documents	*3.29*	*11*	*3.68*	*7*	*3.46*	*9*
lack of coordination and communication between designers from different disciplines	*3.47*	*9*	*3.17*	*11*	*3.34*	*10*
inadequate information from clients	*3.31*	*10*	*3.3*	*10*	*3.31*	*11*
inadequate design reviews with relevant parties	*3.25*	*12*	*2.98*	*13*	*3.13*	*12*
inadequate using of new technology	*3.08*	*14*	*2.95*	*14*	*3.02*	*13*
complicated projects	*3.12*	*13*	*2.83*	*15*	*2.99*	*14*
inadequate number of staff in each specialization (structure, architect, mechanical… etc.)	*2.93*	*15*	*3.02*	*12*	*2.97*	*15*

4.2 Ranking of factors affecting construction material waste

Fifteen factors affecting material waste are identified based on related previous studies and local experts' feedback (Table 2). The participants are asked to rank these factors using 5-points ordinal scale. Results reveal that the top 5 factors (from overall perceptions) are: design mistakes, late design changes, rework, lack of labor experience and purchasing materials not complying with specifications. From consultants' perception, the same top factors are identified but in different order as follow: design mistakes, rework, lack of labor experience, late design changes and purchasing materials not complying with specifications. Contractors indicate that improper storage is a critical factor among the top 5 factors (ranked in position 4).

Design mistakes, late design changes and rework are correlated to each other such that mistakes in design lead to late variations during construction phase which lead to rework. This situation interrupts the smooth performance and causes material waste on site. This result is concluded by (Mahamid, 2020), (Nagapan et al., 2011), (Al-Hajj and Hamani, 2011) and (Agyekum et al., 2013). "Lack of labor experience" mainly leads to misunderstanding of design documents and mistakes in execution which lead to waste production on site. This result agrees with (Ikau et al., 2016) and (Mahamid, 2020). "Materials not complying with specifications" might be rejected by supervisors. So, if the rejection occurs after implementation, rework is the solution. Rework leads to wastage. This result is revealed by (Ikau et al., 2016).

Table 2. *Ranking of material waste factors*

Factors	***Contractor***		***Consultant***		***Overall***	
	Mean	***Rank***	***Mean***	***Rank***	***Mean***	***Rank***
design mistakes	*4.15*	*2*	*4.22*	*1*	*4.18*	*1*
late design changes	*4.29*	*1*	*3.88*	*4*	*4.11*	*2*
Rework	*4.07*	*3*	*4.08*	*2*	*4.07*	*3*
lack of labors experience	*3.81*	*6*	*4.01*	*3*	*3.90*	*4*

purchasing materials not complying with specifications	*3.88*	*5*	*3.75*	*5*	*3.82*	*5*
improper storage	*3.92*	*4*	*3.66*	*6*	*3.81*	*6*
lack of supervisors	*3.54*	*7*	*3.26*	*8*	*3.42*	*7*
lack of coordination and communication between participants	*3.42*	*8*	*3.29*	*7*	*3.36*	*8*
improper handling	*3.21*	*9*	*3.13*	*9*	*3.18*	*9*
poor site control	*2.92*	*11*	*3.02*	*10*	*2.96*	*10*
Weather	*3.05*	*10*	*2.74*	*12*	*2.91*	*11*
material over ordering	*2.77*	*13*	*2.83*	*11*	*2.80*	*12*
improper methods of unloading	*2.89*	*12*	*2.64*	*14*	*2.78*	*13*
lack of tools	*2.66*	*14*	*2.69*	*13*	*2.67*	*14*

4.3 Spearman rank correlation

Using Equation (2), the correlation test indicates a good agreement between participants on the ranking of deign quality factors and material waste factors. The values of Spearman correlation are as follow: deign quality factors (r_s = 0.80) and material waste factors (r_s = 0.82). Results of the test reveal a reliable study.

4.4 Case study

To achieve objective 3, establishing prediction model that shows the impact of design quality on material waste in residential building projects, field data is collected. The data collected form 33 residential building projects implemented in the West Bank – Palestine. It includes information about number of design mistakes and percent of material waste. "Number of design mistakes" is defined as an indicator of design quality and (percent of material waste in concrete works) which is the difference between imported quantity to the site and planned quantity. "Percent of material waste in concrete works" is considered as dependent variable (y), while "number of design mistakes" is considered as independent variable (x). The data collected from related consultancy offices and contracting firms. All data related to 1-5 floor residential buildings implemented during the past 3 years. The area of the buildings is ranging from 200m^2 to 1500m^2. Data are related to skeleton projects. Results show that the average of material waste in concrete works = 23% and the average of design mistakes = 5.

(Table 3) and (Figure 2) indicate a good correlation between material waste in concrete works (dependent variable) and design mistakes (independent variable). With (R^2 = 0.72, $F_{(1, 332)}$ = 84.63, $p < 0.05$), a strong relationship between the dependent and independent variables is established. The predictive model that shows the relation between identified variables is shown in Equation 3: the coefficient of design mistakes shows the value of change in material waste in concrete works due to changes in number of design mistakes that is (5.58). This means that if the number of design mistakes increases or decreases by 1 unit, the percentage of material waste in concrete works will increase or decrease by 5.58 units. The model constant is (-2.73). (Equation 3)

$$y = 5.58x - 2.73 \qquad (3)$$

Where; y = material waste in concrete works (%), x = number of design mistakes.

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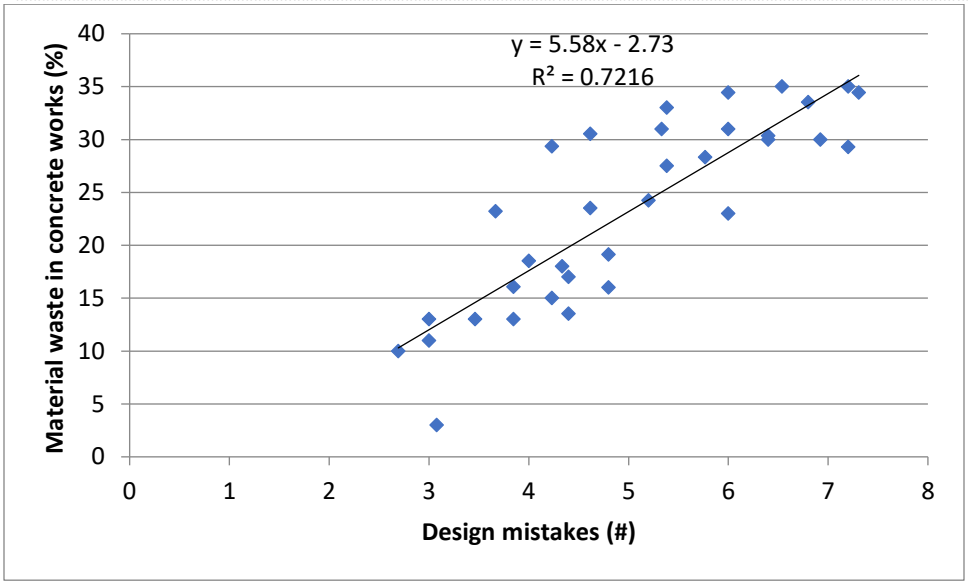

Figure 2. *Design mistakes vs material waste in concrete works in residential projects*

Table 3. *Statistics results for regression model between design mistakes and material waste in concrete works*

Regression Statistics	
Multiple R	*0.81*
R Square	*0.72*
Adjusted R Square	*0.70*
F	*84.63*
Observations	*33*

	Coefficients	*t Stat*	*P-value*
Intercept	*-2.73*	*3.17*	*0.02*
Design mistakes (#)	*5.58*	*5.44*	*0.00*

5. Summary and Conclusion

This study is conducted to develop the relation between design quality and material waste in residential building projects. The study reveals that the top factors of design quality are: lack of staff experience, inadequate time given for design, payments delay for design services, owners award bids for lowest price designer and copying and modifying from previous designs. It also indicates that the significant factors of material waste include: design mistakes, late design changes, rework, lack of labor experience and purchasing materials not complying with specifications. Using Spearman correlation, the study concluded a strong agreement between the participants on the impact of material waste factors and design quality factors.

Based on data collected from 33 building projects, a predictive model is established. The model indicates a good relation between material waste and design quality. It can well predict the change in material waste due to change in design mistakes, such that if the number of design mistakes increases or decreases by 1 unit, the percentage of material waste in concrete works will increase or decrease by 5.58 units.

Based on results of the study, the following recommendations are suggested:

a) *Consultants are recommended to assign experienced and skilled designers; this will increase productivity and reduce mistakes and late changes and then improve design quality and lead to less wastage on site.*
b) *Owners are recommended to pay for design on time. Delay of payments affects ability of design offices to pay for their staff which affects their motivation for work and lead to more mistakes and defects in design which lead to wastage on site.*
c) *Owners are recommended to not award bids for designer with lowest price. They are recommended to check the designer qualifications before awarding the design bid.*
d) *Designers should have enough time for design, review and preparing deign documents. This will minimize mistakes, late changes and rework.*
e) *Contractors are recommended to assign skilled labors to avoid mistakes during construction and then minimizing wastage.*
f) *Contractors are recommended to purchase materials that complying with specifications. This will minimize rework and reduce material waste.*

Data Availability Statement:

All data, models, and code generated or used during the study appear in the submitted article.

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