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# Rework in civil construction projects at design phase: Influencing factors and suggested solutions

Van-Tuan Cao[1], My-Pham Truong[1*], and Ngoc-Loi Dang[2]

[1]*Civil Engineering Faculty, Mien Tay Construction University, Viet Nam*

[2]*Urban Infrastructure Faculty, Mien Tay Construction University, Viet Nam*

**Corresponding author (phamxdmt@mtu.edu.vn)*

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**ABSTRACT**

*Among the various project phases, the design phase often contains errors that result in rework in civil construction projects. This rework can lead to budget overruns, schedule delays, and a decline in construction quality. There is rare knowledge of reworks in civil construction projects, especially in the design phase. This paper presents an overview of the influencing factors and solutions for reworks in civil construction projects at the design phase. To achieve this objective, a survey on the causes of rework was conducted with experts experienced in designing and constructing civil projects in southern Vietnam. Civil engineers and investors involved in the project at the design phases were targets of the survey. Five groups, including designers, design managers, investors, subcontractors, and objective conditions, were selected for designing survey questionnaires. Then, the PCA (principal component analysis) was applied to the collected data to reveal the most influencing factors on rework causes. Based on the results obtained, several suggestions are proposed to minimize rework in civil construction projects. These findings can serve as valuable insights for investors and design consultants, fostering learning and process improvements to reduce rework in future projects.*

## 1. INTRODUCTION

Quality management in a civil construction project is the responsibility of not only the owners, design contractors, and organizations but also every individual involved. In general, achieving high construction quality begins with ensuring a strong and effective design. In the design phase, however, work is often repeated (so-called “rework”) as a result of many causes, as reported in previous studies (Hwang et al., 2009; Love, 2002; Love & Li, 2000). Rework is one of the factors that have negative effects on the cost, schedule, and quality of the project. According to Josephson et al. (2002), design errors originated 50% from the design stage, 40% from the construction stage, and 10% from unforeseen factors. To determine rework causes, Burati et al. (1992) collected data from 9 industrial projects to determine the causes and construction quality causing rework during the design and construction phases. The result suggested that construction costs increased by 12.4% of total project costs, in which the design phase caused an increase of 79% in cost (a part of 12.4% cost) and construction phase lead to growing 17%. Moreover, Love and Smith (2003) conducted a survey study on 161 civil construction projects to find causes and increasing costs of rework. The authors suggested that the main causes due to changes in the design could be listed as: (1) due to requirements of the contractor or the owner; (2) due to user requirements; (3) errors in the contract; (4) ineffective using technologies in designing and constructing projects; and (5) lack of human resources.

Additionally, according to Love et al. (2010), Hussein (2014), Mahamid (2016), Raghuram and Nagavinothini (2016), Love et al. (2021) causes of rework in civil construction projects were lack of experience and knowledge during the design and construction phases. Overall, it is suggested that experience and professional knowledge were one of the main causes.

The main contractors usually have clear criteria and good professional knowledge and experience. For large projects, a main contractor often collaborates with sub-contractors who can have less experience in designing or constructing civil projects. This leads to the supervision from superiors to subordinate ones. A lack of supervision was studied by Alwi et al. (2001), Eze et al. (2018a), Eze et al. (2018b). It is found that the supervision cause rework in the design stage. Moreover, during the design process, the main contractor and sub-contractors usually paid little attention to the project quality due to a given design schedule (Love & Edwards (2004), Aiyetan (2013), Ye et al. (2015). Yap et al. (2016)). The irregular coordination and information exchange among design groups also lead to rework. Pham and Tuan (2021) suggested that most of civil construction projects had to be reworked in the design stages induced from requirements of the contractor, ineffective use of information technology, lack of human resources, lack of experience and knowledge, lack of supervision, little attention the project quality, irregular coordination and information exchange among groups. Using the descriptive method, some variables leading to rework were suggested. However, the variables (questions in the survey) were separately analyzed without considering their effects on the group, leading to difficulties in finding the foremost causes.

Currently, the rework in the design stage of civil construction projects still exists in Vietnam. When the rework is undertaken, it causes negative effects on the quality of projects. Causes leading to rework during the design phase still need to be further analyzed to suggest better views for project construction partners. Therefore, it is urgent to determine the factors affecting rework in the design phase, especially civil construction projects in southern Viet Nam. To achieve the objective, the following approaches were implemented. Firstly, a survey of rework causes was conducted for civil construction projects in some provinces of southern Viet Nam and Ho Chi Minh City. Civil engineers and investors involved in the project's design phases were targets for the study. Influenced factors were separated into five groups, including designers, design managers, investors, subcontractors, and objective conditions. Then, the PCA (principal component analysis) was applied to the collected data to reveal the most influencing factors on rework. Finally, some suggestions for minimizing rework in civil construction projects are proposed.

## 2. MATERIALS AND METHOD

### 2.1. Research flowchart

Figure 1 shows a research flowchart to illustrate involved steps for analyzing rework causes. It has two phases, including data collection (Phase 1) and analyzing data (Phase 2). Each phase has three steps.

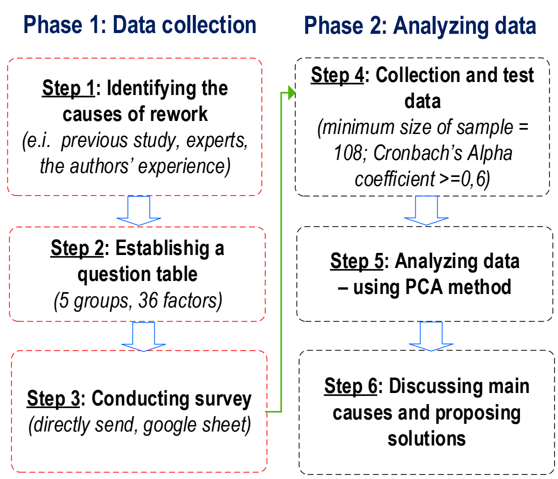



**Figure 1. Research flowchart**

### 2.2. Survey on rework causes in civil construction projects at the design stage

#### *2.2.1. Conducting survey*

Before conducting a survey, it is important to determine the minimum required sample size to ensure statistical reliability in the analysis. Bujang et al. (2012) suggested that the minimum size of samples (i.e., responses) is at least three times of variables (i.e., questions). Based on previous studies (Love and Smith (2003), Love et al. (2010), Aiyetan (2013), Hussein (2014), Eze et al. (2018a), Love et al. (2021), Pham and Tuan (2021)), engineering experts in civil construction projects, and our experiences (more than 10-year experiences in designing and constructing civil projects), a questionnaire table was established to examine rework causes, as shown in Table 1.

The questions were separated into five groups, including Q1: due to manager of design consulting company (8 questions), Q2: due to design staff of design consulting company (12 questions), Q3: due to changes from investigators (9 questions), Q4: due to subcontractors of design consulting company (5 questions), and Q5: due to objective conditions (2 questions). In total, there were 36 questions of rework causes, so the sample size (responses from surveyors) must be larger than 108.

**Table 1. Survey questionnaires for rework causes in civil construction projects**

| No. | Descriptions |
|---|---|
| **Q1** | **Due to manager of design consulting company** |
| Q1.1 | Applying inappropriate design procedures |
| Q1.2 | Less discussion with design staff |
| Q1.3 | Lack of information about design requirements from investor |
| Q1.4 | Unclear work division among design groups |
| Q1.5 | Lack of design staff/team |
| Q1.6 | Many design missions under operations (pressure on time and quality) |
| Q1.7 | Less discussion on project information with other partners |
| Q1.8 | Less effective training strategies for human resources |
| **Q2** | **Due to design staff of design consulting company** |
| Q2.1 | Lack of capacity or experience of design team |
| Q2.2 | Less effectiveness when applying software design |
| Q2.3 | Lack of coordination among design teams |
| Q2.4 | Less discussion in a design group |
| Q2.5 | Not clearly understanding design requirements from team managers |
| Q2.6 | Incomplete mission within a set schedule |
| Q2.7 | Not clear design process or design criteria of design company/team |
| Q2.8 | Not clearly understanding or improperly applying national/international design standards |
| Q2.9 | Multi-design tasks with limited time |
| Q2.10 | Ill-presented technique drawings |
| Q2.11 | Carelessness of checking drawings before sending them to other partners |
| Q2.12 | Lack of understanding types/ specifications of materials/ equipment |
| **Q3** | **Due to investors** |
| Q3.1 | Changes in investment policy (province/ nation /government policy) |
| Q3.2 | Lack of experience in design processes and design national/ international standards |
| Q3.3 | Unreasonable requirement for technical solutions |
| Q3.4 | Requiring an unfeasible design schedule |
| Q3.5 | Insufficient project information to other partners at the beginning project |
| Q3.6 | Changes in design requirements during design stage |
| Q3.7 | Requiring more details, equipment, machine |
| Q3.8 | Not clear design requirements/ideas at the beginning project |
| Q3.9 | Giving inappropriate decisions for technical issues |
| **Q4** | **Due to subcontractors of design consulting company** |
| Q4.1 | Lack of coordination between contractors and subcontractors |
| Q4.2 | Changes in design plans of subcontractors |
| Q4.3 | Fewer discussions between sub-main contractors |
| Q4.4 | Poor professionalism of subcontractors |
| Q4.5 | Multi-projects at the same time with limited design time |
| **Q5** | **Due to objective conditions** |
| Q5.1 | Complex geology at construction-site |
| Q5.2 | Lack of reliability (not enough information at the design phase) of geological survey results |

This study utilized a 5-level scale (proposed by Rennis Likert) to analyze the effects of causes. For each question, a surveyor gave a point that could be 1, 2, 3, 4, to 5. Moreover, the points of all selected surveyors for a question were used to evaluate the effects of influence factors. The influence factors were classified as 1 – less effect, 2 – slight effect, 3 – average effect, 4 – high effect, and 5 – significant effect.

Research questionnaires were sent directly or via email to surveyors to get responses. Moreover, the surveyors were asked to send the questionnaire to their colleagues or acquaintances who have been working in the field of design or investors in civil construction projects. For the feasibility of PCA-based rework causes, the survey was conducted at companies in Ho Chi Minh City and others in the Mekong Delta region (e.g., Can Tho City, Long An, Ca Mau, Vinh Long, An Giang, Dong Thap provinces).

Besides, we also collected information of surveyors, including the number of years working on civil construction projects and their role (investor or designer). It is known that the working experience is a vital parameter because their understanding and experience could provide appropriate views and assessments of the influence factors (by giving from 1 to 5 points for each surveyed question) which lead to rework at the design phase.

*2.2.2. Properties of surveyed data*

There were 149 responses received from surveyors. To select an appropriate response, it should satisfy: (1) having full information (giving points for all questions), (2) inconsistently checked questions (without randomization) and (3) playing the role of investigator or designer. After preliminarily checking, 31 responses were removed from the analyzed data because of data bias. Thus, 118 questionnaires had valued information for performing the PCA technique. It is noted that the number of responses (i.e., 118) is greater than 108 - the minimum number of responses to guarantee statistical reliability of the analysis. Among 118 responses, surveyors have been working as designers as 60% (71 responses) and the remaining 40% have been working as investors (47 responses).

Figure 2 presents the years of experience of surveyors involved in construction projects, based on 118 responses. Surveyors with 6-10 years of experience in civil construction projects represented the highest percentage (34%), while those with more than ten years of experience had the lowest percentage (13%). Overall, the surveyors' experience levels were relatively evenly distributed across four categories. This distribution suggests that their insights into the causes of rework during the design phase of projects are likely to be well-informed.

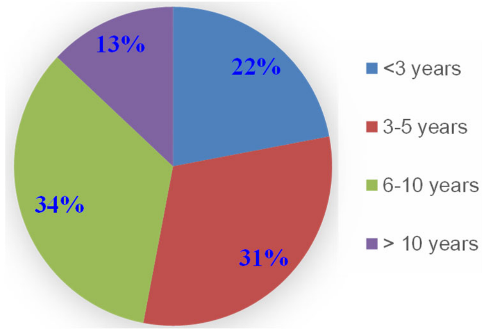



**Figure 2. Years of surveyors' working experience participating in civil construction projects**

Cronbach's Alpha analysis was performed for 36 surveyed questions to test the level of reliability and correlation between observed variables (so-called 36 selected questions). The analyzed result revealed that Cronbach's Alpha coefficient was 0.892, more significant than the standard coefficient (i.e., 0.6). It proved that the measurement scale used in the questionnaire was appropriately designed.

*2.2.3. PCA method-based identification of rework causes at design stage*

Principal Component Analysis (namely PCA) was proposed (Jolliffe, 2002) to lower dimensionality or bring out strong patterns in a complex examined dataset. In the PCA method, the original observed data is transformed into a new dataset (so-called principal components) of uncorrelated ones. For a set of principal components (PCs), only the first few PCs can present the most information on the original data. The PCA method has been extensively used to solve engineering problems such as data compression (Park et al., 2007; Yang et al., 2015). Moreover, the PCA method has been used to find the components that affect the measured data most under environmental changes (Huynh et al., 2018).

In this study, the PCA method was applied to suggest the main causes of rework in civil construction projects. To build a PCA model for analyzing the effects of influence factors, it needs to make a matrix $[DI]_{mxn}$ of each group question (e.g., Group Q1 from Q1.1 to Q1.8 with eight variables, see Table 1), in which *m* is a number of surveyors' responses and *n* is surveyed questions. The covariance matrix of [DI] is computed as follows:

$$[C]_{n\times n} = \frac{1}{m-1}[DI]^T[DI] \quad (1)$$

The square matrix $[C]_{n\times n}$ of variance represents the linear relationship within [DI] between all possible surveyed questions in a separate group. The subspaces in PCA are decomposed by the eigenvalue and eigenvector of covariance matrix $[C]_{n\times n}$ as follows:

$$[C]_{n\times n} = [A][\lambda][A]^T \quad (2)$$

Where [A] is a matrix in which columns are eigenvectors, [λ] a diagonal matrix containing eigenvalues on the main diagonal. The eigenvectors with the highest values contain the most important pattern in the measured data. The columns of [A] are sorted by descending order according to eigenvalues. It meant that principal components (PCs) of the measured data are put in order of significance.

When selecting a reduced number $r < n$ of the PCs, a reduced transformation matrix $[A_R]_{n-r}$ can be considered as the PC model of [DI]. Geometrically, the [DI] can be transformed into a new matrix [P] representing the projection of [DI] over the direction of the PCs, as follows:

$$[P] = [DI][A_R] \quad (3)$$

It is noted that when using full PCs of matrix [A] in Eq. (3), the original data can be inverted ($[DI] = [P][A]^T$). In case of using $[A_R]$, and given P, the original data [DI] is impossibly fully recovered, but it could be partially recovered by projecting back onto n-dimensional spaces as follows:

$$[DI_{Rev}] = [P][A_R]^T = [DI][A_R][A_R]^T \quad (4)$$

It is known that only the first few PCs have most variability in examined data, the remaining PCs should be removed when constructing the PCA model to find factors having the most effects on rework in civil construction projects. To obtain the objective, at first, mean and standard deviation of 118 selected samples was calculated to show average measured points of each variable (i.e., question). Then PCA method was applied to suggest the influences of PCs in the examined data. After removing PCs having fewer contributions to a group, the component matrix (see Eq. (4)) was calculated. Elements of the component matrix were sorted to show the summarizing and discovering pattern of inter-correlations among rework causes in the civil construction projects at the design stage.

## 3. RESULTS AND DISCUSSION

The rework could come from any causes (i.e., questions) in five examined groups. To better suggest a solution for main causes, each group should be separately analyzed. Before applying the PCA method, the Spearman correlation coefficient of the dataset should be checked to ensure it is larger than 0.5.

### 3.1. Rework due to manager of design consulting company (Group Q1)

Figure 3 shows average points calculated from 118 samples for rework causes induced by the design managers of consultant companies. The Spearman correlation coefficient (Hair et al., 2009) was 0.525, which was relatively consistent in evaluation and ranking for statistical sample (0.5), thus enabling applying the PCA method for the examined sample (Group Q1).

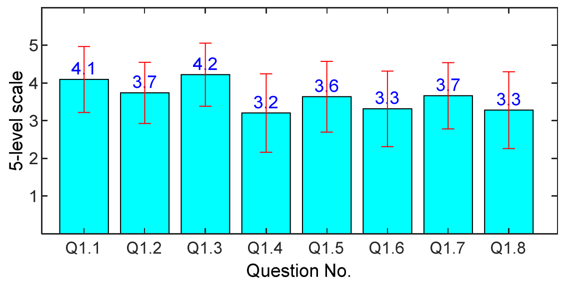



**Figure 3. Average points of rework causes induced by design managers of consultant companies (Group Q1)**

As previously defined, the highest point reveals that the cause had more substantial effects on reworks of the project according to surveyor's viewpoints. As shown in Figure 3, all causes (i.e., Q1.1-Q1.8) were scored higher than 3 points (5-scale level). Two causes had high effects, including Q1.1 and Q1.3. Specifically, the cause "Lack of information about design requirements from investors" (i.e., Q1.3) had the highest score (4.2 points). The main second cause was "Applying inappropriate design procedures" (i.e., Q1.1, 4.1 points). Meanwhile, the lowest score was 3.2 points (Q1.4, Not set clear work division among design groups).

The matrix $[DI]_{118x8}$ that comprises the 118 recorded scores from 118 selected surveyors giving for 8 causes (from Q1.1 to Q1.8) was constructed. The PCs (i.e., 8 principal components) of the matrix were calculated, and the original data was converted into the new coordinate system to display a better view of the data's variation. In the PCA transformation, the PCs were sorted from the highest (PC1) to lowest (PC8) variance, as shown in Figure 4. As seen in the figure, the variance of PC1 was 28.1%, the ones of PC2 and PC3 were 17.1% and 15.9%, respectively. These PCs contributed the largest to the DI matrix. The other PCs was changed from 10% to 4% (PC4 – PC8). As observed, the slight changes in variances of PCs indicated that the observed result was well matched to the Spearman coefficient (0.525).

For this group, the PCA model was established using PC1-PC3 (by removing PC4 to PC8) to summarize and discover the pattern of intercorrelations among rework causes induced by design managers.

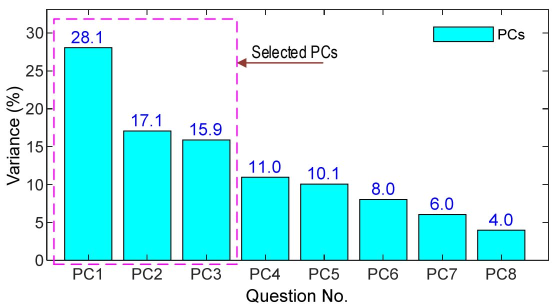



**Figure 4. Variances of principal components of Q1 component matrix**

Table 2 shows the values of influence factors of the rotated component matrix calculated from PC1-PC3 of Q1 component matrix. It is noted that a maximum value of factors would not exceed 1.0 (due to standardization of the coefficients). For the PC1, there were two significant factors (i.e., Q1.8 and Q1.1), and the other factors, which were lower average (0.5) to negative values, were moderately correlated with something else. For the PC2, there are three important factors (i.e., Q1.6, Q1.5, and Q1.4), and other factors were also moderate to negative values (but not significant). For the PC3, the two only variables (so-called influence factors) loaded well on the PC3 (i.e., Q1.3 and Q1.2), and a variable loaded moderately loaded. Meanwhile, other variables were insignificantly loaded.

**Table 2. Rotated component matrix calculated from PC1-PC3 of Q1 component matrix**

| Influence factors | Component (PCs) 1 | 2 | 3 |
|---|---|---|---|
| Q1.8 | ***0.84*** | 0.22 | 0.00 |
| Q1.1 | ***0.79*** | -0.10 | 0.09 |
| Q1.6 | -0.21 | ***0.82*** | 0.04 |
| Q1.5 | 0.12 | ***0.69*** | -0.03 |
| Q1.4 | 0.29 | ***0.57*** | 0.15 |
| Q1.3 | -0.03 | -0.02 | ***0.82*** |
| Q1.2 | 0.09 | 0.05 | ***0.80*** |
| Q1.7 | 0.41 | 0.33 | 0.48 |

From the analysis, the following observations can be made: First, Component 1 appears to reflect rework causes stemming from inappropriate design procedures, likely due to human resource issues. Second, Component 2 seems to highlight problems related to the division of work within the design team. Lastly, Component 3 reveals difficulties in communication among the design staff.

### 3.2. Rework due to design staff of design consulting company (Group Q2)

Figure 5 shows average points calculated from 118 samples for rework causes induced by design staff of design consulting companies. The Spearman correlation coefficient was 0.747, thus indicating that the PCA method could be applied to the sample.

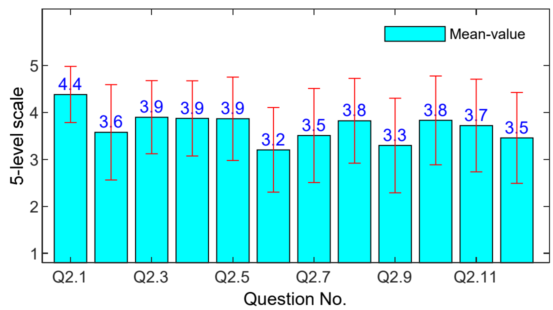



**Figure 5. Average point of rework causes induced by design staff of design consulting company (Group Q2)**

As shown in Figure 5, all causes (i.e., Q2.1-Q2.12) were scored higher than the average point (3 points). The cause, Q2.1, (i.e., Lack of capacity or experience of design team), had high points (i.e., 4.4 points) with less standard deviation (0.60). Meanwhile, the relatively lower scores were 3.2 points for Q2.6 (Incomplete mission within set schedule) and 3.3 points for Q2.9 (Multi-design tasks with limited time).

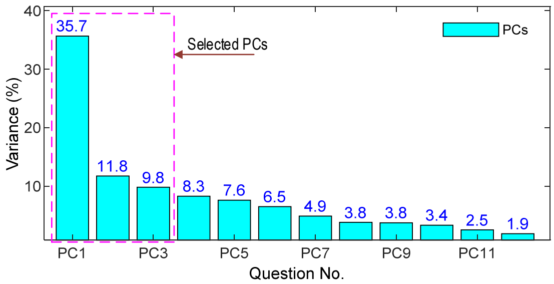



**Figure 6. Variances of principal components of Q2 component matrix**

Then, the matrix $[DI]_{118x12}$ comprising the 118 recorded scores with 12 causes (from Q2.1 to Q2.12) was established. The 12 PCs of the covariance matrix were calculated, and the original data was converted into the new coordinate system. The PCs were sorted from the highest (PC1) to lowest (PC12) variance, as shown in Figure 6. As seen in the figure, the variance of PC1 has the largest variance (i.e., 35.7%), and the ones of PC2 and PC3 were 11.8% and 9.8%, respectively. Meanwhile, the other PCs were changed from 8.3% to 1.9% (PC4 – PC12). The result was also well matched to the Spearman coefficient (0.747). The PCA model was established using PC1-PC3 to summarize and discover the pattern of inter-correlations among causes of rework in group Q2.

**Table 3. Rotated component matrix calculated from PC1-PC3 of Q2 component matrix**

| Influence factors | Component 1 | 2 | 3 |
|---|---|---|---|
| Q2.5 | ***0.78*** | 0.24 | 0.00 |
| Q2.3 | ***0.77*** | 0.23 | 0.05 |
| Q2.7 | ***0.74*** | 0.00 | 0.36 |
| Q2.4 | ***0.58*** | 0.23 | 0.36 |
| Q2.8 | ***0.52*** | 0.11 | 0.39 |
| Q2.10 | 0.01 | ***0.81*** | 0.24 |
| Q2.11 | 0.17 | ***0.78*** | 0.16 |
| Q2.12 | 0.31 | ***0.74*** | -0.15 |
| Q2.2 | 0.25 | ***0.61*** | 0.38 |
| Q2.1 | -0.01 | 0.07 | ***0.81*** |
| Q2.6 | 0.21 | 0.16 | ***0.57*** |
| Q2.9 | 0.20 | 0.10 | 0.47 |

Table 3 shows the values of influence factors of the rotated component matrix calculated from PC1-PC3 of Q3 component matrix. For the PC1, there were five significant factors (i.e., Q2.5, Q2.3, Q2.7, Q2.4, and Q2.8), while other factors were relatively insignificant. For the PC2, there were four meaning factors (i.e., Q2.10, Q2.11, Q2.11, and Q2.2), while the remaining factors were not significant. For the PC3, the two variables loaded well (i.e., Q2.1 and Q2.6).

From the analysis, the following causes could lead to rework in projects induced by design staff. For component 1, the design team leader does not manage and distribute work appropriately induced by professional and skill. The component 2, it seems to reflect problems in the process how to present design products for clients. Last, for the component 3, it looks that the issue comes from experience and professionalism of the design staff.

### 3.3. Rework due to investors (Group Q3)

Figure 7 shows average points also calculated from 118 samples for cause of rework induced by investors (Group 3). The Spearman correlation coefficient was 0.717, thereby demonstrating that the PCA method can be applied for the examined sample. As observed in the figure, all variables (i.e., Q3.1-Q3.9) were scored higher than 3.4 points. Specifically, the first largest point was Q3.1 (4.6 points with low deviation compared to other variables), which was “Changes in investment policy”. The second large variable was Q3.6 with the score of 4.5 points. Meanwhile, variables also got relatively high point from 3.4 (Q3.4, Requiring unfeasible design schedule) point to 3.9 points for (Q3.8, No clear design requirements).

The matrix $[DI]_{118x9}$ was constructed to determine variances of the 9 PCs, as shown in Figure 8. It is obvious that the PC1 had the highest variance (i.e., 37.5%) about 2.5 times larger than that of PC2 (i.e., 14.5%). The third largest component was PC3, with variance of 12.1%. Meanwhile, the other variances of PCs were slightly decrease from 9.1% (PC4) to 3.0% (PC9).

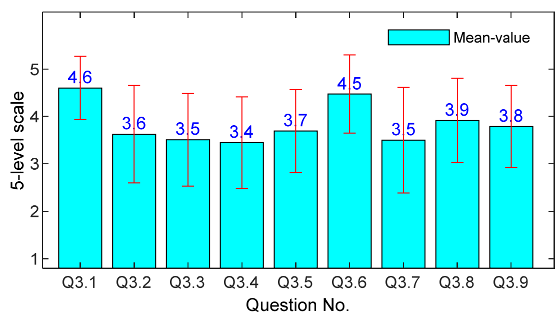



**Figure 7. Average point of rework causes induced by changes due to investigators (Group Q3)**

For this group, the PCA model was established using PC1-PC3 to find the rework causes induced by investors.

Table 4 shows the values of influence factors of the rotated component matrix calculated from PC1-PC3 of the Q3 component matrix. As observed, for the PC1, five over nine factors had significant values (except Q3.1, Q3.2, Q3.3 and Q3.6). For the PC2, there are two important factors (i.e., Q3.2 and Q3.3), while other factors were also moderate from 0.29 to negative value values (but not significant). For the PC3, the two variables loaded well on the PC3 (i.e., Q3.6 and Q3.1), and a variable loaded moderately loaded (i.e., Q3.7). Meanwhile, other variables were insignificantly loaded.

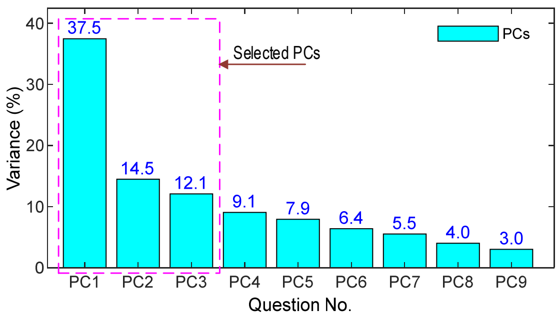



**Figure 8. Variances of principal components of Q3 component matrix**

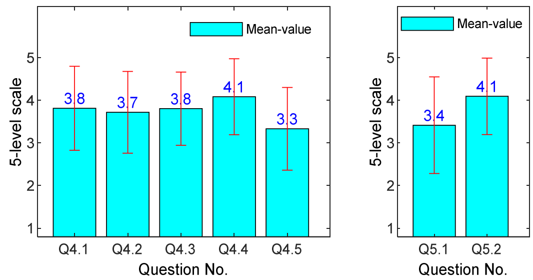
**Table 4. Rotated component matrix calculated from PC1-PC3 of Q3 component matrix**

| Influence factors | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Q3.5 | ***0.81*** | -0.07 | 0.18 |
| Q3.9 | ***0.69*** | 0.29 | 0.01 |
| Q3.8 | ***0.66*** | 0.18 | 0.06 |
| Q3.4 | ***0.64*** | 0.17 | 0.07 |
| Q3.7 | ***0.52*** | 0.18 | 0.44 |
| Q3.2 | 0.11 | ***0.91*** | 0.13 |
| Q3.3 | 0.48 | ***0.72*** | 0.04 |
| Q3.6 | 0.20 | -0.13 | ***0.84*** |
| Q3.1 | -0.02 | 0.28 | ***0.80*** |

From the analysis, it can be observed as following. First, the component 1 appears to reflect the rework causes from the inappropriate requirement from investors (e.g., unfeasible schedule, more requirement, giving inappropriate decisions). Second, the component 2 seems to reflect problems in professional and experience of investor. Last, the component 3 strongly reveals reworks coming from changes in national policy.

### 3.4. Rework due to subcontractors of design consulting company (Group Q4)

Figure 9a shows average points calculated from 118 samples for rework causes with the correlation coefficient of 0.792. The Q4.4 (poor professional of subcontractors) shows the highest point (4.1 points), indicating the high effects on the rework. Meanwhile, the other variables varied from 3.3 points (above average effect) to 3.8 points, Q4.3 (lower high effect).




(a) (b)

**Figure 9. Average point of rework causes induced Group Q4 (a) and Group Q5 (b)**

The matrix $[DI]_{118x5}$ was also constructed to calculate variances of each variable in the dataset. Then it was transformed to the new coordinate system to establish rotated component matrix. As seen in Figure 10, the variance of PC1 was 58.5%, the one of PC2 and PC3 were 16.2% and 10.6%, respectively. Meanwhile, the other PCs were changed from 10.6% to 7.2% (PC3—PC5).

For this group, the PCA model was established using PC1 only to discover the pattern of inter-correlations among rework causes induced by subcontractors.

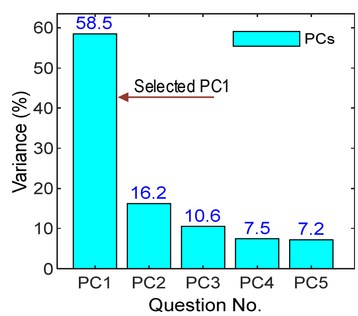



**Figure 10. Variances of principal components of Q4 component matrix**

Table 5 shows the values of influence factors of Q4 component matrix extracted from PC1. For the selected principal component, all of five variables were loaded in the PC1, and their values were significant from 0.831 (Q4.3, Less discussion between sub-main contractors) to 0.698 (Q4.5, Taking multi-projects). The analyzed result revealed that the rework could be from the sub-contractors having less project information combined with taking multi-projects.

**Table 5. Component matrix calculated from PC1 of Q4 component matrix**

| Influence factors | Component 1 |
|---|---|
| Q4.3 | 0.831 |
| Q4.2 | 0.774 |
| Q4.1 | 0.758 |
| Q4.4 | 0.757 |
| Q4.5 | 0.698 |

### 3.5. Rework due to objective conditions (Group Q5)

Figure 9b presents the average scores calculated from 118 samples for two rework causes attributed to objective conditions, with a Spearman correlation coefficient of 0.50. It also indicates that Group 5 did not have a sufficient number of measured samples, suggesting that the PCA method is not appropriate in this case. Instead, a descriptive method based on score values was applied to this sample.

For two causes of the rework, Q5.2 (Lack reliability of geological survey results) shows higher point (i.e., 4.1 points), which was high effect on rework at design stage, than that of Q5.1 (Complex geology at the construction-site).

### 3.6. Discussions and suggested solutions for rework causes

As seen in Figure 11, the average points calculated for all questions in each group were the insignificant different values, that is, Q3, Q4, and Q5 groups had 3.8 point, the Q2 group had 3.7 points, and the Q1 group was 3.6 point. It is known that each group has primary roles in the civil construction project. Thus, it leads to difficulty in deciding what the main rework cause is when the descriptive method was used. This statement is verified through our research results, as shown in Figure 11.

Based on PCA method-based rework causes analyses for Group Q1-Q5, it can be withdrawn. First, due to changes in investors (Q3), the main causes were the inappropriate requirement (e.g., unfeasible schedule or giving inappropriate decisions); lack of professional and experience. Second, due to the design team (Q2), the main causes were ill-professional/experience of team leader, ill-presenting design products for clients, and less experience or professional of the design staff. Third, due to chief or manager of design company (Q1), the main causes were inappropriate design procedures, work division for design team, and difficult communication in design staff. Four, due to sub-contractors (Q4), the main cause was sub-contractors having less project information combined with taking multi-projects. Due to objective conditions (Q5), the lack reliability of geological survey results was the issue.

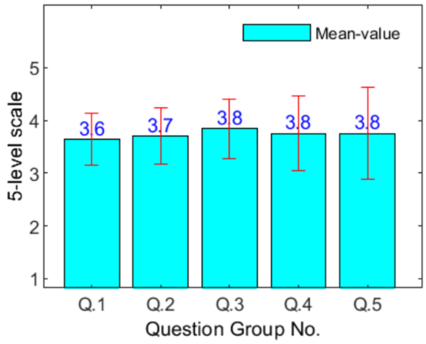



**Figure 11. Average point of rework causes induced questions in each group**

Some suggested solutions to minimize rework in the design phase as follows. For group Q3, the investor should minimize changes of requirements during the design stage. It means that the investor needs to carefully prepare the project information at the beginning from ideas to investing document, thus requiring experienced investors. For less experienced investor, it is necessary to have a project management unit to help the preparation of project information, schedule, or engineering design technique. For group Q2, the design teams need to comply with the regulations and processes of the design company or the team leader by applying the correct standards, smoothly coordinating with other partners, and frequently making activities of reports, examinations, and managements of products. Moreover, the design teams need to improve personal skills by participating in professional training, self-improvement of professional skills, updating the latest design software.

For group Q1, design managers of consulting design companies need to have the complete process of designing, checking and evaluating project to set clear work division about design team. Moreover, the soft communication between managers and staffs also needs to be improved by weekly meeting on work or team activities besides working time. For group Q4, subcontractors need to be competent according to main contractors' regulations by well-preparing human recourses, and professional skills to adapt better work under multiple jobs. For group 5, multiple experimental methods should be combined to test the reliability of the examined geology results.

## 4. CONCLUSION

This paper presented the influencing factors and solutions for reworks in civil construction projects during the design phase. At first, the survey on the causes of rework was conducted focusing on civil engineers and investors involved in the projects at the design phase. Then, the PCA method was applied to the collected data to reveal the most influencing factors on rework causes for each group, including designers, design managers, investors, subcontractors, and objective conditions.

From the analysis, the following remarks can be drawn: 1) the PCA method was a useful tool on analyzing rework causes, 2) the professionalism and skill of investors, project managers, team leaders have to be good to minimize the rework at the design phase among the other parameters, 3) Soft communication among investor, design team leader and staff is also noted to help to reduce rework.

Rework can result in budget overruns, schedule delays, or compromised construction quality. Future studies should focus on the impact of rework on budget using statistical models in comparison with PCA estimation. Additionally, expanding the research to other project types (e.g., infrastructure projects) is recommended for further investigation.

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