



## REQUIREMENTS DEFINITION AND MANAGEMENT PRACTICE TO IMPROVE PROJECT OUTCOMES

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**Abstract.** Poor project requirements definition and management (RDM) is one of the major causes of project failure. However, many organizations do not adequately manage a project's requirements leading to a poor design basis. Thus, quality of requirements is critical to the success of any construction project. The primary purpose of this research was to investigate the mediating effect of requirements quality on the relationship between RDM practice and project performance. The second objective was to determine whether the impact of RDM practice on project performance was moderated by project characteristics. A three-phase approach was employed to investigate construction projects in the Taiwanese building industry. The testing supports a role for requirements quality as a partial mediator in the relationship between RDM practice and project performance. The findings also indicate that project characteristics have a moderating effect on the relationship between requirements quality and overall project performance.

**Keywords:** project requirements, requirements definition and management, project performance, project characteristics.

### 1. Introduction

Many studies have shown that preproject planning effort may contribute to project performance in terms of cost, schedule, and operational characteristics (Griffith *et al.* 1999; Sobotka, Czarnigowska 2005; Ling *et al.* 2009; Hanna, Skiffington 2010). The development of project requirements definition is one of the major subprocesses. It is the process by which projects are defined and prepared for execution (Cho, Gibson 2001). Additionally, it is the stage where project risk assessments are undertaken and the specific project execution methods are analyzed. Success during the detailed design, construction, and start-up phases of a project is highly dependent on the level of effort expended during this stage (Cho, Gibson 2001; Yang, Wei 2010; Chang *et al.* 2010).

Requirements definition and management (RDM) is the term used to describe the process of eliciting, documenting, analyzing, prioritizing, and agreeing on requirements, and then controlling, managing, and overseeing changes and risk (Oberge *et al.* 2000; Zowghi 2002). Requirements quality affects work performed in subsequent phases of a project. Thus, the compliance with requirements is crucial to the success of a project. However, the literature in construction has largely ignored the impact of requirements definition and management on project success. In recent years, there has been a

growing trend towards increased requirements definition and management effort on construction projects. Some construction organizations adopt the best industry practices for project planning in the attempt to reduce the cost and schedule of a project. These companies also examine their operations for ways to improve stakeholder satisfaction. However, since the benefits of practices can be rather intangible, this has slowed the adoption of RDM practice. Accordingly, the importance of requirements definition and management has been one of the major issues for both industry and academic fields. Many studies indicated that one of the major challenges in project/construction management is the definition and management of project requirements. In order to understand the issue, there is a need for quantification of the associations among RDM effort, quality of project requirements, and project outcomes. Research on the relationships should offer guides to project planning process.

Early planning in many cases is not performed well in the construction industry (Cho, Gibson 2001). Furthermore, the building sector suffers from poor or incomplete requirements definition (Gibson *et al.* 1997). While many studies have promoted project planning as a means to enhance project performance, very few published studies in construction have explored the benefits of requirements definition and management effort from the perspectives of major stakeholders. Additionally,

there is little evidence to support the relationships between RDM practice and project performance. In order to explore the benefits of RDM effort, a three-phase approach was used to investigate projects in the Taiwanese building industry. Phase 1 included determining the applicability of the proposed project requirements. Phase 2 of the research entailed exploring the importance of project requirements. Phase 3 consisted of examining the relationships among RDM practice, quality of requirements, and project success.

## 2. Literature review and research hypotheses

Requirements definition and management is an important component of effective project planning. The literature stated that the problems related with requirements management are one of the main reasons for project failures. Research suggested that most of the project requirements were difficult to identify and some were not clear and well organized (Oberg *et al.* 2000; Jepsen, Eskerod 2009; Anastasopoulos *et al.* 2010). Prior research also indicated that 40% of the requirements generate rework during the project life cycle (Zowghi 2002). It is evident that if a problem is detected during the preproject planning phase, many other problems are minimized in the following phases. Thus, RDM is often cited as one of the most important, but difficult, phases of a project (Brooks 1987; Le *et al.* 2009). The results of previous studies indicated a correlation between RDM effort and project performance. Additionally, a review of the literature suggests that RDM effort may improve requirements quality in terms of correctness, consistency, and completeness, which subsequently affecting the performance of a project (Damian, Chisan 2006; Procaccino *et al.* 2002; Brooks 1987; Kauppinen *et al.* 2004; Herbsleb, Goldenson 1996; Radujković *et al.* 2010; Huang, Hsueh 2010; Toor, Ogunlana 2010). This study extends previous studies by addressing the impact of RDM effort on quality of requirements and construction project performance in the building industry. Based on the relevant literature, the following hypotheses were postulated and tested:

- H1: RDM practice (requirements documentation, verification, and validation) positively influences construction project performance.
- H2: Requirements quality positively influences construction project performance.
- H3: Requirements quality may act as a mediator between RDM practice (requirements documentation, verification, and validation) and construction project performance.

Above previous studies indicated that RDM may play an important role in the performance of a project. In other words, projects can be made more successful by improving requirements definition and management. Additionally, prior research has stated that project characteristics may play a moderating role in the relationship between practice use and project performance (Müller, Turner 2007; Yang *et al.* 2006; Jiang *et al.* 1996). Based on the previous research, the following research hypothesis was developed:

- H4: Project characteristics may act as a moderator between RDM practice (requirements documentation, verification, and validation) and construction project performance.

This research adds to the literature in two valuable ways. First, it develops quantitative measures of associations among RDM practice, requirements quality, and construction project outcomes. Second, it offers important results on the identification of the roles of project characteristics in relationship between requirements quality and construction project performance.

## 3. Phase 1 research

This research was divided into three phases. Phase 1 included determining the applicability of the proposed project requirements. A survey was developed to investigate the degree, if any, to which the proposed requirements apply to building projects. The survey was designed to include requirements that were thought to have substantial impact on building projects. The listing of project requirements, which resulted from both brainstorming and a literature search (Dumont *et al.* 1997; Cho, Gibson 2001), contained over 100 items. Therefore, a systematic method for eliminating some of the less important requirements was developed. Each requirement was then tested to ensure it applies to building projects. As such, the requirements were based on previous studies and interviews with construction practitioners. The industry interviews encompassed 11 executives from the Owner, Architect/Engineering (A/E), and General Contractor (GC) groups. For each proposed project requirements, the survey asked the participants to assess the extent to which individual requirements apply to projects in the building sector. This survey offered respondents three optional responses: applicable, not applicable, or need to be revised. The survey also allowed the participants to offer additional comments on a potential revision. The refined assessment items were included in the Phase 2 survey questionnaire. Finally, the Phase 2 survey makes use of 81 project requirements in assessing their relative importance.

## 4. Phase 2 research

### 4.1. Procedure

Phase 2 of the research entailed exploring the importance of building project requirements. In other words, the purpose of Phase 2 was to determine key requirement items and factors. A questionnaire was developed based on the results of the work done in Phase 1. As such, the content validity of the questionnaire used in Phase 2 was tested through a literature review and interviews with the construction executives conducted in Phase 1. From a thorough literature review and discussions with the 11 practitioners, the 81 project requirements were included in the questionnaire. Additionally, copies of a draft survey were sent to several industry professions to pre-test for the clarity of questions. Their insights were also incorporated into the final version of the survey questionnaire. The

questionnaire was used to assess how important each of the requirements is in planning building projects. Responses are given on 7-point scale, from 1 (not at all important) to 7 (very important).

This research employed survey methodology for Phase 2 data collection. The survey instrument was used to measure the relative importance of building project requirements from the viewpoints of major stakeholders involved in projects. Thus, the sample for this study focused on the Owner, Architect/Engineering, and General Contractor groups in the Taiwanese building industry. Individuals interested in participating in this phase were identified by a search from a number of industry associations. The Owners' sample was selected from various public and private owners. In addition, the A/E's sample was selected from the *National Association of Architect, Taiwan* and *Chinese Association of Engineering Consultants*. On the other hand, the sample of GC was drawn from members of *General Contractors Association, Taiwan*. The survey questionnaire was sent to more than 800 senior practitioners on June 30, 2008. Some of the organizations were then contacted via phone or email to identify the manager or the person involving in building projects by name and title. Reminders were sent by e-mail or phone after survey mailing. The initial mailing elicited 89 usable responses. Finally, four weeks after the initial mailing a second mailing of the survey was made to non-respondents. A reminder letter, too, followed the second mailing. An additional 46 usable responses were returned. In summary, of the 811 questionnaires sent, 137 were returned. The overall response rate was 17.12%. Among the returned surveys, 2 were discarded since they contained too many missing values. Ultimately, 135 survey responses were used in the analysis.

#### 4.2. Participants

The sample was composed of 39 practitioners from the Owner group. With respect to years of experience, 17.95% of the respondents are more than 20, 12.82% are between 16 and 20, 25.64% are between 11 and 15, 23.08% are between 6 and 10, and the remaining 20.51 are less than 6. Furthermore, 35.90% of the respondents indicated that they held a master's degree, while another 28.21% held a bachelor's degree. The remaining 35.90% held an associate's degree. The sample consisted of 62 practitioners from the Architect/Engineering group. With respect to years of experience, 23.73% of the respondents are more than 20, 13.56% are between 16 and 20, 32.20% are between 11 and 15, 20.34% are between 6 and 10, and the remaining 10.17 are less than 6. Furthermore, 57.63% of the respondents indicated that they held a master's degree, while 42.37% held a bachelor's degree. Additionally, the sample also included 34 professionals from the General Contractor group. Regarding years of experience, 6.06% of the respondents are more than 20, 18.18% are between 16 and 20, 24.24% are between 11 and 15, 33.3% are between 6 and 10, and the remaining 18.18 are less than 6. Additionally, 30.30% of the respondents indicated that they held a master's degree, while another

45.45% held a bachelor's degree. The remaining 24.24% held an associate's degree.

#### 4.3. Non-response bias and preliminary analysis

Non-response bias was examined using the procedures recommended by Armstrong and Overton (1977). It was assessed by comparing early (those responding to the first mailing) and late (those responding to the second mailing) respondents. Using a t-test, each variable was tested to determine if there is a significant difference in means between early and late respondents at the 5% significance level. The results from the t-tests suggest that the early respondents do not significantly differ from the late responses. Accordingly, non-response bias was not considered a problem. After data are collected, a preliminary data analysis was conducted. Factor analysis was employed to reduce the building project requirements into several factors. The items associated with these key factors were selected to assess requirements quality in Phase 3.

### 5. Phase 3 research

#### 5.1. Survey process and structure

Phase 3 consisted of examining the relationships among RDM practice, requirements quality, and project performance. A third data collection tool was used to assess the relationships between RDM practice and requirements quality and their impacts on project performance. As such, the primary purpose of Phase 3 was to investigate the mediating effect of requirements quality on the relationship between RDM practice and project performance. The second objective was to investigate whether the impact of requirements quality on project performance was moderated by project characteristics. Hypotheses were developed and tested to determine the statistical significance of the hypothetical relationships.

A survey instrument was used to measure RDM practice, quality of requirements, and the performance of projects in the Taiwanese building industry. The data collection tool was developed based on variables used in previous studies. The survey was composed of four sections: 1) requirements definition and management effort; 2) quality of requirements; 3) project performance; 4) project and personal information. The first section assessed aspects of RDM practice employed on the subject project. RDM practice was considered along the two dimensions: requirements documentation and requirements verification and validation. The second section of the survey measured requirements quality in terms of correctness, consistency, and completeness. As previously discussed, the items identified in Phase 2 were used to evaluate quality of requirements at this stage. Requirements quality was measured by project design parameter, project plan, site information, project control, project strategy, and building programming. The third section evaluated project performance. Project performance was assessed by cost and schedule success and quality performance. The fourth section obtained information concerning the project and the respondent. These subject projects were categorized according to seven data class

variables: initial site, project size, project duration, team size, project typicality, owner regulation, and complexity. These variables are defined as follows (Müller, Turner 2007; Turner 2004): 1) Initial site – Participants were provided with three optional responses: greenfield (or new), renovation, or expansion; 2) Project size (total installed cost) – three cost categories are presented: small size (i.e., <\$5 Million), medium size (i.e., \$5–20 Million), and large size (i.e., >\$20 Million); 3) Project duration – respondents were asked to provide project duration. The projects are classified into three categories: short (i.e., <12 months), medium (i.e., 12–24 months), long (i.e., >24 months); 4) Team size (number of core team member) – three categories are presented: small team (i.e., <10 members), medium team (i.e., 10–20 members), and large team (i.e., >20 members); 5) Project typicality – respondents were asked to compare the subject project to other company projects relative to methods and approaches used. Two optional responses were provided: traditional or innovative; 6) Owner regulation – this variable allowed researchers to distinguish private projects from public projects; 7) Complexity – respondents were asked to compare the subject project to other company projects relative to complexity. Three optional responses were provided: low, medium, and high. In summary, the importance of project requirements was explored in Phase 2. Phase 3 further examined the associations among RDM practice, quality of requirements, and project performance. The mediating role of requirements quality and moderating role of project characteristics were also identified at this stage.

## 5.2. Sample selection and data collection

An industry-wide survey of RDM practice, requirements quality, and performance on construction projects was conducted in Taiwan between March 2009 and February 2010. The data collection tool was developed to collect project-based data. Project responses were collected through personal interviews. A structured interview was conducted for each subjective project. This approach allows the interviewers to explain the questions and requirement items. Thus, misunderstandings can be eliminated. Individuals interested in participating in this phase were identified by a search from various industry associations. In order to obtain a truly representative sample, not only was the geographic mix of projects intentionally diverse, but a diverse mix of participation was sought with respect to project size. Additionally, a specified mix of team size was targeted in order to obtain a representative sample of the industry. More than 150 projects were investigated and some were not included in the analysis because they contained insufficient information. In addition, the projects were examined to ensure that no duplicate project information was collected. Ultimately, 148 survey responses were used in the analysis.

The sample's respondents consisted of project managers, project directors, project planners, and project superintendents. With respect to years of experience, 8.11% are more than 20, 20.27% are between 16 and 20, 18.92% are between 11 and 15, 32.43% are between 5

and 10, and the remaining 20.27% are less than 5. Finally, 6.08% of the respondents indicated that they held a master's degree, while another 46.62% held a bachelor's degree. Additionally, 41.22% of the respondents indicated that they held associate's degree. The remaining 6.08% held a high school diploma.

## 5.3. Variable measurement

The scales used to measure RDM effort were based on the items developed by Sommerville and Ransom (2005), Damian and Chisan (2006), and Parviainen and Tihinen (2007). RDM effort was evaluated based on the two dimensions: requirements documentation and requirements verification & validation. Each dimension is composed of several survey items that measure its various aspects. Each item was rated on a 6-point scale, where 1 represented never used and 6 represented used throughout the project in a standardized way.

As previously discussed, the items identified in Phase 2 were employed to evaluate quality of project requirements in terms of correctness, consistency, and completeness. In other words, quality of project requirements was evaluated based on the items selected from Phase 2. For each requirement item, the respondents were asked to indicate how successful their projects have been in achieving specific goals: correctness, consistency and completeness (i.e., requirements quality). A six-point scale was utilized with 1 = not at all successful and 6 = extremely successful.

These project requirements selected for use in the survey include:

- 1) Project design parameter:
  - electrical and mechanical design;
  - civil design;
  - architectural design;
  - piping system requirements;
  - site survey;
  - civil information;
  - utility sources with supply conditions;
  - construction process;
  - structural design;
  - evaluation of existing facilities;
  - geotechnical information;
  - structural requirements;
  - site layout;
  - plot plan;
- 2) Project plan:
  - owner approval requirements;
  - building use planning;
  - design plan and approval;
  - space evaluation;
  - purpose of building use;
  - project objective statement;
  - construction plan and approval;
  - facility requirements;
  - project design criteria;
  - evaluation of adjacent building;

- site location;
  - future expansion considerations;
- 3) Site information:
- safety management;
  - waste treatment requirements;
  - site life safety considerations;
  - fire protection;
  - safety procedures;
  - water treatment requirements;
  - soil tests;
  - maintenance philosophy;
  - operating philosophy;
  - transportation requirements;
  - training requirements;
  - reliability philosophy;
- 4) Project control:
- project schedule control;
  - project cost control;
  - project schedule estimate;
  - project cost estimate;
  - overview of work scope;
  - project control requirements;
  - project management strategy;
- 5) Project strategy:
- value-analysis process;
  - project strategy;
  - marketing strategy;
  - human resource management;
  - economic analysis;
  - alternatives considerations;
- 6) Building programming:
- indoor rooms;
  - open space requirements;
  - compartment requirements;
  - painting requirements;
  - windows and doors;
  - storage space;
  - identifying materials.

Questions from Müller and Turner (2007), Keller (1994), Freeman and Beale (1992), Shenhar *et al.* (1997), and Westerveld (2003) were adopted to measure project performance. Project performance was assessed by cost and schedule success and quality performance. Each dimension is composed of several survey items that measure its various aspects. Each item was rated on a 6-point scale, where 1 represented strongly disagree and 6 represented strongly agree.

A composite score is calculated by averaging the values from each of sub-dimensions that make up the composite measure. Each sub-dimension is composed of several survey items that measure its various aspects. Composite score of RDM practice is computed by averaging the values from each of two sub-dimensions. This pattern held true for requirements quality and project performance as well.

#### 5.4. Dealing with validity and reliability

The content validity of the survey used in Phase 3 was tested through a literature review and interviews with practitioners. In other words, the survey items were based on previous studies and discussions with these industry executives. The industry interviews encompassed nine construction industry executives. A specified group involvement was also targeted in order to acquire a comprehensive knowledge from different perspectives. The industry interviews encompassed nine executives from the Owner, A/E, and GC groups (three practitioners from each group). Each of the professionals has over 20 years of senior management experience in the industry. The refined assessment items were included in the final survey. Finally, copies of a draft survey were sent to several industry professions to pre-test for the clarity of questions. Their insights were also incorporated into the final version of the survey. The construct validity was tested by factor analysis. Factors were extracted using Varimax rotation. As suggested by Hair *et al.* (1995), an item is considered to load on a given factor if the factor loading from the rotated factor pattern is 0.50 or more for that factor. Cronbach's coefficient ( $\alpha$ ) was also computed to test the reliability and internal consistency of the responses. The values of Cronbach's  $\alpha$  above 0.7 are considered acceptable and those above 0.8 are considered meritorious (Nunnally 1978).

### 6. Results and analysis

#### 6.1. Factor structure of scales

In Phase 2 of this study, factor analysis with Varimax rotation was used to identify key requirement factors. Eigenvalues greater than one were used to determine the number of factors in each data set (Churchill 1991). Only variables with a factor loading greater than 0.5 were extracted (Hair *et al.* 1995). The 81 items of project requirements are classified into six factors. In other words, results indicated that six factors were found to underlie the various sets of project requirements in the building sector. Twenty-four items were dropped due to low factor loading. The factor loadings for the other items range from 0.505 to 0.804. The six constructs categorized are project design parameter, project plan, site information, project control, project strategy, and building programming. As previously discussed, Phase 3 then evaluated quality of the 57 key requirements associated with the six factors.

Factor analysis was also used to decide the grouping of RDM practice and project performance in Phase 3. The 15 items of RDM practice are classified into two factors. One item was dropped due to low factor loading. The factor loadings for the other items range from 0.535 to 0.818. The subscales are requirements documentation and requirements verification and validation. Additionally, two factors were found to underlie project performance. In other words, the 20 items of project performance construct are classified into two factors. All of the factor loadings range from 0.627 to 0.870, indicating a high level of internal consistency among the project performance items. The subscales are cost and schedule success and quality performance. Factor loadings for the survey items are presented in Table 1.

**Table 1.** Factor loadings and Cronbach's alpha values for the survey items

Construct	Subscale	Mean	Standard deviation	Cronbach's alpha	Range of factor loadings
RDM practice	Requirements documentation	4.38	0.82	0.876	0.631 to 0.788
RDM practice	Requirements verification and validation	4.44	0.75	0.905	0.535 to 0.818
Requirements quality	Project design parameter	4.32	0.62	0.907	0.511 to 0.778
Requirements quality	Project plan	4.53	0.69	0.926	0.534 to 0.723
Requirements quality	Site information	4.47	0.69	0.931	0.505 to 0.697
Requirements quality	Project control	4.41	0.77	0.915	0.538 to 0.804
Requirements quality	Project strategy	3.91	0.90	0.914	0.510 to 0.710
Requirements quality	Building programming	4.46	0.87	0.941	0.529 to 0.726
Project performance	Cost and schedule success	4.27	0.89	0.958	0.627 to 0.870
Project performance	Quality performance	4.24	0.93	0.946	0.710 to 0.834

**Table 2.** Regression analysis results

Independent variable	Cost and schedule success	Quality performance	Cost and schedule success	Quality performance
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
Documentation	0.123 <sup>a</sup>	0.143 <sup>a</sup>	–	–
Verification and validation	0.484 <sup>a,***</sup>	0.595 <sup>a,***</sup>	–	–
Project design parameter	–	–	0.053 <sup>a</sup>	0.114 <sup>a</sup>
Project plan	–	–	0.034 <sup>a</sup>	0.012 <sup>a</sup>
Site information	–	–	0.113 <sup>a</sup>	0.145 <sup>a</sup>
Project control	–	–	0.504 <sup>a,***</sup>	0.274 <sup>a,*</sup>
Project strategy	–	–	0.039 <sup>a</sup>	0.194 <sup>a</sup>
Building programming	–	–	0.193 <sup>a</sup>	0.077 <sup>a</sup>
F-statistics	24.010 <sup>***</sup>	46.897 <sup>***</sup>	13.934 <sup>***</sup>	13.506 <sup>***</sup>
R squared	0.333	0.494	0.476	0.468
Durbin-Watson statistic	1.820	1.982	1.843	2.117
Variance-inflation factors	<2	<2	<4	<4

<sup>a</sup>The number denotes the beta coefficient for the particular variable.

\* significant at the 0.05 level; \*\*\* significant at the 0.001 level

Cronbach's coefficient ( $\alpha$ ) was computed to test the reliability and internal consistency of the responses. Reliability was assessed for RDM practice at 0.927, quality of requirements at 0.978, and project performance at 0.971. The values of Cronbach's  $\alpha$  of 0.6 to 0.8 are considered acceptable and those above 0.8 are considered meritorious (Nunnally 1978). Cronbach's alpha values for the subscales are also presented in Table 1. All of the  $\alpha$  values for the sub-dimensions are above 0.8, indicating a high degree of internal consistency in the responses.

## 6.2. Regression analysis results

Two regression models were developed using the two RDM practice dimensions as independent variables and each of the two project performance measures as a dependent variable in each model. The regression results of these models are presented in Table 2. As shown in Table 2, when cost and schedule success was used as the dependent variable (Model 1), one independent variable was identified to be significant: "requirements verification and validation". The findings indicate that require-

ments verification and validation is significantly related to project cost and schedule success. The results (Model 2) also suggest that requirements verification and validation may contribute to project quality performance. The multiple coefficient of determination (R squared) was 0.494. In other words, the independent variable, requirements verification and validation, explained 49.4% of the variation in the dependent variable, project quality performance. Additionally, Kennedy (1998) noted that a variance-inflation factors (VIF) greater than 10 may be cause for concern. However, no evidence of strong multicollinearity was found in the two estimated models (i.e., the variance-inflation factors for the two models <2). Thus, H1 is supported.

Two regression models were developed using the six requirements quality dimensions as independent variables and each of the two project performance measures as a dependent variable in each model. The regression results of these models are also presented in Table 2. To examine the relationship between requirements quality and project performance, a regression analysis for cost and schedule success (Model 3) was conducted. Project

control emerged as a key independent variable in regression when the dependent variable used was cost and schedule success. Additionally, the results of Model 4 also suggest that project control has a positive relationship with project performance, as measured by quality performance. In addition, no evidence of strong multicollinearity was found in any of the estimated models (i.e., the variance-inflation factors for the two models < 4). Thus, H2 is partly supported. The equations for Models 1 to 4 are expressed as follows:

$$\text{Model 1: CSS} = 0.123D + 0.484V, \quad (1)$$

$$\text{Model 2: QP} = 0.143D + 0.595V, \quad (2)$$

$$\text{Model 3: CSS} = 0.053PDP + 0.034PP + 0.113SI + 0.504PC + 0.039PS + 0.193BP, \quad (3)$$

$$\text{Model 4: QP} = 0.114PDP + 0.012PP + 0.145SI + 0.274PC + 0.194PS + 0.077BP, \quad (4)$$

where: CSS is cost and schedule success; QP is quality performance; D is documentation; V is verification and validation; PDP is project design parameter; PP is project plan; SI is site information; PC is project control; PS is project strategy; and BP is building programming.

**6.3. Mediator between RDM and project performance**

Based on the data collected in Phase 3, formal mediation testing was subsequently conducted to determine whether requirements quality mediates the relationships between RDM practice and project performance. The mediating role of requirements quality was examined by investigating changes in beta coefficients and R-squared when entering requirements quality variable in a series of regression models. In the relationship between RDM practice and project performance, the first three conditions for mediation specified by Baron and Kenny (1986) were met by requirements quality dimension. Thus, requirements quality variable was subsequently tested to determine if it fulfilled the fourth condition for mediation.

The analysis assessed the effect of including requirements quality in hierarchical linear regressions where individual subscales of RDM practice (i.e., requirements documentation and requirements verification & validation) were the independent variables and

cost and schedule success was the dependent variable. Multiple regression models were developed with subscales of RDM practice, quality of requirements, and cost and schedule success in order to measure the mediating role of requirements quality. While cost and schedule success is the dependent variable, subscales of RDM practice were entered on the first step (Model 1) and quality of requirements was entered on the second step (Model 2).

Table 3 presents summary of Hierarchical Regression Analysis for requirements documentation. The first model (i.e. requirements documentation) explained 21.6% of the variance in cost and schedule success (p<0.001). Model 2 (i.e. requirements documentation and requirements quality) explained 46.5% of the variance in cost and schedule success (p<0.001). No evidence of strong multicollinearity was found in Model 2 (i.e., the variance-inflation factors for the model < 2). The analysis results from Model 2 indicate that project performance can be achieved with better requirements documentation as well as higher levels of requirements quality. Both of requirements documentation and requirements quality are significant variables. In other words, an index of requirements quality was added in the second model and this explained an additional 24.9% of the variance. However, with the addition of requirements quality, standardized regression coefficients (β) for requirements documentation decreased by 52.04% (from 0.465 to 0.223). The testing shows that the inclusion of requirements quality yields significant reductions in the beta-coefficients for requirements documentation. Although the requirements documentation index continued to be a significant explanatory variable, its contribution was reduced. The testing supports a role for requirements quality as a partial mediator in the relationship between indices of requirements documentation and cost and schedule success. On the other hand, multiple regression models were developed with subscales of RDM practice, quality of requirements, and quality performance in order to measure the mediating role of requirements quality. As shown in Table 3, requirements quality partially mediates the effect of requirements documentation and project quality performance.

**Table 3.** Mediator between requirements documentation and project performance

Independent variable	Cost and schedule success		Quality performance	
	Model 1	Model 2	Model 1	Model 2
Documentation	0.465 <sup>a,***</sup>	0.223 <sup>***</sup>	0.563 <sup>***</sup>	0.332 <sup>***</sup>
Requirements quality		0.555 <sup>***</sup>		0.529 <sup>***</sup>
R-Squared	0.216	0.465	0.317	0.544
F-Statistic	26.737 <sup>***</sup>	41.778 <sup>***</sup>	45.022 <sup>***</sup>	57.162 <sup>***</sup>
Durbin-Watson statistic	–	1.853	–	2.159
Variance-inflation factors	–	<2	–	<2

<sup>a</sup>The number denotes the beta coefficient for the particular variable.

<sup>\*\*\*</sup> significant at the 0.001 level

Additionally, the equations for models of cost and schedule success are expressed as follows:

$$\text{Model 1: CSS} = 0.465D, \tag{5}$$

$$\text{Model 2: CSS} = 0.223D + 0.555RQ, \tag{6}$$

where: CSS is cost and schedule success; D is documentation, and RQ is requirements quality.

The equations for models of quality performance are expressed as follows:

$$\text{Model 1: QP} = 0.563D, \tag{7}$$

$$\text{Model 2: QP} = 0.332D + 0.529RQ, \tag{8}$$

where: QP is quality performance; D is documentation, and RQ is requirements quality.

Similarly, Table 4 presents summary of Hierarchical Regression Analysis for requirements verification and validation. The findings indicate that construction project performance can be achieved with better requirements verification & validation as well as higher levels of requirements quality. Additionally, the testing supports a role for requirements quality as a partial mediator in the relationship between requirements verification and validation and cost and schedule success. The results also suggest that requirements quality may partially mediate the effects of requirements verification and validation on project quality performance. Thus, H3 is supported.

Furthermore, the equations for models of cost and schedule success are expressed as follows:

$$\text{Model 1: CSS} = 0.571V, \tag{9}$$

$$\text{Model 2: CSS} = 0.334V + 0.491RQ, \tag{10}$$

where: CSS is cost and schedule success; V is verification and validation; RQ is requirements quality.

The equations for models of quality performance are expressed as follows:

$$\text{Model 1: QP} = 0.696V, \tag{11}$$

$$\text{Model 2: QP} = 0.483V + 0.441RQ, \tag{12}$$

where: QP is quality performance; V is verification and validation; RQ is requirements quality.

#### 6.4. Identification of project clusters with the same levels of RDM practice

In order to identify homogeneous projects clusters with the same levels of RDM practice, a K-means cluster analysis was performed on the basis of the two dimensions of RDM practice. To validate the results of the cluster analysis, a discriminant analysis was also conducted. The cluster analysis has identified two clusters for RDM practice, with the cluster mean values of discriminating variables given in Table 5. The discriminant analysis classified 99.0% of the projects as the cluster analysis did, indicating extremely good differentiation and a correct classification. These results further suggest that the two clusters are distinctive. In addition, independent-samples *t* tests were undertaken to assess the internal validity of the cluster results. The independent-samples *t* tests shown in Table 5 confirm that the two variables do significantly differentiate across the two clusters. The first cluster was labelled projects with high degree of RDM practice. The second cluster consists of projects with low degree of RDM practice.

**Table 4.** Mediator between requirements verification and validation and project performance

Independent variable	Cost and schedule success		Quality performance	
	Model 1	Model 2	Model 1	Model 2
Verification and validation	0.571 <sup>a,***</sup>	0.334 <sup>***</sup>	0.696 <sup>a,***</sup>	0.483 <sup>***</sup>
Requirements quality		0.491 <sup>***</sup>		0.441 <sup>***</sup>
R-Squared	0.326	0.511	0.484	0.633
F-Statistic	46.892 <sup>***</sup>	50.064 <sup>***</sup>	90.935 <sup>***</sup>	82.730 <sup>***</sup>
Durbin-Watson statistic	–	1.828	–	2.148
Variance-inflation factors	–	<2	–	<2

<sup>a</sup> The number denotes the beta coefficient for the particular variable.

<sup>\*\*\*</sup> significant at the 0.001 level

**Table 5.** Cluster means of discriminating variables

Variable	Projects with high levels of RDM practice		Projects with low levels of RDM practice		t-statistic	p-value
	Number	Mean	Number	Mean		
Documentation	118	4.70	30	3.38	9.809	0.000
Verification & validation	118	4.69	30	3.13	11.952	0.000

**Table 6.** Results of two-way ANOVAs

Variable	Moderator						
	Initial site (IS)	Project size (PS)	Project duration (PD)	Team size (TS)	Project typicality (PT)	Owner regulation (OR)	Complexity (C)
RDM practice (RDMP)	0.066	0.088	2.252	1.579	4.266*	4.271*	0.266

\*significant at the 0.05 level

**6.5. Moderating roles of project characteristics**

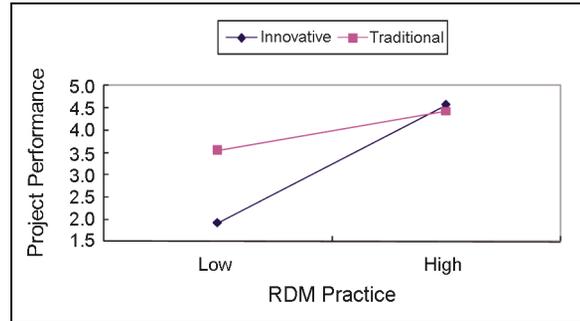
These subject projects were categorized according to seven data class variables: initial site, project size, project duration, team size, project typicality, owner regulation, and complexity. In other words, project characteristics were assessed by using these attributes. As previously discussed, the projects were also examined by clustering them on the basis of differences in the RDM practice dimensions. The study revealed two segments for the RDM practice dimensions. Thus, to test for the moderating influence of project typicality on the relationship between RDM practice and overall project performance, 2 (RDM practice) x 2 (project typicality) analysis of variance (ANOVA) were performed. The two-way ANOVA was utilized to determine the joint effects of RDM practice and project typicality on overall project performance in terms of cost and schedule success and quality performance.

Table 6 summarizes the results of the ANOVAs. The results indicate a significant interaction of RDM practice (RDMP) and project typicality (PT) for overall project performance,  $F = 4.266, p < 0.05$ . These findings indicate that project typicality has a moderating effect on the relationship between RDM practice and overall project performance. Since the interaction term was significant, the form of interaction was graphically represented to evaluate the direction of the differences within each of the conditions.

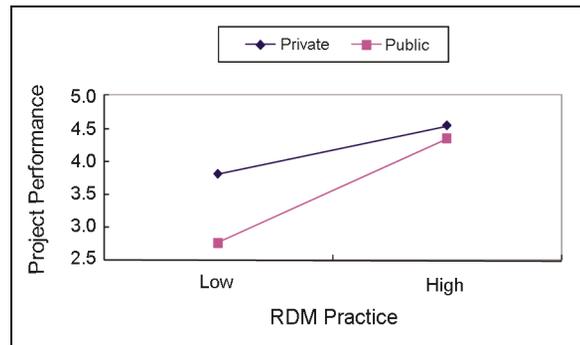
Fig. 1 shows the relationship between RDM practice and overall project performance at different levels of project typicality. It is clear that innovative projects were more likely to be successful when they experienced a high level of RDM practice than traditional projects. Additionally, the results show a significant interaction of RDM practice (RDMP) and owner regulation (OR) for project performance,  $F = 4.271, p < 0.05$ . The analyses suggest that public projects were more likely to be successful when they experienced a high level of RDM practice than private projects (see Fig. 2). However, there was no significant interaction for the other project characteristics (initial site, project size, project duration, team size, and complexity). Thus, the results partially support H4.

**7. Conclusions**

While the diverse benefits of preproject planning have received substantial attention, the number of studies dealing with the importance of requirements definition and management in construction is rather scarce. Additionally, empirical evidence that supports the benefits of RDM practice in the building sector is lacking. Thus, developing



**Fig. 1.** Moderating role of project typicality



**Fig. 2.** Moderating role of owner regulation

such support will illustrate the relationships among RDM effort, quality of requirements, and project outcomes. This study attempts to fill the gap in the literature by identifying the roles of requirements quality and project characteristics in the relationship between RDM effort and project performance.

The primary purpose of this study was to examine the mediating effect of requirements quality on the relationship between RDM practice and project performance. The second objective was to determine whether the impact of RDM practice on project performance was moderated by project characteristics. In order to exploring the benefits of RDM effort, a three-phase approach was employed to investigate projects in the Taiwanese building industry. Phase 1 of the research included determining the applicability of the proposed project requirements in the building sector. Phase 2 entailed exploring the importance of building project requirements. In other words, the purpose of Phase 2 was to determine key requirement items and factors. A questionnaire was developed based on the results of the work done in Phase 1. Phase 3 consisted of examining the associations among RDM practice, quality of requirements, project characteristics, and project performance. A third data collection tool was used

to assess the relationships between RDM practice and requirements quality and their impacts on project performance. The items identified in Phase 2 were selected to assess quality of requirements at this stage.

In this study, formal mediation testing was subsequently conducted to determine whether requirements quality mediates the relationships between RDM practice and project performance. The findings indicate that construction project performance can be achieved with better requirements documentation, verification, and validation as well as higher levels of requirements quality. The testing supports a role for requirements quality as a partial mediator in the relationship between indices of requirements documentation and project performance in terms of cost and schedule success and quality performance. The results also suggest that requirements quality may partially mediate the effects of requirements verification and validation on project cost and schedule success and quality performance.

The findings suggest that project typicality and owner regulation have a moderating effect on the relationship between RDM practice and overall project performance. It is clear that innovative projects were more likely to be successful when they experienced a high level of RDM practice than traditional projects. The results also suggest that public projects were more likely to be successful when they experienced a high level of requirements quality than private projects.

The research results offer guides to project planning process. Findings from this study are helpful to project planners in deciding whether to adopt RDM practice in the building sector. Project planners can use the research results to modify their current project planning. However, one limitation of this study is its cross-sectional design. An objective for future study is to determine how RDM practice is changing over time. Survey with a longitudinal design may be needed to gain deeper insights into the benefits of RDM effort. Furthermore, the sample for this study focused on projects in the building industry. Consideration should be given to investigate the project requirements for other sectors (industrial and infrastructure projects). This could also lead to greater insights into the importance of project requirements in the building industry. Finally, requirements prioritization for construction projects also need to be considered in further research.

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## REIKALAVIMŲ APIBRĖŽIMAS IR VADYBA GERINANT PROJEKTO REZULTATUS

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Santrauka

Prastai apibrėžti ir valdomi projekto reikalavimai – viena iš pagrindinių projekto nesėkmės priežasčių. Tačiau daug organizacijų neskiria pakankamai dėmesio projekto reikalavimų valdymui, todėl sukuriamas prastas projektavimo pagrindas. Taigi kokybės reikalavimai yra esminis sėkmės garantas bet kuriame statybų projekte. Pagrindinis šio tyrimo tikslas – išnagrinėti, kaip reikalavimų kokybė veikia jų apibrėžimo ir valdymo ryšį su projekto efektyvumu. Antrasis tikslas – nustatyti, ar projekto savybės mažina reikalavimų apibrėžimo ir valdymo poveikį projekto efektyvumui. Pritaikius trijų etapų metodą, išnagrinėti statybų projektai Taivano statybų sektoriuje. Bandymai patvirtino, kad reikalavimų kokybė iš dalies keičia jų apibrėžimo ir valdymo ryšį su projekto efektyvumu. Išvados taip pat rodo, kad projekto savybės riboja reikalavimų kokybės bendram projekto efektyvumui poveikį.

**Reikšminiai žodžiai:** projekto reikalavimai, reikalavimų apibrėžimas ir valdymas, projekto efektyvumas, projekto savybės.

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