Investigating the Relationship between Project Complexity and Success in Complex Construction Projects

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Abstract: Although widely recognized both in literature and among practitioners, project complexity may cause poor project success, with little empirical evidence supporting this contention. Therefore, this study analyzed, for the first time, the relationship between project complexity and success in complex construction projects and investigated how project complexity affects project success. First, project complexity is hypothesized to be negatively related to project success. Second, on the basis of literature review and expert interviews, a total of 245 questionnaire surveys on project complexity and project outcomes were collected in China. Project complexity was measured as information, task, technological, organizational, environmental, and goal complexities by correlation and factor analyses. Finally, the structural-equation modeling technique was used to test the hypothesis and explore the effect of different complexities on project success. The findings of this study support the hypothesized negative relationship between the complexity and success of complex construction projects. Furthermore, information complexity and goal complexity have significant negative effects on project success. The research would have significant theoretical and practical significance for improving the theory of complex project management and achieving project success in complex construction projects for project managers. **DOI: 10.1061/(ASCE)ME.1943-5479.0000471.**

Author keywords: Complex construction projects; Project complexity; Project success; Relationships; China.

Introduction

The rapid rate of urbanization in recent years has resulted in an increase in the number of complex construction projects in China, with large amounts of dollars invested in infrastructure construction (He et al. 2015; Hu et al. 2012). The lack of relevant knowledge on the part of project managers often results in these projects being beset with issues such as low performance, cost overruns, and schedule delays (Kennedy et al. 2011; Thomas and Mengel 2008). Success is the ultimate goal of project management (Chan et al. 2004) and its factors play an important role in the planning, design, and construction of successful building projects (Parfitt and Sanvido 1993). Not all complexity factors have a significant effect on project success. Thus, project managers should understand how various project complexity components affect project performance. This approach can help project managers focus on the complexity components that may have the greatest potential effect on project success.

Studies have shown that project complexity affects project performance. However, in-depth analyses are lacking on specific relations and effects, thus resulting in poor application in practice. First, existing papers on the relationship between project success and complexity mostly focus on the general project complexity from an enterprise perspective and do not consider the characteristics of complex construction projects. There is a particular lack of empirical study in China (He et al. 2015). Second, the indicators of project complexity and success are macroscopic and abstract; thus, applying the research results in practice is difficult. For example, in addition to the traditional golden triangle (quality, time, and cost), project success indicators should also consider other successful statistics to provide references for project managers in handling projects (Macheridis and Nilsson 2004).

Accordingly, a total of 245 questionnaires about complex construction projects were collected in China to empirically investigate the relationship between project complexity and success. The data were used to address the following questions:

- What are the key components of project complexity for complex construction projects?
- How does project complexity affect project success?
- Do the various components of project complexity affect project success equally? If not, how do they differ?

The structural-equation model (SEM) is the main tool used for path analysis and is unrestricted by regression analysis assumptions. SEM can not only handle multiple dependent variables at the same time but can also estimate factor structure and factor relations (*AMOS version 3.6*). Project complexity and success are composed of multiple dimensions and present a certain structure and gradation between each dimension. Therefore, SEM is appropriate to use in this study to investigate the effect of project complexity on project success in complex construction projects.

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Literature Review and Hypotheses

Project Complexity

Complexity is a vague term and it is hard to precisely quantify (Corning 1998). Complexity is defined as having a large number of interacting parts, whereas complexity science is the study of these interactions. Accordingly, project complexity is considered one of the most fundamental properties of the project and results from the interaction of different parts with structural, dynamic, and uncertain properties (Mihm et al. 2003; Xia and Chan 2012).

Given that project complexity is difficult to quantify precisely, many scholars have conducted a number of studies to identify its measurement factors and categorization (Bosch-Rekveldt et al. 2011; Gransberg et al. 2013; He et al. 2015). Baccarini (1996) classified project complexity into organization complexity and technology complexity. Tatikonda and Rosenthal (2000) believed that project complexity is closely related to the interactions among organizational elements and subtasks. Maylor et al. (2008) identified the elements of project complexity as mission, organization, delivery, stakeholders, and team. Brockmann and Girmscheid (2008) divided complexity into five categories: task, society, culture, operation, and cognition complexity.

As shown in the literature review of project complexity, each scholar has a different classification and perspective on project complexity (He et al. 2012; Hu et al. 2012; Maylor et al. 2008; Remington and Pollack 2007; Tatikonda and Rosenthal 2000; Vidal and Marle 2008; Vidal et al. 2011). In the authors' prior study as He et al. (2015), a six-category framework of project complexity consisting of technological, organizational, goal, environmental, cultural, and information complexities was proposed with a comprehensive literature review to measure the complexity of mega construction projects in China (He et al. 2015). However, the effect of the aforementioned complexity factors on project complexity is not fully understood and is still under investigation. Therefore, the first objective of this study was to develop a measure for project complexity by examining the relationship between complexity factors and project complexity.

Project Success

The concept of project success has remained ambiguously defined in the construction industry (Chan et al. 2004; Joslin and Müller 2015). Stakeholders cannot achieve a consensus on project success when it comes to project practices (Joslin and Müller 2015; Lim and Mohamed 1999). Project success and project performance are two similar but slightly different concepts, with project success having a greater weight than project performance (Chan et al. 2004). Project performance mainly focuses on the indicators of project execution, but the time range of project success, such as the project's influence after completion, is also included (Lim and Mohamed 1999).

The earliest criterion of project success is the *golden triangle*, which consists of time, cost, and quality (Atkinson 1999; Jugdev and Müller 2005; Molenaar et al. 2013). These measures are important but do not include the necessary measures of modern factors for project success (Atkinson 1999; Ika 2009). In addition to the redefinition of project success, the roles and responsibilities of a project manager go far beyond the traditional golden triangle, including relations, cultural, and stakeholder management (Lam et al. 2011; Meng et al. 2011; Ozorhon and Cinar 2015; Wong and Cheung 2005). Bosch-Rekveldt (2011) stated that project success should be measured from internal and external perspectives. In addition to guaranteeing project completion within a specified budget and time, the criteria of success should also consider the end user and the availability of project results.

According to the project success of construction projects, Lim and Mohamed (1999) tried to analyze the success criteria of construction projects from both macro- and microperspectives. A macroperspective primarily considers the relationship between project planning and the end user's satisfaction, whereas a microperspective primarily contemplates the time, cost, and quality of project construction. Bryde and Robinson (2005) indicated that owners and contractors have a different understanding of project success. Owners emphasize stakeholders' satisfaction, whereas contractors focus on traditional measures, such as time, cost, and quality. Chan et al. (2004) proposed the success standard system of construction projects on the basis of literature review, including time, cost, quality, health and safety, environmental performance, participants' satisfaction, user satisfaction, and commercial value. Yu et al. (2006) yielded five major categories, including project-related factors, human-related factors, process-related factors, input-related factors, and output-related factors. In China, Lin et al. (2005) divided the project success criteria into preliminary, construction, and operation success criteria from the project lifecycle and all stakeholders' perspectives. Wang and Xu (2009) subdivided the indicators of success into project implementation and project results. Project implementation mainly focuses on the objective control, interest demands of participators, satisfaction, motivation, and harmony realization and is divided into 24 evaluation standards to measure the success of project delivery. Project results consider the externality factors of fairness and sustainable development and the satisfaction of the whole process.

In conclusion, project success is very broad. It not only contains the project process but also includes the effect after project completion. Project success can involve various project participants and other stakeholders related to the project. A unified definition of project success is not needed; thus, project success in this study refers to the success of the whole construction project. According to comprehensive existing research, the research of Chan et al. (2004) was chosen as a reference to the measures of project success because of its comprehensive literature review and because it has the most citations about success factors of construction projects. They stated that the standard evaluation system for construction project success includes time, cost, quality, health and safety, environmental performance, participants' satisfaction, user satisfaction, and commercial value.

Hypothesis Development

A number of studies have tried to investigate the influence of project complexity on project performance. Puddicombe (2011) demonstrated via an analysis of more than 1,300 projects that technical complexity and novelty are important characteristics of a project that have distinct effects on project performance. Antoniadis et al. (2011) established in five case studies that the effects of the socio-organo complexity of interconnections have similarities with the behavior of underdamped control systems and found that socio-organo complexity is caused by interconnections that lead to a reduction in performance if not managed. Furthermore, Lebcir and Choudrie (2011) built a project complexity framework for construction projects and evaluated the effect of this framework on project cycle time by using a system dynamics simulation model that integrates project complexity, project operations, and time performance. Tam (2010) assessed the effects of project technical complexity on building production influences by using a clustering and knowledge-based system. Bosch-Rekveldt (2011) concluded that project complexity negatively influenced project performance in large engineering projects by distinguishing the technical, organizational, and external dimensions of project complexity. Some authors in China also investigated the effect of project complexity. Li (2009) proposed the assumptions about the influence of organizational complexity, technical complexity, and project complexity on project performance.

Moreover, some authors set project complexity as a moderated factor to analyze the relationships between two other factors. Muller et al. (2011) investigated the moderating effect of project complexity on the relationship between the leadership competence of project managers and their project success. McComb et al. (2007) found that the two dimensions of project complexity moderate the flexibility–performance relationship by using data collected from 60 cross-functional project teams. Liu (1999) examined the effects of the two moderators, namely, goal commitment and project complexity, on the perceived project outperformance of project participants. Kennedy et al. (2011) conducted virtual experiments to examine team communication and performance when teams work under varying types and levels of project complexity. Williamson (2011) showed that the difficulty of information technology (IT) projects is directly related to project complexity. However, project complexity is negatively related to IT project success.

In conclusion, some authors analyzed the relationship between project complexity and project performance but research on project success is lacking. Studies agree that project complexity has a negative effect on project performance. Thus, complexity is generally assumed to decrease project performance. As discussed in the preceding paragraphs, the definition scope of project success is greater than project performance, which should consider other success indicators in addition to the traditional golden triangle.

The following hypothesis was proposed:

H0: Project complexity negatively affects project success in complex construction projects.

Methodology

A deductive, positivistic approach was used, and project managers were given a web-based questionnaire to assess the project complexity and success of their last completed complex construction projects. A total of 256 responses were obtained, in which 245 were usable and analyzed:

1. Correlation analysis to identify the key factors of project complexity, and factor analysis to verify and further develop the measurement scales;
2. Reliability and validity analysis to verify the scale of reliability and validity; and
3. SEM analysis to investigate the relationship between project complexity and project success.

Preparation of Variables

Six categories of project complexity, namely, technological, organizational, goal, environmental, cultural, and information complexities, were proposed based on a literature review in a previous study (He et al. 2015). To verify the factors derived from the literature review and make it fit with the Chinese context of complex construction projects, a series of structured face-to-face interviews were conducted. Therefore, on the basis of prior research results and combined with the characteristics of complex construction projects and practices, potential factors of complexity were screened through expert interviews.

Experts who participated in complex construction projects were interviewed as a supplement to the initial indicators of project complexity and success as discussed in the preceding paragraphs. The

Table 1. Background of Experts

Interviewee	Employer	Position	Years of experience
A	Contractor	Project manager	35
B	Owner	Civil budgeting engineer	15
C	Owner	Tender business manager	5
D	Owner	Civil engineer	3
E	Consultant	Civil engineer	4
F	Government	Deputy chief of quality supervision department	8
G	Contractor	Project engineer	25
H	Consultant	Deputy general manager	33
I	Designer	Architect engineer	35

Delphi questionnaire survey method was used to obtain the consolidated views of a group of experts via several rounds of intensive questionnaires interspersed with controlled opinion feedback (Linstone and Turoff 1975; Xia and Chan 2012). In this study, two rounds of Delphi questionnaires were conducted. Delphi research usually selects less than 20 experts (Ludwig 1997; Vidal et al. 2010). In this study, 9 experts that participated in complex construction projects were chosen; these experts were also from different departments (the background of the experts is shown in Table 1).

Open questionnaires on the project complexity of complex construction projects were successfully conducted in the first round of the Delphi study. According to the interview results, the complexity factors of complex construction projects were supplemented on the basis of a literature review:

1. Cultural complexity was combined with organizational complexity.
2. Task complexity was added as a dimension of project complexity. On the basis of interviews, experts agreed that construction projects have various complex tasks and dependence among tasks.
3. Several factors were supplemented in the project complexity, such as change, owner demands, numerous participants, long project durations, and tight deadlines.

In the second round of the Delphi survey, the experts were asked to reassess the results in light of the consolidated results obtained in the first round of the survey. The results showed that experts reached consensus on the modified factors of project complexity.

In conclusion, through 2 rounds of interviews, a total of 41 potential factors of project complexity for complex construction projects were identified. Certain factors such as information complexity (IC), task complexity (TAC), technological complexity (TEC), organizational complexity (OC), environmental complexity (EC), and goal complexity (GC) were obtained. A total of 8 project success measures were acquired (shown in Table 2).

Data Collection

On the basis of the measures, a five-point Likert scale was used to design the questionnaire, with 1 corresponding to *strongly disagree* and 5 corresponding to *strongly agree*. A questionnaire survey was then conducted from November 2013 to April 2014, based on a critical incident approach. With the exception of optimizing questionnaire expression, the choices of respondents were also controlled. To avoid the biases introduced by the chosen projects, such as the possibility of respondents providing data only about the most successful project, the survey asked respondents to report about their most recently completed complex construction project.

Table 2. Potential Complexity Factors and Success Measures of Complex Construction Projects

Type	Potential factors
Goal complexity	Diversity of goals (PC1); uncertainty of goals (PC2); inconsistency of project goals (PC3); number of stakeholder requirements change (PC4); project urgency for time limit (PC5); urgency for project cost (PC6)
Organizational complexity	Number of organizational structure hierarchies (PC7); number of organizational units and departments (PC8); cross-organizational interdependence (PC9); experience of participants (PC10); change of project organization (PC11); trust among project organization (PC12); sense of cooperation (PC13); cultural differences of project organization (PC14)
Task complexity	Diversity of tasks (PC15); dependence of relationship among tasks (PC16); dynamics of task activities (PC17); uncertainty of project management methods and tools (PC18); availability of resources and skills (PC19); sources of funding way (PC20); complexity of contractual relationship (PC21)
Technological complexity	Diversity of technology in project (PC22); dependence of technological processes (PC23); risk of using highly difficult technology (PC24); knowledge of new technology (PC25); novelty of construction products (PC26)
Environmental complexity	Environment of changing policy and regulation (PC27); environment of changing economy (PC28); environment of changing nature (PC29); complicated geological conditions (PC30); changes in the project construction environment (PC31); remoteness of project location (PC32); the influence of external stakeholders (PC33)
Information complexity	Information uncertainty (PC34); level of processing information (PC35); capacity of transferring information (PC36); degree of obtaining information (PC37); integration of more than one system or platform (PC38); dependence of information system (PC39); variety of language involved (PC40); number of countries or nationality involved (PC41)
Project success	Time (PS1); cost (PS2); quality (PS3); health and safety (PS4); environmental performance (PS5); participants' satisfaction (PS6); user satisfaction (PS7); commercial value (PS8)

Software *SPSS version 17.0* and *AMOS version 16.0* were adopted for the analysis in this study; thus, a considerable number of data had to be collected. However, scholars have not yet reached a consensus for the sample number. For instance, Hou et al. (2004) concluded that most of the SEM models need at least 100–200 samples. Marsh et al. (1998), from the aspects of convergence and fitting index, indicated that a greater number of samples leads to better results. Hair et al. (1998) argued that sample size is better than 200 but cannot become excessive because data with more than 400 samples will result in a poor fitness index. Wu (2010) believed that the best sample is 5 times the number of scale questions. In this study, a total of 314 questionnaires were handed out and 256 questionnaires were collected; thus, the recovery rate was 81.5%. After excluding 11 invalid questionnaires, 245 valid questionnaires were received; hence, the effective recovery rate was 78%. In this sample, the majority of the respondents were male (76.7%) and possess a bachelor's degree (54.7%). Details are given in Table 3.

Table 3. Respondents' Demographics

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	188	76.7
	Female	57	23.3
Education	Ph.D.	9	3.7
	Master's degree	60	24.5
	Bachelor's degree	134	54.7
	Others	42	17.1
Work experience	≤5 years	109	44.5
	6–10 years	77	31.4
	11–20 years	47	19.2
	>20 years	12	4.9
Designation	Project manager	41	16.7
	Department manager	25	10.2
	Professional manager	55	22.4
	Project engineer	73	29.8
	Others	51	20.8
Project type	Residential project	122	49.8
	Public project	81	33.1
	Industrial project	15	6.1
	Others	27	11.0
Project size	≤10 million RMB	14	5.7
	10–50 million RMB	34	13.9
	50–100 million RMB	35	14.3
	100–500 million RMB	98	40.0
	>500 million RMB	64	26.1
Project duration	≤12 months	20	8.2
	13–24 months	79	32.2
	25–36 months	92	37.6
	>36 months	54	22.1

Operationalization of Variables

Project Complexity

The operationalization of project complexity of information, task, technological, organizational, environmental, and goal complexity was based on the questionnaire. A total of 41 questions were originally developed, reviewed, and validated through a series of data analyses (Luo et al. 2015).

First, correlation analyses of each item and of the total project complexity were conducted to identify the key project complexity factors of complex construction projects. Pearson correlation was used to explore the relationship between the project complexity factors and the overall complexity and to investigate whether there is a significant correlation between them. The correlation coefficient analysis between project complexity factors and the total complexity needs to reach a significant level. Moreover, the correlation coefficient should be at least 0.4 (Wu 2010). The correlation analysis result between potential factors and total project complexity is shown in Table 4. Table 4 shows the correlation coefficient among PC2, PC4, PC7, PC8, PC10, PC11, PC12, PC13, PC14, PC15, PC16, PC18, PC19, PC21, PC22, PC24, PC25, PC26, PC27, PC28, PC31, PC33, PC34, PC35, PC36, PC37, and PC39, and the total project complexity is greater than 0.4 and significant at the 0.01 level (two-tailed). Thus, the variables related to the project complexity of complex construction projects include PC2, PC4, PC7, PC8, PC10, PC11, PC12, PC13, PC14, PC15, PC16, PC18, PC19, PC21, PC22, PC24, PC25, PC26, PC27, PC28, PC31, PC33, PC34, PC35, PC36, PC37, and PC39.

The exploratory factor analysis method was subsequently adopted to classify the 27 key factors of project complexity for complex construction projects. A principal component method was conducted to extract the common factor and the maximum variance method was used for factor rotation. A factor is extracted when the eigenvalue is greater than 1 and vice versa (Wu 2010). This step

Table 4. Correlation Analysis between Potential Factors and Total Project Complexity

Item	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20	PC21
Pearson correlation	0.347[a]	0.440[a]	0.260[a]	0.513[a]	0.158[b]	0.283[a]	0.431[a]	0.408[a]	0.390[a]	0.525[a]	0.522[a]	0.582[a]	0.558[a]	0.566[a]	0.528[a]	0.417[a]	0.364[a]	0.489[a]	0.529[a]	0.174[a]	0.505[a]
Significance (two-tailed)	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
Item	PC22	PC23	PC24	PC25	PC26	PC27	PC28	PC29	PC30	PC31	PC32	PC33	PC34	PC35	PC36	PC37	PC38	PC39	PC40	PC41	
Pearson correlation	0.455[a]	0.365[a]	0.458[a]	0.467[a]	0.446[a]	0.466[a]	0.532[a]	0.379[a]	0.382[a]	0.500[a]	0.320[a]	0.459[a]	0.630[a]	0.649[a]	0.556[a]	0.541[a]	0.380[a]	0.406[a]	0.335[a]	0.290[a]	
Significance (two-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

[a]Correlation is significant at the 0.01 level (two-tailed).
[b]Correlation is significant at the 0.05 level (two-tailed).

was supported by a high Kaiser-Meyer-Olkin (KMO) and Bartlett test; the KMO value of project complexity measures is 0.870 and greater than 0.8, whereas the value of the Bartlett's spherical test is significant at the 0.05 level. Tables 5 and 6 present the results of the factor analyses and show the six factors to be extracted from 27 items of project complexity, with the eigenvalues cumulatively explaining 59.230% of the total variance, which is close to 60%. Factor loading of items was above 0.400, which indicates that the 6 extracted common factors can effectively reflect the 27 variables. The grouping of variables was similar to the original concepts of project complexity; therefore, the names of project complexity constructs were kept as information complexity, task complexity, technological complexity, organizational complexity, environmental complexity, and goal complexity.

Finally, a reliability analysis was conducted to verify the scale reliability. Corrected item-total correlation (CITC) and Cronbach's alpha reliability coefficient were adopted for reliability analysis. CITC is for purifying the items, whereas Cronbach's alpha is for internal consistency (Wu 2010). Table 7 presents the reliability testing for project complexity and shows that all Cronbach's alpha coefficient values are greater than 0.60, thus indicating good internal consistency. With the exception of task complexity, the CITC values were greater than 0.300, thus indicating that each item is highly consistent with the sum of other items. Alpha if item deleted is less than Cronbach's alpha, thus indicating that the scale of internal consistency reliability is good.

According to the scale of task complexity, the alpha coefficient of task complexity is 0.660, which is greater than 0.60; thus, the internal consistency reliability is good. The CITC value of TAC4 is 0.227, which is less than 0.300, and alpha if item deleted is 0.726, which is greater than 0.660. Therefore, the item TAC4 was deleted, with the result shown in brackets in Table 7. After deleting TAC4, the factor scale alpha coefficient value of TAC is 0.726, which is greater than 0.70. This result indicates good internal consistency reliability. All CITC values are between 0.511 and 0.598 (greater than 0.300), thus indicating that each item is highly consistent with the sum of other items. Alpha if item deleted is less than 0.726, thus indicating that the task complexity has good internal consistency reliability.

Project Success

According to comprehensive existing research, the research of Chan et al. (2004) was chosen as the reference for the project success questionnaire. They proposed the construction project success evaluation standard system, including time, cost, quality, health and safety, environmental performance, participants' satisfaction, user satisfaction, and commercial value.

Table 8 presents the reliability analysis result of project success and shows that the overall alpha coefficient value of project success scale is 0.837, which is greater than 0.8. The CITC values are between 0.404 and 0.650 (greater than 0.300), thus indicating that each item is highly consistent with the sums of other items. Alpha if item deleted values, with the exception of item PS8, are slightly greater than 0.837. If item PS8 is deleted, then the internal consistency alpha of the other items will increase but will be close to the original internal consistency alpha value. The other items are less than 0.837; thus, the project success scale has good internal consistency reliability.

Results

Relationship between Project Complexity and Success

The relationship between project complexity and success of complex construction projects was investigated by SEM. The six dimensions of project complexity are the latent variables in the

Table 5. Total Variance of Key Factors of Project Complexity

Factor	Initial eigenvalues			Extraction sums of squared loading			Rotation sums of squared loading		
	Total	Percentage of variance	Cumulative %	Total	Percentage of variance	Cumulative %	Total	Percentage of variance	Cumulative %
1	7.504	27.794	27.794	7.504	27.794	27.794	5.244	19.422	19.422
2	3.245	12.018	39.812	3.245	12.018	39.812	2.410	8.927	28.348
3	1.613	5.972	45.784	1.613	5.972	45.784	2.233	8.271	36.619
4	1.476	5.468	51.252	1.476	5.468	51.252	2.194	8.127	44.747
5	1.126	4.170	55.422	1.126	4.170	55.422	2.186	8.096	52.842
6	1.028	3.808	59.230	1.028	3.808	59.230	1.725	6.388	59.230
7	0.984	3.644	62.873	—	—	—	—	—	—
8	0.874	3.236	66.109	—	—	—	—	—	—

Table 6. Rotating Component Matrix for Key Factors of Project Complexity

Item	Factor					
	1	2	3	4	5	6
PC13	**0.821**	0.048	0.015	0.231	0.024	0.012
PC12	**0.784**	0.034	0.034	0.190	0.081	0.054
PC36	**0.743**	0.114	0.064	−0.251	0.152	0.223
PC37	**0.726**	0.051	0.110	−0.296	0.182	0.165
PC14	**0.725**	0.211	0.077	0.118	0.020	-0.020
PC35	**0.701**	0.160	0.167	−0.220	0.317	0.190
PC10	**0.665**	0.049	0.053	0.127	0.056	0.192
PC34	**0.464**	0.097	0.379	0.038	0.370	0.121
PC18	**0.460**	−0.221	0.383	−0.067	0.248	0.221
PC16	0.087	**0.738**	0.062	0.141	0.039	−0.045
PC22	−0.028	**0.638**	0.342	0.267	−0.114	0.286
PC15	0.177	**0.580**	0.163	0.406	0.080	0.084
PC39	0.257	**0.510**	−0.123	−0.271	0.268	0.158
PC26	−0.045	0.160	**0.668**	0.160	0.207	0.104
PC24	0.007	0.435	**0.622**	−0.041	−0.020	0.275
PC25	0.450	0.055	**0.594**	0.009	0.012	−0.134
PC19	0.367	−0.085	**0.511**	0.026	0.317	0.033
PC7	0.050	0.171	0.084	**0.803**	0.184	0.095
PC8	0.020	0.185	0.045	**0.745**	0.135	0.218
PC27	0.169	−0.099	0.174	0.148	**0.785**	0.019
PC28	0.202	0.108	−0.008	0.063	**0.675**	0.322
PC31	−0.013	0.376	0.279	0.217	**0.457**	0.085
PC33	0.107	0.267	0.343	0.193	**0.453**	−0.189
PC4	0.090	0.311	0.044	0.224	0.116	**0.583**
PC11	0.452	−0.147	0.028	0.250	0.106	**0.536**
PC2	0.452	−0.113	0.174	−0.198	0.007	**0.483**
PC21	0.208	0.245	0.103	0.224	0.137	**0.472**

Note: The principal component extraction method and the Kaiser standardization rotation method were used, as well as orthogonal rotation after 14 times the iterative convergence. The bold text signifies that the items were classified into different factors.

SEM model, whereas the key factors of project complexity are the dominant variables. The testing result of the theoretical model is shown in Fig. 1 and Tables 9 and 10. The analysis result shows that the path coefficient of project complexity to project success is −0.254 and is significant at $p < 0.001$, thereby supporting hypothesis H0. It is suggested that project complexity has a significant negative correlation with project success in Chinese complex construction projects.

The goodness-of-fit (GOF) indices are essential tools for assessing the fitness of SEMs. Table 9 shows that the model fitness of the final SEM for project complexity and project success is supported by the results of the indices. The results of the model fitting show that χ^2/df is 1.667 (less than 3), $p = 0.000$, and a significant level is reached. Therefore, significant differences exist between the covariance matrix of the measurement model and the covariance matrix of empirical data; thus, other measures should be used to comprehensively evaluate the fitting degree of the model. From the absolute fitting metrics, the goodness-of-fit index (GFI) value is 0.841, the adjusted GFI (AGFI) value is 0.798 (slightly lower than 0.90 standards), and the root-mean square error of approximation (RMSEA) value is 0.048, which is less than 0.08. From the relative fitting index, the normal fit index (NFI) value is 0.799, the incremental fit index (IFI) value is 0.909, and the comparative fit index (CFI) value is 0.906; thus, both IFI and CFI are greater than 0.90, with the exception of NFI. Given that no mature scale is available for the project complexity of complex construction projects, the measurement scales in this study are developed from existing theory and interview results. Accordingly, the GFI, AGFI, and NFI values are also acceptable. Therefore, the fitting index of project complexity and project success (PC&PS) model can be regarded as good.

A summary of the standardized coefficients of the final model is shown in Table 10. All path coefficients are positive and significant at $p < 0.05$; thus, their significance to the model is augmented. In the SEM model, project complexity was classified as information complexity, task complexity, technological complexity, organizational complexity, environmental complexity, and goal complexity; project success was directly reflected by eight project targets, namely, time, cost, quality, health and safety, environmental performance, participants' satisfaction, user satisfaction, and commercial value.

Relationships between Different Complexity and Project Success

Different complexities have various effects on project success. SEM was then used to analyze the influence of different complexities on project success, including information complexity, task complexity, technological complexity, organizational complexity, environmental complexity, and goal complexity. The SEMs are shown in Figs. 2–7.

Table 9 presents the results of GOF measures and shows that the model fitting χ^2/df is less than 3, $p = 0.000$, and a significant level is reached. Therefore, significant differences exist between the covariance matrix of the measurement model and the covariance matrix of empirical data. Therefore, other measures should be used to comprehensively evaluate the fitting degree of the model. From the absolute fitting metrics, the GFI and AGFI values are close to or greater than 0.90; the RMSEA value is 0.048, which is less than 0.08. From the relative fitting index, the NFI, IFI, and CFI values are almost greater than 0.90. Accordingly, the results

Table 7. Reliability Testing for Project Complexity

Classification	Code	Measurement item	CITC	Alpha if item deleted	Cronbach's alpha
Information complexity (IC)	IC1	Trust among project organization	0.671	0.877	0.891
	IC2	Sense of cooperation	0.689	0.876	
	IC3	Capacity of transferring information	0.738	0.872	
	IC4	Degree of obtaining information	0.722	0.873	
	IC5	Cultural differences	0.611	0.882	
	IC6	Level of processing information	0.767	0.869	
	IC7	Experience of participants	0.575	0.885	
	IC8	Information uncertainty	0.559	0.886	
	IC9	Uncertainty of project management methods and tools	0.512	0.890	
Task complexity (TAC)	TAC1	Dependence of relationship among tasks	0.496 (0.511)	0.559 (0.683)	0.660 (0.726)
	TAC2	Diversity of technology in project	0.517 (0.542)	0.537 (0.650)	
	TAC3	Diversity of tasks	0.551 (0.598)	0.513 (0.577)	
	TAC4	Dependence of information system	0.227 (deleted)	0.726 (deleted)	
Technological complexity (TEC)	TEC1	Novelty of construction products	0.422	0.579	0.645
	TEC2	Risk of using highly difficult technology	0.418	0.581	
	TEC3	Knowledge of new technology	0.453	0.558	
	TEC4	Availability of resources and skills	0.408	0.590	
Organizational complexity (OC)	OC1	Number of organizational structure hierarchies	0.700	—	0.820
	OC2	Number of organizational units and departments	0.700	—	
Environmental complexity (EC)	EC1	Environment of changing policy and regulation	0.524	0.547	0.664
	EC2	Environment of changing economy	0.460	0.587	
	EC3	Changes in the project construction environment	0.414	0.618	
	EC4	The influence of external stakeholders	0.393	0.636	
Goal complexity (GC)	GC1	Number of stakeholder requirements change	0.357	0.518	0.664
	GC2	Change of project organization	0.471	0.424	
	GC3	Uncertainty of goals	0.313	0.552	
	GC4	Complexity of contractual relationship	0.324	0.545	

Table 8. Reliability Testing for Project Success

Code	Measurement item	CITC	Alpha if item deleted	Cronbach's alpha
PS1	Time	0.618	0.811	0.837
PS2	Cost	0.650	0.806	
PS3	Quality	0.577	0.817	
PS4	Health and safety	0.474	0.829	
PS5	Environmental performance	0.559	0.819	
PS6	Participants' satisfaction	0.631	0.810	
PS7	User satisfaction	0.631	0.810	
PS8	Commercial value	0.404	0.839	

of GOF measures showed that the fitness of all SEMs is acceptable.

Table 10 summarizes the testing results of different project complexities and successes and shows the following results. Information complexity, which is a dimension of project complexity (standardized coefficient = 0.895), has a significant negative effect on project success (standardized coefficient = −0.312). Nine factors have a substantial correlation with information complexity: trust among project organization (IC1), sense of cooperation (IC2), capacity of transferring information (IC3), degree of obtaining information (IC4), cultural differences (IC5), level of processing information (IC6), experience of participants (IC7), information uncertainty (IC8), and uncertainty of project management methods and tools (IC9).

Task complexity is an essential dimension of project complexity (standardized coefficient = 0.415) and is directly reflected by three attributes: dependence of relationship among tasks (TAC1), diversity of technology in projects (TAC2), and diversity of tasks (TAC3). However, task complexity has no significant effect on project success (standardized coefficient = 0.111).

Technological complexity is another dimension of project complexity (standardized coefficient = 0.80) and is directly reflected by four attributes: novelty of construction products (TEC1), risk of using highly difficult technology (TEC2), knowledge of new technology (TEC3), and availability of resources and skills (TEC4). However, technological complexity also has an insignificant effect on project success (standardized coefficient = −0.013).

Organizational complexity is a dimension of project complexity (standardized coefficient = 0.258), which can be measured by a number of organizational structure hierarchies (OC1) and a number of organizational units and departments (OC2). However, organizational complexity also has no significant effect on project success (standardized coefficient = 0.103).

Environmental complexity, which is a dimension of project complexity (standardized coefficient = 0.659), can be measured by four factors: environment of changing policy and regulation (EC1), environment of changing economy (EC2), changes in the project construction environment (EC3), and the influence of external stakeholders (EC4). An insignificant negative correlation was found between environmental complexity and project success (standardized coefficient = −0.110).

Significant and negative correlations were also found between goal complexity and project success (standardized coefficient = −0.231). Goal complexity is a dimension of project complexity (standardized coefficient = 0.855), which is directly reflected by four attributes: number of stakeholder requirements change (GC1), change of project organization (GC2), uncertainty of goals (GC3), and complexity of contractual relationship (GC4).

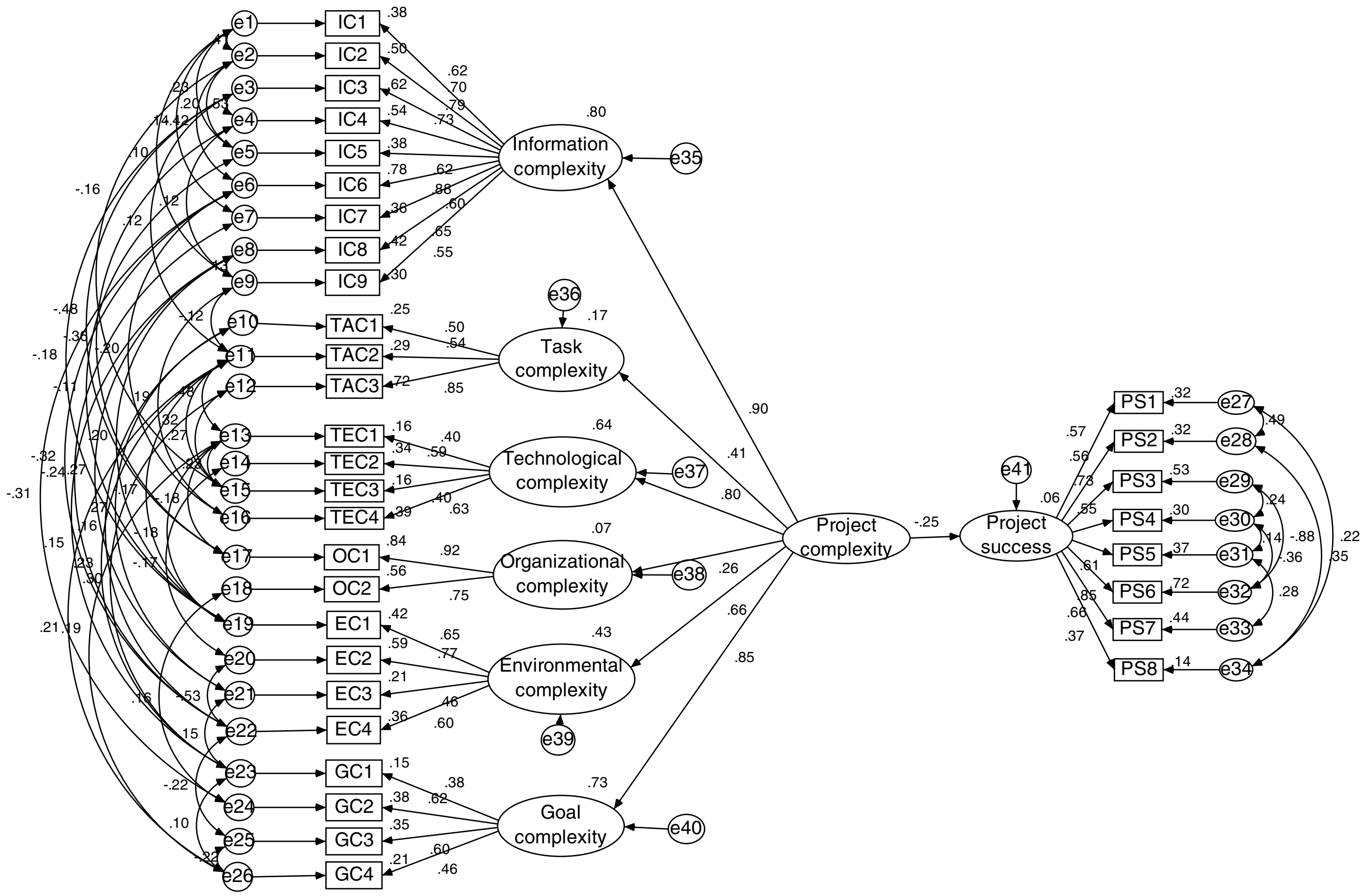

Fig. 1. SEM model of project complexity and project success (PC&PS)

Table 9. Results of GOF Measures

Goodness-of-fit (GOF) measure	Recommended level of GOF measure	PC&PS	IC&PS	TAC&PS	TEC&PS	OC&PS	EC&PS	GC&PS
χ^2/df	Recommended level from 1 to 2	1.667	1.763	1.381	1.740	1.346	1.865	1.837
Goodness-of-fit index (GFI)	0 (no fit) to 1 (perfect fit)	0.841	0.933	0.967	0.952	0.974	0.949	0.949
Adjusted goodness-of-fit index (AGFI)	0 (no fit) to 1 (perfect fit)	0.798	0.887	0.938	0.916	0.944	0.909	0.909
Root-mean square error of approximation (RMSEA)	<0.05 indicates very good fit—threshold level is 0.10	0.048	0.056	0.040	0.055	0.038	0.060	0.059
Normal fit index (NFI)	0 (no fit) to 1 (perfect fit)	0.799	0.922	0.947	0.913	0.962	0.914	0.910
Incremental fit index (IFI)	0 (no fit) to 1 (perfect fit)	0.909	0.965	0.985	0.961	0.990	0.958	0.957
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0.906	0.964	0.984	0.960	0.990	0.957	0.956

Discussions

The measurement of project complexity developed in this study was therefore thoroughly verified and checked for completeness, resulting in an updated version of the framework for complex construction projects. Project complexity was classified as information complexity, task complexity, technological complexity, organizational complexity, environmental complexity, and goal complexity. The measurement model of project complexity can be used to identify and measure the key factors, so as to give references for managing project complexity. The research investigated the relationship between project complexity and project success, which is helpful for achieving project success in complex construction projects for project managers.

The SEM results suggested that project complexity has a significant negative correlation with project success. The result is consistent with Lebcir and Choudrie (2011), who simulated the effects of project complexity on time to complete construction projects. Bosch-Rekveldt (2011) also confirmed that project complexity generally is assumed to decrease project performance, and Williamson (2011) showed that project complexity is negatively related to IT project success. To address project complexity, the client could adopt the program management approach to simplify the complexities and sustain the control of the dispensed execution of the project (Hu et al. 2014). Remington and Pollack (2007) stated that program management is a pragmatic means of dealing with nearly all types of project complexity.

Information complexity has a significant negative effect on project success (standardized coefficient = −0.312). Senescu et al. (2014) has proved that project complexity affects collaboration, sharing, and understanding; therefore, the industry will need to consider improving the timing and the approach taken to implement

Table 10. Standardized Coefficient Values of Paths in Structural Equation Modeling

Path	Estimate[a]
Information complexity ← project complexity	**0.895**
Task complexity ← project complexity	**0.415**
Technological complexity ← project complexity	**0.800**
Organizational complexity ← project complexity	**0.258**
Environmental complexity ← project complexity	**0.659**
Goal complexity ← project complexity	**0.855**
Project success ← project complexity	−0.254
TAC3 ← task complexity	0.846
TAC2 ← task complexity	0.537
TAC1 ← task complexity	0.497
TEC4 ← technological complexity	0.627
TEC3 ← technological complexity	0.400
TEC2 ← technological complexity	0.585
TEC1 ← technological complexity	0.396
OC2 ← organizational complexity	0.751
OC1 ← organizational complexity	0.915
EC4 ← environmental complexity	0.598
EC3 ← environmental complexity	0.456
EC2 ← environmental complexity	0.771
EC1 ← environmental complexity	0.647
GC4 ← goal complexity	0.459
GC3 ← goal complexity	0.595
GC2 ← goal complexity	0.618
GC1 ← goal complexity	0.385
IC9 ← information complexity	0.546
IC8 ← information complexity	0.647
IC7 ← information complexity	0.602
IC6 ← information complexity	0.882
IC5 ← information complexity	0.616
IC4 ← information complexity	0.735
IC3 ← information complexity	0.786
IC2 ← information complexity	0.705
IC1 ← information complexity	0.617
PS1 ← project success	0.570
PS2 ← project success	0.563
PS3 ← project success	0.729
PS4 ← project success	0.552
PS5 ← project success	0.608
PS6 ← project success	0.849
PS7 ← project success	0.663
PS8 ← project success	0.368

[a]All standardized coefficient values are significant at $p < 0.05$. The bold text signifies the different dimensions of project complexity and the relationship between project complexity and project success.

appropriate techniques (Antoniadis et al. 2011). According to the factors of information complexity identified in this study, the client could establish a separate communication management system to promote and integrate communication activities among designers, contractors, suppliers, and governmental agencies, as well as analyze the progress information and meet the information needs of decision makers (He et al. 2015; Hu et al. 2014).

Task complexity has no significant effect on project success (standardized coefficient = 0.111). Task complexity was added as one new dimension of project complexity for Chinese complex construction projects in the Delphi study of open questionnaires. The results demonstrated that even though complex construction projects have diverse tasks and high dependence on the relationships among tasks, task complexity does not have a significant effect on project success, as supposed before.

The SEM result showed that technological complexity has an insignificant effect on project success (standardized coefficient = −0.013). Tam (2010) and Puddicombe (2011) also demonstrated that technological complexity and novelty are important characteristics of a project that have distinct effects on project performance. Accordingly, project managers need to explicitly make an analysis of technical complexity and novelty and make them part of their planning calculus if superior performance is to be achieved (Puddicombe 2011).

Organizational complexity also has no significant effect on project success (standardized coefficient = 0.103). This research result contrasts with that of Antoniadis et al. (2011), who found that socio-organo complexity is caused by interconnections that, if not managed, could lead to a reduction in performance. The reason is that organizational complexity in this study is primarily identified as organization structure, including the number of organizational structure hierarchies, organizational units, and departments. However,the level of training of project team members and implementation of appropriate actions were selected by Antoniadis et al. (2011) as the influence factors for project performance, which is consistent with the relationship between information complexity and project success in this study.

An insignificant negative correlation was found between environmental complexity and project success (standardized coefficient = −0.110). Bosch-Rekveldt (2011) reached the same conclusion that the negative correlations between project complexity elements and project performance were found in the areas of interfaces between different disciplines and a lack of company internal support.

Significant negative correlations between goal complexity and project success (standardized coefficient = −0.231) were also found through the SEM result. The result was also proved by Bosch-Rekveldt (2011), who found the strongest correlations between project complexity elements and project performance (negative) in the areas of goals and scope. According to goal complexity, a client organization could apply the project breakdown structure and work breakdown structure (PBS/WBS) tools to align the tasks of different organizational units and the overall objectives of complex construction projects; some divisions such as the cost

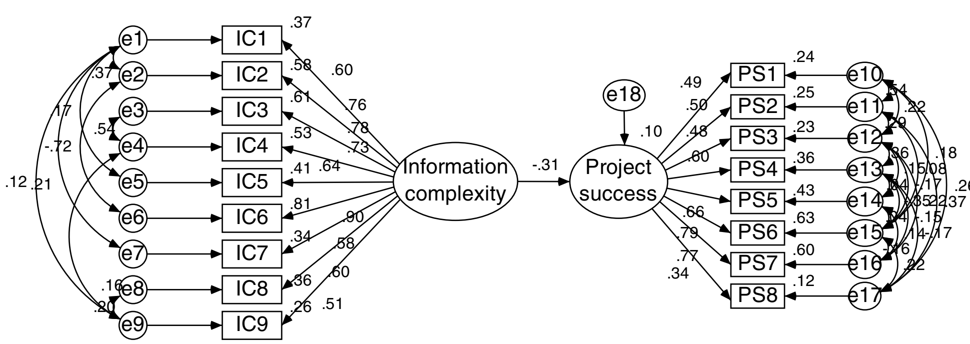

Fig. 2. SEM model of information complexity and project success (IC&PS)

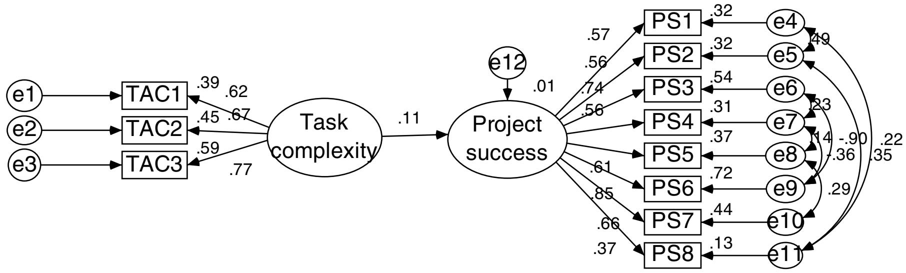

Fig. 3. SEM model of task complexity and project success (TAC&PS)

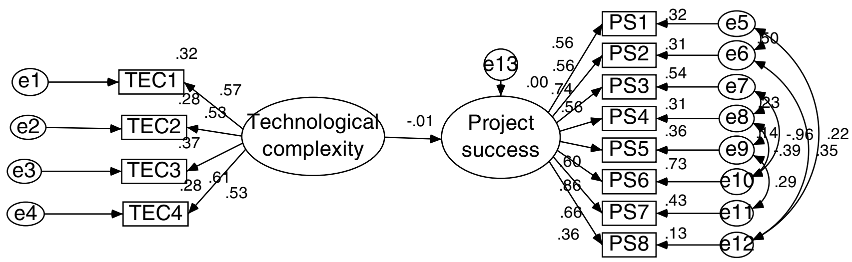

Fig. 4. SEM model of technological complexity and project success (TEC&PS)

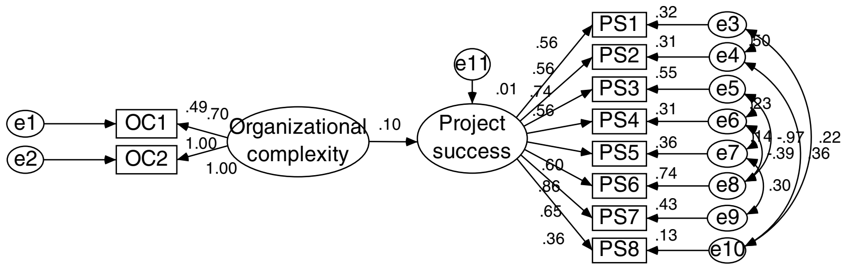

Fig. 5. SEM model of organizational complexity and project success (OC&PS)

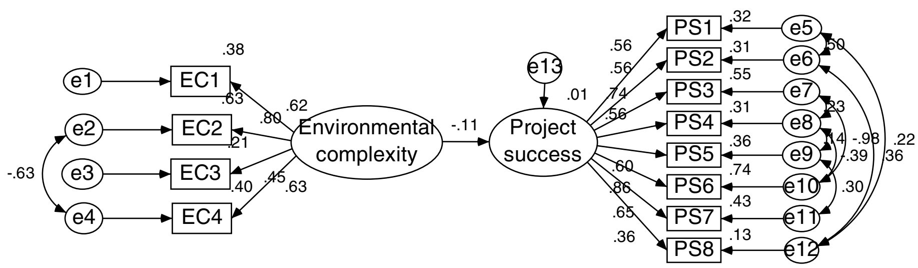

Fig. 6. SEM model of environmental complexity and project success (EC&PS)

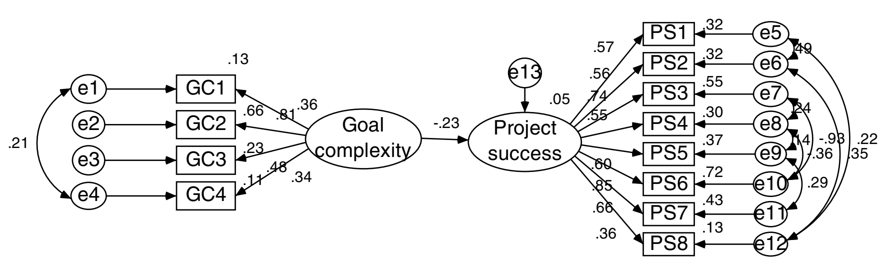

Fig. 7. SEM model of goal complexity and project success (GC&PS)

management division and time management division could also be established within the client organization to monitor the implementation of all key objectives (He et al. 2015).

Conclusions

This study empirically validated the complexity measurement of complex construction projects, including information complexity, task complexity, technological complexity, organizational complexity, environmental complexity, and goal complexity. From the literature review, project complexity is difficult to quantify precisely. The authors' prior study made progress in defining what constitutes complexity, that is, those aspects that make projects complex to manage. However, the model is still not empirically validated (He et al. 2015; Muller et al. 2011). This study presents a complexity measurement of complex construction projects that was successfully validated empirically. The measurement items identified constitute a valid and reliable instrument for measuring project complexity, making them appropriate for use in the scientific community for future empirical research. This new instrument will enable fine-grained research, particularly for measuring the complexity level within different complex construction projects, which can also provide a reference for managing project complexity.

On the basis of project complexity measures, SEM was used to analyze, for the first time, the relationship between project complexity and success of complex construction projects. The analysis results show that the strong relationship between project complexity and project success is augmented by the standardized coefficient value of −0.254 between them. The SEM supports the hypothesis that the success of complex construction projects in China is significantly correlated with project complexity. Among the six dimensions of project complexity, the results showed that information complexity and goal complexity have significant negative effects on project success. The results have many practical implications. This means that client organizations of complex construction projects in China should pay more attention to the management of information complexity and goal complexity. To address information complexity, client organizations should pay more attention to communication. They could adopt more effective ways to communicate, including using new communication technology, integrating work teams, adopting a project information management system, and providing a building information modeling (BIM) model as a visual communication tool. To address goal complexity, the project manager of the client organization should pay more attention to the survey of the project's functional requirements and control the quality of the design work effectively to reduce the uncertainty of goals and the amount of changes from the contractor or owner. Client organizations of complex construction projects should periodically review project objectives and the project's adaptability to the environment and market, to make sure that the project goals can be adjusted to changes in the environment and the market as soon as possible and thereby promote project success.

This study had some deficiencies. The sample size was not very large, and the research result was obtained based only on the data of complex construction projects collected in China. Therefore, more research should be done in other countries to compare the results and obtain more generic results about the relationship between project complexity and project success. Also, the theoretical model provides a framework and tool to explore the influence path. Future studies could consider moderate variables and mediating variables.

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