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The Impact of Construction Project Complexity on Performance: an Empirical Study from China's Construction Industry

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Abstract:

There are many reasons for poor project management performance, and underestimating complexity is considered one of the main reasons. However, there are still debates on the impact of project complexity on performance, and there is a lack of similar empirical studies in China. Contractors are the main actors concerned with project management performance and need to manage their perceived project complexity. Firstly, literature analysis method was used to determine the construction project complexity framework, a description model of social complexity, environmental complexity, technical complexity and stakeholder complexity was constructed, and 17 complexity factors were screened. Then questionnaire survey method was used to obtain data, 267 valid samples were collected from large-scale construction projects in China. Structural model path analysis shows that social complexity has a significant negative impact on performance, environmental complexity and stakeholder complexity have a negative but not significant impact on performance, and technological complexity has a positive impact on performance. Thus, different dimensions of complexity have different impacts on project management performance. Contractors should pay more attention to social complexity factors, strengthen communication with investors and local governments, concern on material supply chain risks and contract risks.

Keywords*: Project management, Construction project complexity, Project management performance, Social complexity.*

I. INTRODUCTION

Large engineering construction projects play a huge role in promoting economic growth, solving employment and promoting regional economic balance, but cost overruns and delay of construction period are also common in large engineering construction projects. According to a study conducted by Ahsan and Gunawan [1] on more than 100 large construction projects around the world, as many as 86% of them have delays and more than 70% of them have cost overruns.

For large-scale construction projects, stakeholder’s requirements is not consistent, professional and technical difficulty is high, social and political environment often changed, and so on, thus construction

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project formed a complex operation system. This kind of complex project system involves the interaction and dynamic changes that no amount of planning can't eliminate the uncertainty existing in the management process, which leads to cost overruns and delays. There are many reasons for low project management performance, the increase of Complexity and the underestimate of Complexity are the main reasons [2]. Sauer and Cuthbertson [3] also put forward that project Complexity leads to low project performance in terms of time and budget. Of course, current studies have not found an approving explanation for how to reduce project complexity or its impact on project performance yet [4].

Many people believe that project complexity reduces project performance, but current research results do not fully support this causal relationship. As Qazi [5] specifically reminds, too often people focus only on the negative implications of complexity and associate complexity with traditional performance criteria (quality, time, and cost), thus avoiding the opportunity to exploit the positive impact of complexity on performance. At present, research results in the field of engineering construction in China only provide limited evidence to support the negative impact of complexity on project success, but there is a lack of empirical research on the relationship between project complexity and performance. Therefore, from the perspective of contractors, this paper focuses on the impact of project complexity on performance to lay a foundation for project complexity management.

II. METHODOLOGY

2.1 Project Complexity

Complexity is an important but controversial topic in the field of project management. So far, there has not been a unified understanding of the concept of complexity. The American Project Management Association gives a more comprehensive definition of project complexity: Complexity is a feature of a project or its environment that is difficult to manage due to human behaviour, system activities, and ambiguity [6]. This definition covers the management activities of the project team and its members, organizational behaviour, communication activities and other factors, and the project system itself, especially emphasizes the important impact of project environment.

Most studies on complexity classification of construction projects adopted the classification framework of organizational complexity and technical complexity proposed by Vidal et al.[7] Such as the cognitive framework of organization, technology implementation, planning management, environment and uncertainty[8], a framework of complexity including organization, technology and uncertainty[9]. The classic complexity framework was proposed by Bosch-rekveldt et al [10], which including technology, organization and environment. Later, Nguyen et al [11] took transportation construction projects in Vietnam as the research object, expanded the above-mentioned framework with socio-political and scope dimensions, and the infrastructure dimension.

Most of research results follow the description framework based on organization, technology and environment in China, emphasizing the specific complexity factors and characteristic of the project.

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According to the latest research of He et al [12], the complexity model of engineering projects can be divided into internal complexity (organization, task, technology) and external complexity (environment, system, society). It is emphasized that external complexity has an important influence on the complexity degree of major projects. In general, the project complexity model can also be regarded as the description of the project, the management team and the external environment of the project.

One of the challenges in building a complexity framework is how to deal with the factors such as team members and their management activities. Mamédio and Meyer [13] took human dimension as one important part of project complexity. Human behaviour can lead to complexity, such as collusion, bribery, distortion or resistance [6], but teamwork and effective management activities can also reduce complexity. We are inspired by the opinion that project managers often deal only with perceived complexity for practical purposes [14]. Therefore, we identified perceived complexity from project team member's perspective and separated the observer and his or her response behaviour from complexity. In order to address the challenges posed by the institutional and technical complexity inherent in projects, project managers need to address them through appropriate planning arrangements. In the whole complexity framework, institutional complexity has a greater impact. If planning arrangements and other management deployment are sufficiently matched, the impact of complexity can be mitigated and reduced to improve project performance [15].

Some scholars proposed the classification methods of Objective Complexity and Subjective Complexity [16]. Subjective Complexity is also known as Perceived Complexity, which holds that Complexity is subjective and must be Perceived through the observer's perception. When the Complexity of a task exceeds the capability of the task implementers, the observer will perceive the Complexity of the task [17]. Although describing ontology complexity from an objective perspective has always been the focus of project complexity research, project complexity may be in the eye of the beholder [18].

To sum up, based on the actual situation of construction projects in China, this paper focus on the perceived complexity of contractors, stripping out the complexity factors caused by the project team and its behaviour, considering about the influence of stakeholders, the institutional or social factors. At the same time, factors such as environmental and technical are introduced to form a project complexity classification framework, which including social complexity, environmental complexity, technological complexity and stakeholder complexity. On this basis, we screened complexity factors of construction projects using the literature analysis, and the overall complexity framework including 17 factors is obtained [10-11,15,19-27] as Table I shows.

TABLE I. Four-dimensional framework of construction project complexity

Complexity Classification	Complexity Factors
Social complexity	Resource availability (SC_1), Project fund(SC_2), Local government influence(SC_3), Contractual relation(SC4),

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Complexity Classification	Complexity Factors
	Legal environment (SC_5), Project objective (SC_6)
Environmental complexity	Geological conditions(EC_1), Site compensation and Clearance(EC_2), Climate conditions(EC_3), Construction site conditions (EC_4), Market price(EC_5)
Technological complexity	Project scope (TC_1), Survey and design quality(TC_2), Technical risk(TC_3)
Stakeholder complexity	Stakeholder relationship (STC_1), Stakeholder number(STC_2), Professional activity dependence(STC_3)

2.2 Project Management Performance

In the field of project management, performance is the unity of the outcome and the process (behaviour) that produces it, taking into account the future effects of the project [28]. In order to distinguish the difference between process performance and result performance, some scholars point out that project performance is different from project management performance, which is usually measured by time, cost and quality, while project performance is a broader concept involving the objectives of all stakeholders in the whole project life cycle [29]. Dilek and SiTKi [30] also point out that time, cost and quality are the three classic KPIs, although they are influential during the project execution phase, they lose their importance when the project is completed, and project stakeholder satisfaction becomes the KPIs. Later, considering the social and business benefits of future projects, project success was put forward as a broader concept different from project performance, and pay more attention to customer satisfaction, profitability, environmental sustainability, health and safety, and even aesthetics and education after the project is put into use [31].

Therefore, project performance is the combination of project management performance and product success. Project management performance can be regarded as the short-term performance of the project, while project success can be regarded as the long-term performance of the project. From this point of view, some projects have extended time limit, cost overruns and poor project management performance, but it does not mean that the project is not successful. Contractors pay more attention to short-term project performance, while investors and owners pay more attention to long-term performance.

This paper studies the impact of construction project complexity on performance from the perspective of contractors, which focuses on short-term performance. In addition to time, cost and quality, safety and environmental protection are also very important and common objectives in China. Therefore, in the study of this paper, the project management performance is expressed by multi-dimensional objective, and the performance measurement indicators include five indicators, including time, cost, quality, safety and environmental protection.

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2.3 Project Complexity and Performance

Dalchar [32] early pointed out that complexity affects project completion ability. However, it is still a topic of continuous debate in the field of project management [33]. Early research analyse the impact of project complexity on performance mainly from a technical perspective. Tatikonda and Rosenthal [34] took product development projects as objects and found that project complexity was closely related to poor unit cost. Puddicombe [35] also believes that technical complexity and novelty are important features of the project, which has a significant adverse impact on project cost and schedule performance.

Later scholars gradually cast their eyes on non-technical factors. Antoniadis et al [36] considered the impact of complexity caused by interconnected characteristics, and the research results proved that there was a negative correlation between interconnected complexity and project performance. With the significant increase of interconnection complexity, the overall average performance decreased significantly. A follow-up study by the same team using cases from the UK construction industry showed a negative correlation between socio-organizational complexity and schedule performance, with an average 39% reduction in overall schedule performance over the project life cycle of the cases if the interconnected complexity was not managed [37].

As there are different classification for project complexity, some scholars have found that different complexity have different impacts on project performance. Lebcir and Choudrie [38] believe that the complexity of a project is driven by the uncertainty of the project, the novelty of the infrastructure, the interconnection of the infrastructure and the scale of the infrastructure, all of which have an impact on the time performance of the construction project. The uncertainty of the project is the most important factor affecting the project duration; Through the case analysis of large construction projects, Ma and Fu[39] found that different dimensions of project complexity portfolio have different impacts on different indicators of project performance; Qazi[5] also evaluated the effect of different dimensions of complexity on performance, studies have shown that under the condition of considering the interdependencies, technical complexity does not affect time performance indicator. Organization complexity is the main driving force of long-term interests and quality performance. Environmental complexity affects short-term performance indicators such as cost and time; Trinh and Feng found that the complexity of project technology and environment has negative influence on safety performance[40]; Luo et al[41] considered the dynamic interaction among complexity, and the analysis results showed that information complexity, goal complexity and environmental complexity were negatively correlated with project success, while technical complexity, task complexity and organizational complexity were positively correlated with project success.

After reviewing existing studies and summarizing existing research results, hypotheses are proposed as follows:

Hypothesis 1: Social complexity of construction projects has a significant negative impact on performance

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Hypothesis 2: Environmental complexity of construction projects has a significant negative impact on performance

Hypothesis 3: Technical complexity of construction projects has a significant negative impact on performance

Hypothesis 4: Stakeholder Complexity of construction project has a significant negative impact on performance

2.4 Methods

Structural equation model (SEM) is a statistical data analysis tool that integrates multiple regression analysis, path analysis and confirmatory factor analysis, which can be used to explain the relationship between one or more independent variables and one or more dependent variables [42]. This paper needs to analyse the impact of project complexity on performance. Structural equation model can help clarify the relationship between them and verify research hypotheses through a large amount of data. The specific steps are as follows: First, two measurement models of complexity and project management performance are established, and the ability of the measurement model to fit actual data is verified by confirmatory factor analysis (CFA). Then, a structural model of each latent variable is constructed to verify the causal relationship between complexity and performance.

2.5 Data Collection

This paper takes construction projects in China as the object of investigation, and the investigation mainly focuses on large construction projects under construction or completed. As this paper studies the complexity from the perspective of contractors, so the interviewees are limited to "project team members of contractors with certain work experience". In order to dig out the characteristic information of the respondents about the projects under construction or completed projects, the survey paid special attention to the following points :(1) the respondents were required to participate in or are implementing construction projects; (2) Avoid personnel without project management experience participating in the investigation; (3) Avoid the participation of newly recruited interns in the survey; (4) Avoid issuing too many questionnaires for the same project.

This investigation lasted for half a year from the design of the questionnaire to the completion of the survey. In order to ensure the quality of the survey, the survey is mainly carried out by my own classmates and graduated students working in engineering construction enterprises. Most of them are project managers, middle-level project leaders or engineers of construction projects. Due to a good trust relationship, the respondents communicated the matters needing attention well, and they forwarded the questionnaire to their subordinates, friends and colleagues to expand the scope of the questionnaire distribution as much as possible. In order to facilitate the respondents to fill in the questionnaire, the

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questionnaire was made, distributed and collected by www.wjx.cn.

According to Wu [43], if stable SEM analysis results are pursued, the number of tested samples had better be more than 200. Of course, when the sample number is too large and SEM is used to estimate parameters, the chi-square value of model fitness will be overly sensitive and easily reach a significant level ($P<0.05$), and the chance of model rejection will also increase. Therefore, Huang [44] believes that the evaluation of SEM model and the acceptance of the model should refer to the multi-dimensional index value to make a comprehensive judgment.

In order to meet the needs of CFA and SEM analysis, a total of 300 questionnaires were distributed in this study, and 273 were recovered, with a recovery rate of 91%. The returned questionnaires were numbered, and 6 questionnaires with missing options were removed: No.93, No.98, No.101, No.170, No.176, No.201, and 267 valid questionnaires were obtained. The ratio of valid questionnaires to scale items was more than 9:1, which met the needs of subsequent statistical analysis.

2.6 Variable Measurement

This paper includes 5 measurement scales, namely social complexity scale, environmental complexity scale, technological complexity scale, stakeholder complexity scale, and project management performance scale. The number of items ranges from 3 to 6 for each scale, meeting the basic requirements of measurement model, as shown in Table II. For the constructs in the model, a 5-point Likert scale (" 1 "= very inconsistent," 5 "= very consistent) was used to evaluate them.

In this paper, Cronbach's α reliability coefficient was used as the reliability test index, and CFA was used to test the construction validity. In this study, SPSS20.0 software was used for reliability analysis of the collected data, and the analysis results are shown in Table III.

TABLE II. Variable settings and variable description

Constructs	Variable	Variable Description
Social complexity	Resource availability	The project is in short supply of manpower/materials(SC_1)
	Project fund	The project is poorly funded(SC_2)
	Local government influence	The project is heavily influenced by local government(SC_3)
	Contractual relation	The fairness of the project contract is poor(SC_4)
	Legal environment	The project is subject to changes in laws and policies(SC_5)
	Project objective	The project has high construction standards or unreasonable goals(SC_6)
Environmental complexity	Geological conditions	The geological conditions of the project are complex(EC_1)
	Climate conditions	The project is located in harsh weather conditions(EC_2)
	Site compensation and Clearance	The Site compensation and Clearance progress of project is not smooth(EC_3)

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	Construction site conditions	The construction site of the project is narrow, the infrastructure is not complete or the surrounding interference is serious(EC_4)
	Market price	The price of labor/materials fluctuates greatly in this project(EC_5)
Technological complexity	Project scope	The scope of this project contract is vague(TC_1)
	Survey and design quality	The preliminary survey and design work of the project is poor in quality(TC_2)
	Technical risk	The project uses new technology or is difficult to construct(TC_3)
Stakeholder complexity	Stakeholder relationship	The relationship between project stakeholders is not harmonious(STC1)
	Stakeholder number	The number of stakeholders of the project is large(STC_2)
	professional activity dependence	The project has a strong dependency between professional activities(STC_3)
Project management performance	Time	Achievement of the project duration target(PP_1)
	Cost	Achievement of the project cost target(PP_2)
	Quality	Product quality or process quality of the project is qualified(PP_3)
	Safety	The safety objectives of the project have been well achieved(PP_4)
	Environment protection	The environmental objectives of the project have been achieved well(PP5)

TABLE III. Cronbach's α coefficient and reliability level statistics of the scale

Scale	Items	Cronbach's α	Reliability level
Social complexity	SC_1-SC_6	0.856	High
Environmental complexity	EC_1-EC_5	0.833	High
Technological complexity	TC_1-TC_3	0.777	Acceptable
Stakeholder complexity	STC_1-STC_3	0.777	Acceptable
Project management performance	PP_1-PP_5	0.879	high

As can be seen from Table III, Cronbach's α coefficients of technical complexity and social complexity scales are greater than 0.7, while Cronbach's α values of other scales are greater than 0.8, indicating that each variable has passed the reliability test and can be analyzed in the next stage.

According to the descriptive statistics of the samples, 91% of samples the project duration is more than one year, and 90.3% of samples the project scale is more than 100 million yuan. The project types mainly involve subway project, housing project, railway project and highway project, reflecting the actual situation of large construction projects in China. In addition, project managers (21.3%) and middle project leaders (44.6%) accounted for the majority of respondents, and the survey results more reflected the perception of project complexity and performance by project team members.

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III. RESULTS AND DISCUSSION

3.1 Measurement Model Analysis

By building the measurement model of project complexity and performance, we use AMOS software to fit the model, the fitting indexes and parameter estimation results of the measurement model were obtained, as shown in Table IV and Table V. The χ2/ DF of the complexity measurement model was less than 3, the GFI, IFI and CFI equivalents were all greater than 0.9, NFI was slightly less than 0.9, AGFI was greater than 0.85, and RMSEA was less than 0.08, indicating that the model fit was good and the measurement model was effective.

TABLE IV. Fitting indexes of measurement model

Models	χ2/df	RMSEA	GFI	AGFI	CFI	NFI	IFI
Project complexity	1.713	0.052	0.921	0.893	0.955	0.899	0.955
Project performance	2.024	0.062	0.991	0.955	0.996	0.992	0.996

TABLE V. Parameter estimation results of measurement model

Latent variable	Items	R	T-value	R2	CR	AVE
Social complexity	SC_1	0.837	11.851***	0.701	0.860	0.508
	SC_2	0.694	10.127***	0.482		
	SC_3	0.648	9.516***	0.420		
	SC_4	0.703	10.241***	0.494		
	SC_5	0.695	10.141***	0.483		
	SC_6	0.686	-	0.471		
Environmental complexity	EC_1	0.726	10.935***	0.527	0.834	0.503
	EC_2	0.620	9.371***	0.384		
	EC_3	0.712	10.738***	0.507		
	EC_4	0.736	11.079***	0.542		
	EC_5	0.745	-	0.554		
Technological complexity	TC_1	0.741	9.805***	0.549	0.779	0.540
	TC_2	0.750	9.860***	0.562		
	TC_3	0.713	-	0.507		
Stakeholder complexity	STC_1	0.794	9.291***	0.630	0.781	0.546
	STC_2	0.764	9.243***	0.584		
	STC_3	0.650	-	0.422		

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Project management performance	PP_1	0.625	-	0.391	0.867	0.570
	PP_2	0.713	12.867***	0.508		
	PP_3	0.921	10.531***	0.848		
	PP_4	0.779	10.182***	0.607		
	PP_5	0.704	9.434***	0.496		

As shown in Table V, the standardized load of each measurement index is above 0.5, and all the standardized coefficients reach the significant level. The reliability of the five potential variables and their combination were all over 0.6, and AVE was all greater than 0.5, indicating that the measurement of each potential variable showed good internal consistency and the reliability indexes were acceptable.

3.2 Structural Model Analysis

AMOS20.0 software is used to conduct fitting analysis on data and structural model. The results of model analysis are shown in Figure 1, and statistical indicators of fitting results are shown in Table VI.

As can be seen from Table VI, social complexity has a moderate negative impact on project management performance (standardization coefficient=-0.047) and reaches a significant level. Environmental complexity and stakeholder complexity has a negative but not significant impact on project management performance. Technical complexity has a positive impact on project management performance but does not reach a significant level.

The fit index of the model showed that $\chi 2/$ DF =1.791, less than 3. In terms of absolute fit index, GFI=0.895, close to the standard of 0.9, RMSEA=0.055, less than 0.08. In terms of relative suitability indexes, NFI=0.878, IFI=0.942, CFI=0.942 all reached or approached 0.90. Since there is no mature scale for the study of construction project complexity in China, this study is a pioneering one, and most of the measurement scales used are self-designed by literature analysis and theory. Therefore, according to the above situation, it can be considered that the fitting indexes of the theoretical model meet the requirements as a whole.

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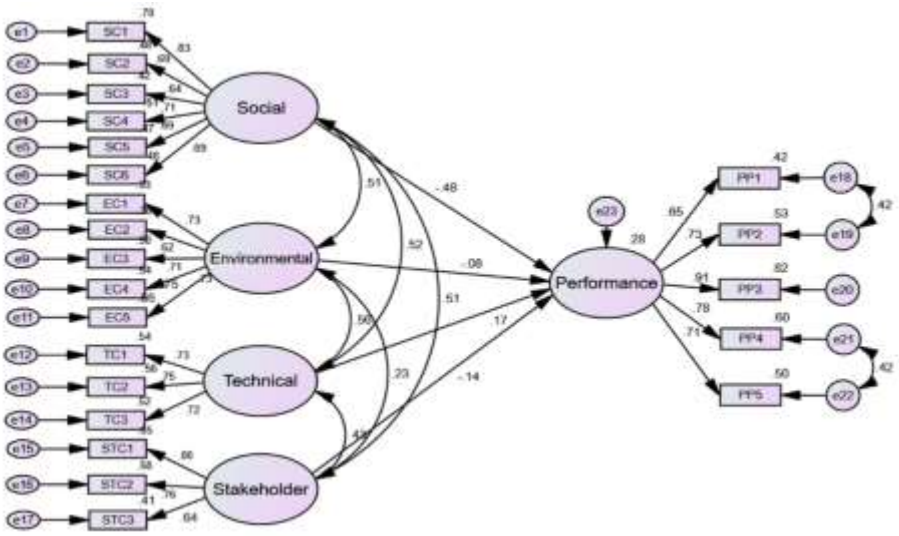

Fig 1: Fitting results of complexity - performance structure model

TABLE VI. Statistical values of fitting results of complexity - performance structure model

Relationship between variables	Nonstandardized path coefficient	S.E.	C.R.	Standardized path coefficient	P
Social complexity-Performance	-0.478	0.104	-4.607	-0.477	***
Environmental complexity-Performance	-0.078	0.085	-0.921	-0.083	0.357
Technical complexity-Performance	0.183	0.106	1.732	0.170	0.083
Stakeholder complexity-Performance	-0.143	0.087	-1.636	-0.140	0.102
Fitting index	$\chi 2/df$=1.791，RMSEA=0.055，GFI=0.895，AGFI=0.865，CFI=0.942，NFI=0.878，IFI=0.942				

3.3 Discussion

Structural equation model analysis results shows that different impact on the performance by different dimensions of complexity, and only research hypothesis H2 was verified. This conclusion confirms the view of many scholars [24, 39, 41].

Research finds that social complexity has a moderate and significant negative impact on performance,

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which is basically consistent with the views of Antoniadis et al [36], Muller et al [45]. That is, the interaction between projects, industries, governments and other social levels will increase complexity. If such complexity cannot be well managed, it may lead to decreased performance or unsuccessful projects; In addition to this, environmental complexity affects short-term performance indicators such as cost and time [5], and environmental complexity is negatively correlated with project success [41], which is consistent with the findings in part of this paper. Project complexity is largely affected by the environment, and it is generally accepted that environmental complexity will affect performance.

There are no consistent conclusions about the relationship between technical complexity and performance. This paper found that the technical complexity have a positive influence on performance but not significant, this view supported by Luo et al [41] and other research, they found that the technical complexity positively related to the project success. To take high and new technology, while facing a certain amount of technical risk, but new technology adopted will have positive influence on project performance and long-term success. It does not necessarily result in cost overruns or construction delays. Of course, in the field of R&D projects, some scholars have found that technological complexity and novelty have a negative impact on product cost and schedule performance [34,35], as the research object of this paper is construction project, different from the R&D product field above, the impact of technical complexity on performance needs to be verified by more results.

This paper finds that stakeholders' factors have a negative but not significant impact on project performance. No similar empirical research results have been found to support it yet. Based the construction project environment in China, although the infrastructure construction will be influenced by stakeholders, but in recent years, the better legal environment, the construction of harmonious society, the prohibition of forced demolition and other beneficial factors have formed a good atmosphere for stakeholders to support the construction projects, partly explains the rationality of the research results.

IV. CONCLUSION

Based on the survey data and SEM analysis, the results show that different dimensions of complexity have different impacts on project management performance. Social complexity has a significant negative impact on project management performance, environmental complexity and stakeholder complexity have a negative but not significant impact on project management performance, and technological complexity has a positive but not significant impact on project management performance. Contractors in China shall pay more attention to social and organizational interaction aspects, such as construction funds and resources, influence of local government, contract relations, law and regulations change, strengthen the communication with investors and local governments.

The thesis still has the following deficiencies: Sample selection does not belong to random sample in strict sense, and the data obtained are static interfacial data, which cannot reflect the dynamic changes of project complexity; In addition to the concept of project complexity, the complexity scale from the perspective of contractor only reflects the description and measurement of project complexity in the

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contractor planning stage, which is not applicable to other research perspectives and research purposes, and thorough investigation and inspection are still needed in the follow-up.

It is suggested to further improve the understanding of perceptual complexity from the perspective of contractors, to summarize the dynamic changes of complexity factors of construction projects in the whole-life stage, and continue to explore the impact of different complexity and specific performance indicators (e.g., cost, schedule, safety).

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