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# Influence of Integrated Project Delivery Principles on Project Performance in China: An SEM-Based Approach

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**Abstract:** Although integrated project delivery (IPD) is still in its infancy in the construction industry worldwide, some principles can be effective without formal contractual languages and enforcements when IPD is employed as a philosophy as opposed to a delivery method. This paper aims to investigate the effect of IPD principles on project performance in China, providing a reference for improvement of project performance by the application of IPD principles in countries or regions where IPD is considered as a philosophy. A total of 205 data samples were collected from different IPD-related participants in China via a questionnaire survey. Eight hypotheses are proposed based on a literature review, and these are verified using a structural equation model (SEM). According to the results of the exploratory factor analysis, IPD principles, including behavioral principles, contractual principles, collaboration-related principles, and catalysts, are classified, and the internal relationship of various IPD principles is explored using SEM to analyze the impact path between IPD principles and project performance. It was discovered that project performance is directly affected by collaboration-related principles and catalysts. The contractual principles have positive impacts on both behavioral principles and collaboration-related principles, while the catalysts show positive impacts on behavioral principles. This work provides insights and managerial implications for local applications of IPD for construction practitioners, which should be considered by promoting regional IPD practices; it contributes to both theoretical and practical perspectives for improving project performance by the effective implementation of IPD in construction projects.

**Keywords:** integrated project delivery (IPD); project management; project performance; structural equation model (SEM)

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## 1. Introduction

A construction project is implemented by a number of participants throughout various stages. The project performance greatly depends on the participants' collaboration. However, due to the scattered and isolated nature of the architectural/engineering/construction (AEC) industry, participants often have poor collaboration awareness in many projects, causing misunderstandings, redundant work, and disputes that may detract from the overall project performances. Integrated project delivery (IPD), which is known for supporting efficient collaboration, is considered a promising project implementation and delivery mode in the AEC industry [1–6]. In most of the published IPD case studies, the projects were completed on time and under budget. Existing literature normally verifies that IPD implementation in construction projects has several advantages, such as the enhancement of team performance [7] and project outcomes [8–10]. Therefore, some research has shown that IPD projects are conducted with better performance than non-IPD projects [1,11–15]. However, in practice, it is difficult to apply pure IPD to most projects due to technical, managerial, and legislative limitations [16]. Given this fact, this paper focuses on those construction projects that utilize IPD as a philosophy rather a delivery mode. IPD is still in the test stage in the construction sectors of China. Although there has been a huge interest in IPD principles, the employment of some IPD principles is currently blocked in China's construction industry [17–19]. The reasons are as follow: (1) Due to the absence of a systematic understanding and widespread popularization of the concept, practitioners in China who use some IPD principles in traditional construction models do not understand that they belong to the category of IPD. (2) Some IPD principles, such as multiparty agreement, shared financial risk and reward based on project outcome, fiscal transparency between key participants, etc., are not yet able to be implemented because of the current state of the construction industry in China, including its business characteristics and bidding mechanism. Thus, according to the IPD categorization method presented by Boodai [1] and the current state of China's construction industry, IPD is more suitable for China as a philosophy than as a practice.

Most researchers insisted that it is much easier to incorporate the philosophy of IPD, namely some IPD principles, rather than the practice of IPD, into construction projects to improve their performance. For instance, contract provisions and project procedures can be modified to encourage the early involvement and collaboration of the project team [20,21]. Some customized contract forms and terms other than an IPD multiparty contract can effectively handle the defects in scheduling performance [11,15]. Projects using IPD (or using a large number of IPD principles) show better performance with respect to the change, business, and communication performance areas [8]. By embedding IPD principles into the DBB delivery method, the implementation of IPD principles can improve the performance of case study projects by 1.3 times [22]. As non-pure IPD projects make up the majority of all the global construction projects, such improvement is significant to the AEC industry. The aforementioned research is of great significance in exploiting the value of IPD in project performance. Nonetheless, there are some limitations yet to be solved. The current literature focuses on construction projects with relatively mature IPD contracts, but this kind of project makes up a minority of construction projects, and IPD is not likely to be widely implemented in the AEC industry in the near future. Introducing IPD principles into construction projects may provide some potential benefits of IPD; however, extant scholarship in general is not concerned with how to address these IPD principles in certain IPD projects [23]. It stands to reason that there is a research gap on the mechanism of how IPD principles influence project performance. Moreover, executable instructions for how to apply the IPD principles are not available, which can lead to the misuse of the principles and weaken the improvement of the project performance.

This study provides a detailed and systematic analysis of the influence of IPD principles on project performance in China. The influence of IPD principles on project performance is first analyzed via a questionnaire survey conducted in China, where a large number of construction projects are taking place. Based upon exploratory factor analysis (EFA), the classifications of IPD principles in China are then determined. This paper then proposes theoretical hypotheses by building a structural equation model (SEM) to discover the influence mechanism of IPD principles on project performance, as well as to examine the interactions of the principles. Based on the mechanism of how IPD principles affect project performance discovered via SEM, the last section of this paper offers some suggestions for the application of IPD principles to construction projects. The results of this paper contribute to both academic work and practice. At a scholarly level, this study broadens the breadth and depth of IPD related research, further supplementing the fundamental knowledge included in project delivery system research, and at a practical level, this paper provides insights and managerial implications for construction practitioners for the local application of IPD, which should be incorporated to promote the regional practice of IPD principles in order to improve project performance.

## 2. Research Design and Methodology

### 2.1. Research Design

The research design mainly employs the test methods of the measurement model and the theoretical hypotheses, where the former includes a reliability test and a validity test, and the latter consists of structural equation models and a discussion of hypothesis testing. Having collected data through the use of a questionnaire survey, this paper zeros in on the impact of IPD principles on project performance via establishing a SEM. As shown in Figure 1, LISREL software is used for confirmatory factor analysis (CFA) and structural equation modeling, while the rest of the data analysis is conducted using SPSS software. The validity test is used to indicate the validity of the collected data, including content validity, criterion validity, and construct validity. Since content validity and criterion validity are generally confirmed using literature analysis and the interview method, the measurement tools are verified by using similar methods multiple times [24]. By taking a closer look at the existing literature, it can be found that CFA has become a dominant paradigm for testing the construction validity, and the fitting index includes $\chi^2$/df, RMSEA, NNFI, CFI, etc. In order to determine whether to conduct a factor analysis, the sample data must be conditionally tested with the help of factor analysis before constructing a validity test. Generally, the basis for judging whether the sample data can be subjected to factor analysis depends on the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test.

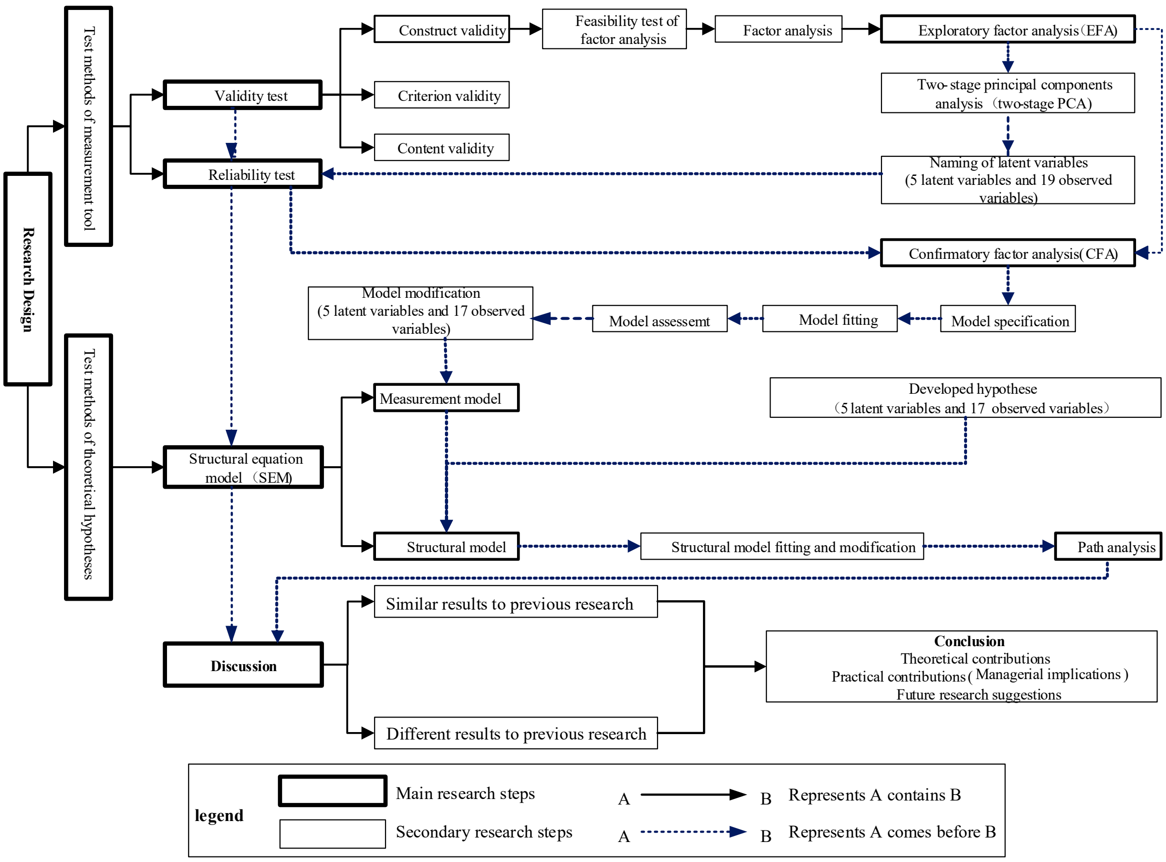



**Figure 1.** Research design.

This paper adopts SEM to validate the theoretical hypotheses, including the measurement model and the structural model. SEM analyzes the hypothesized relationship between latent variables and their observed variables with the measurement model, and it links the independent and dependent latent variables with a structural model [25]. The latent variables are renamed after the EFA and before the CFA, while the hypotheses are added after the establishment of the measurement model and before the establishment of the structural model. Both the measurement and the structural model are established and modified several times according to the fit indices to obtain the best fitting model. The path analysis in the best SEM model is used to test the statistical significance of the effect of the explanatory variables on the independent variables. Next, the paper conducts the comparative analysis between the hypothesis-testing results and the results of previous research, obtaining several managerial implications. Using such a comparative approach, this paper can best showcase the theoretical contributions and shed light on further research.

### *2.2. Questionnaire Design*

#### 2.2.1. Observed Variables

No matter how IPD principles are classified, the core is collaboration. According to the degrees of collaboration (as shown in Table 1), this paper used 15 IPD principles adapted from NASFA et al. [26]. Although the studies differed by target project type, data set characteristics, or performance metrics, most findings have shown that IPD is conducive to improving project performance [27,28]. Apart from the three main traditional project performance indicators—cost, schedule, and quality—this paper also takes the request for information as the indicator of communication performance. To measure the project performance, this paper presents construction cost ($CC_1$), schedule cost (SC), quality cost (QC), and communication cost ($CC_2$) as the key performance indicators.

**Table 1.** Summary of factors and observed variables.

| Factors | Observed Variable | Item/Indicator | References |
|---|---|---|---|
| IPD principles | x1 | KPBTE: key participants bound together as equals | [6,26] |
| | x2 | LWKP: liability waivers between key participants | |
| | x3 | EIKP: early involvement of key participants | |
| | x4 | FT: fiscal transparency between key participants | |
| | x5 | JDPTC: jointly developed project target criteria | |
| | x6 | SRR: shared financial risk and reward based on project outcome | |
| | x7 | ID: intensified design | |
| | x8 | CDM: collaborative decision making | |
| | x9 | MRT: mutual respect and trust | |
| | x10 | WTC: willingness to collaborate | |
| | x11 | OC: open communication | |
| | x12 | MA: multiparty agreement | |
| | x13 | BIM: building information modeling | |
| | x14 | LC: lean design and construction | |
| | x15 | CT: colocation of team | |
| project performance | x16 | $CC_1$: projects can be completed at agreed costs or at less cost. | [29] |
| | x17 | SC: the project has not incurred additional costs by taking appropriate measures to achieve the contract goal as scheduled. | [30] |
| | x18 | QC: all necessary expenses and economic losses incurred by the failure to meet quality standards. | [30] |
| | x19 | $CC_2$: the project has not incurred additional costs due to the rate of requests for information(RFI). | [11] |

#### 2.2.2. Questionnaire Design

These issues related to this questionnaire include: What is the type and nature of your company? How many years have you worked in project management (less than 3 years; 3~5 years; 6~9 years; 10~15 years; more than 15)? How many years has your company used BIM technology (never; less than 3 years; 3~5 years; more than 5)? How familiar are you with IPD and LC (those who are experienced with IPD or LC; those who are inexperienced, though informed about IPD or LC; and those that are inexperienced and unfamiliar with IPD or LC)? Based on your experience in project management, which option do you think is most in accordance with the actual situation of most project implementation (more inconsistent, slightly inconsistent, uncertain, slightly consistent, more consistent)? The matrix questionnaire was designed with 5 options as the horizontal axis, and the above 19 observed variables as the longitudinal axis. Using the 5-point Likert scale, the questionnaires were issued through email, WeChat (a popular social media platform for free messaging and calling), and an online questionnaire platform (https://www.wjx.cn/jq/7855429.aspx (accessed on 31 October 2021)) (Supplementary Materials). Through joining a forum (the second peak forum of wisdom construction in China) and searching the related literature, the contact information of experts and practitioners was obtained. Then, invitations to complete the questionnaires were sent by email and WeChat.

### *2.3. Data Collection*

The questionnaires were further screened according to their completeness and the relevance of the information. Ultimately, 225 questionnaires were sent out, of which 205 viable questionnaires were returned, which is a 91.1% retrieval rate. After screening, 205 sets of data were obtained. Boomsma [31] suggested that the sample size should be at least greater than 100, but greater than 200 is better. The correlation matrix is not stable when the sample size is less than 100, as that would reduce the reliability of the SEM results. Loehlin [32] and Jietai et al. [33] proposed a similar idea in their studies. In light of this, the sample size in this paper meets the recommended requirements.

Among the 205 respondents, 42% came from state-owned enterprises, 36% from private enterprises, 8% from public institutions, and less than 5% from other units. The background of the respondents spanned seven types of companies (departments of trade and industry associations, universities or research institutes, owners, design institutes, construction units, supervisor department, consulting units, and other), with proportions of 1%, 9.8%, 8.8%, 25.4%, 34.6%, 0%, and 13.7%, respectively. The respondents from design institutes, construction units, and consulting units were more interested in IPD. It is worth noting, however, that the enthusiasm of owners who would benefit the most from IPD was lower than that of the staff of universities or research institutes. Interestingly, IPD had not yet attracted the attention of the supervising departments. A total of 38.05% of the respondents have been engaged in project management for more than 5 years, including timeframes of 6~9 years (18.54%), 10~15 years (8.29%), and more than 15 years (11.22%). A total of 70.3% of the respondents have used BIM, for timeframes including less than 3 years (40%), 3~5 years (24.4%), and more than 5 years (5.9%), demonstrating that BIM is gradually becoming popular in China, although most users have employed it for less than 3 years. The proportion of respondents who are inexperienced with LC, inexperienced but informed about LC, and experienced with LC was 53.2%, 39.5%, and 7.3%, respectively, proving that the LC method is used less often than BIM technology in China. The statistical absolute values of skewness and kurtosis were respectively less than or equal to 3, and not greater than or equal 10, demonstrating that the sample data satisfied the condition of normal distribution.

## 3. Results

### *3.1. Validity Test*

#### 3.1.1. Feasibility Test of Factor Analysis

The data set was checked for the feasibility of factor analysis via the KMO measure of sampling adequacy and Bartlett's test of sphericity. Date is not suitable for factor analysis when the value of KMO < 0.5 [34]. The Bartlett's test of sphericity was significant, indicating that there is a strong correlation between variables [35]. The values of KMO were well above the minimally accepted level of 0.50, and the Bartlett's test of sphericity indicated that the variables are interdependent (KMO = 0.939, Sig. = 0.000). All of results attest to the suitability of the data set for factor analysis.

#### 3.1.2. Exploratory Factor Analysis

Based on the idea of "dimension reduction" in principal component analysis (PCA), an EFA will eliminate the correlation between variables. Taking the characteristic value of greater than 1 and the factor load of greater than 0.5 as criteria, the method of varimax rotation was used for the orthogonal transformation of the initial factor loading matrix to explain the latent variables.

To further unfold the relationship between the observed variables, the method of two-stage PCA was used in this paper. In the first PCA, the principal component eigenvalues of the three principal components were 9.160, 1.313, and 1.134, respectively, and the final cumulative variance contribution rate was 61.087%. Based on a factor load of greater than 0.5, three principal component factors were extracted in the second PCA. In the second PCA, the principal component eigenvalues of the three principal components were 6.317, 0.823, and 0.658, respectively, and the final cumulative variance contribution rate was 70.883%. As shown in Table 2, the results of EFA based on PCA show that 19 observed variables needed to be explained by 5 latent variables.

**Table 2.** Rotated component matrix of PCA.

| PCA | Observed Variable | Component | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| The first PCA | x1 | **0.760** | 0.184 | 0.168 |
| | x2 | **0.803** | 0.178 | 0.227 |
| | x3 | **0.656** | 0.272 | 0.209 |
| | x4 | **0.829** | 0.236 | 0.156 |
| | x5 | **0.496** | 0.322 | 0.400 |
| | x6 | **0.695** | 0.156 | 0.366 |
| | x7 | **0.515** | 0.469 | 0.276 |
| | x8 | **0.452** | 0.425 | 0.342 |
| | x9 | **0.632** | 0.368 | 0.214 |
| | x10 | **0.568** | 0.481 | 0.175 |
| | x11 | **0.558** | 0.421 | 0.263 |
| | x12 | 0.212 | **0.684** | 0.235 |
| | x13 | 0.196 | **0.803** | 0.097 |
| | x14 | 0.365 | **0.707** | 0.174 |
| | x15 | 0.168 | **0.604** | 0.256 |
| | x16 | 0.280 | 0.320 | **0.676** |
| | x17 | 0.126 | 0.307 | **0.797** |
| | x18 | 0.236 | 0.338 | **0.676** |
| | x19 | 0.404 | −0.054 | **0.652** |
| The second PCA | **x1** | **0.801** | 0.277 | 0.152 |
| | **x2** | **0.775** | 0.287 | 0.295 |
| | **x3** | 0.347 | 0.336 | **0.670** |
| | **x4** | **0.658** | 0.362 | 0.422 |
| | **x5** | 0.292 | 0.196 | **0.851** |
| | **x6** | **0.691** | 0.267 | 0.348 |
| | **x7** | **0.594** | 0.396 | 0.221 |
| | **x8** | 0.203 | **0.640** | 0.400 |
| | **x9** | 0.367 | **0.746** | 0.184 |
| | **x10** | 0.335 | **0.803** | 0.111 |
| | **x11** | 0.271 | **0.726** | 0.280 |

Note: Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in six iterations.

Referring to the classifications from NASFA et al. [26] and AIA [36], the latent variables in this study were slightly modified based on the results of the two-stage PCA, considering the applicability and feasibility of these principles in China. Hence, the five latent variables were renamed project performance, contractual principles, collaboration-related principles, behavioral principles, and catalysts. The contractual principles may be written into agreements. The behavioral principles are necessary for project optimization, but are ultimately choice-based. The catalysts can be greatly beneficial for optimizing project results. The collaboration-related principles can be implemented, to a large extent, if all parties agree to collaborate. Compared with the categories from NASFA et al. [26] and

AIA [36], some contractual elements are subdivided into collaboration-related principles. Collaborative decision making is added to the behavioral principles.

3.1.3. Confirmatory Factor Analysis

A measurement model will be established by a CFA, assessing how well the observed variables will reflect the latent variables they are intended to measure. Based on multiple iterations and through the elimination of the observed variables with loadings (standard coefficient) on the latent variable of less than 0.6, this paper obtains a set of modified measurement models ($\chi^2$/df = 1.917, RMSEA = 0.067, NNFI = 0.980, CFI = 0.980) that have achieved the threshold value of each fit index suggested in the research methodology (shown in Table 3). However, the two observed variables of "communication cost" and "colocation of team" were deleted in the modified measurement model. Therefore, the measurement model of SEM included 5 latent variables and 17 observation variables.

**Table 3.** Fit indices of modified structural model.

| Index | Acceptable Values | References | MA-7 Model |
|---|---|---|---|
| $\chi^2$ | | | 211.592 |
| $\chi^2$/df | <3 | [37] | 1.889 |
| GFI | ≥0.90 | [38] | 0.891 |
| AGFI | ≥0.80 | [39,40] | 0.851 |
| RMSEA | <0.08 | [33,38] | 0.0660 |
| NFI | ≥0.90 | [38] | 0.967 |
| NNFI | ≥0.90 | [33,41] | 0.981 |
| CFI | ≥0.90 | [33,42] | 0.984 |

Note: $\chi^2$ = chi-square; GFI = goodness of fit index; AGFI = adjust goodness of fit index; RMSEA = root mean square error of approximation; NFI = normed fit index; NNFI = non-normed fit index; CFI = comparative fit index.

### *3.2. Reliability Test*

A reliability test is necessary, as it checks the internal consistency and stability of the statistical scale and describes the standard degree of the measurement tool. The value of Cronbach's alpha is directly proportional to the reliability of the statistical scale, especially when alpha > 0.7, which indicates that the reliability is high [43]. The results of the reliability test showed that alpha > 0.7 (contractual principles: 0.885; collaboration-related principles: 0.733; behavioral principles: 0.832; catalysts: 0.79; project performance: 0.799; general alpha value: 0.939), indicating good reliability.

### *3.3. Developed Hypotheses based on Literature Review*

**Hypothesis 1 (H1).** *Behavioral principles have a positive impact on project performance.*

The behavioral principles included collaborative decision making (CDM), mutual respect and trust (MRT), open communication (OC), and willingness to collaborate (WTC). IPD emphasizes mutual respect and effective communication for the implementation of a project [44]. If the participants are not in an environment of MRT, the participants will give up behaviors that are "most beneficial to the overall project performance" [26]. Collaborative decision making significantly reduced the cost of field rework, while implementation of open communication was found to have a significant effect on reducing project cost overrun [21]. MRT can improve project performance in the construction process [2]. Driven by the owner, the participants can stimulate innovation by open communication so that decisions will be made jointly and will be as practical as possible [45]. It is essential to nurture an environment that supports and encourages participants to choose to collaborate. Collaboration also needs to be based on open, direct, and sincere communication. OC requires mutual trust, but mutual trust cannot replace OC. Project performance can be attributed to the owner's choice of a project delivery strategy, the depth of team integration, the extent of team cohesion, etc. Team integration is measured by the high-quality interaction of team members based on MRT, WTC, and CDM [46,47]. Team cohesion is improved by OC and commitment to project goals (Franz, 2014). Higher team integration can improve team cohesion on construction projects and can also have a positive impact on project performance [48].

**Hypothesis 2 (H2).** *Contractual principles have a positive impact on behavioral principles.*

The contractual principles include key participants bound together as equals (KPBTE), shared financial risk and reward based on project outcome (SRR), intensified design (ID), liability waivers between key participants (LWKP), and fiscal transparency between key participants (FT). A contractually defined relationship in which all parties are equals supports collaboration and consensus-based decisions [26]. First, the team members clearly define roles and contractual relationships as equals by open communication, and define shared financial risk and reward based on project outcome, to support collaboration and consensus-based decisions. Second, the predefined incentive compensation structure of IPD projects will encourage an increase in the early involvement of the participants. The improvement of project outcomes is attributed to SRR, KPBTE, and improved team collaboration [49,50]. Third, ID improves the design quality, and reduces and simplifies the more expensive construction work [6], which can be regarded as the basis of collaborative decision making. Fourth, by forming a common culture of liability waivers, team members will share a collective commitment to and understanding of the project objectives, develop mutual respect and trust, and interact with an improved flow of communication. Last but not the least, in an environment of mutual trust and respect, FT contains the visible and controllable contingency costs, contributing to shared financial risk and reward.

**Hypothesis 3 (H3).** *Contractual principles have a positive impact on project performance.*

From the perspective of contractual and relational management, relevant studies indirectly demonstrate that contractual and behavioral principles impact project performance. The improvement of the relationship between project parties, such as joint target and teamwork, shared financial risk and reward, mutual respect, liability waivers, open communication, project solving, risk allocation, performance measurement, and continuous improvement, can reduce the occurrence of poor performance [2]. Contractual and relational management is indispensable to improving construction project performance in China [51]. Contractual management is more effective in the improvement of project performance, while relational management indirectly impacts project performance by means of intermediary variables [52]. The effect of relational attitudes and teamwork quality on project performance has been confirmed by empirical research, in which relational attitudes indirectly affect project performance via teamwork quality [53]. MRT, SRR, OC, LWKP, and FT, etc. are the basic elements of relational attitudes, while communication, coordination, joint efforts, mutual support, cohesion, and affective trust affect teamwork quality (Pinto et al., 2009). Better project performance depends on relational attitudes and teamwork quality [54].

**Hypothesis 4 (H4).** *Collaboration-related principles have a positive impact on project performance.*

Jointly developed project target criteria (JDPTC) and early involvement of key participants (EIKP) are collaboration-related principles. Unlike the pursuit of self-interest in traditional practice, JDPTC links the respective commitment of goals or objects from different participants [55], and it pays more attention to the overall success of the project. The best value and mutual benefit can only be achieved by participants' joint commitment. Early integration emphasizes the integrating of resources, efforts, information, and experiences among participants as quickly as possible at the beginning of a construction project [1,56]. That is also why many scholars agree that integration requires active participation in the early stages of a construction project [57,58]. In the case of collaboration, trust, and early involvement, the construction performance in terms of cost, time, efficiency, and productivity will be improved [59].

**Hypothesis 5 (H5).** *Contractual principles have a positive impact on collaboration-related principles.*

When the work scope and responsibility have an explicit definition by contract, an IPD project will be more reliable and clearer, prompting potential participants to jointly develop project target criteria [60,61]. According to the definition, contractors can expect the risk they normally bear to be shared, and other project participants can easily access advanced technologies, information, and other benefits through active involvement. The realization of contractual principles lays the foundation for early involvement and jointly developed project target criteria by the key participants.

**Hypothesis 6 (H6).** *Behavioral principles have a positive effect on collaboration-related principles.*

The most influential drivers of project delivery performance are communication, alignment of interest and objectives, teamwork, and trust, etc. [62]. The collaborative climate based on trust and commitment to project goals better facilitates project performance in terms of decreased cost overruns, time performance, quality, and customer satisfaction. IPD is conducive to overcoming barriers to collaboration by encouraging a willingness to collaborate, open communication, and collaborative decision making; these factors improve the early involvement of the key participants and enhance the level of trust among key stakeholders, helping to eliminate barriers to the implementation of BIM [59].

**Hypothesis 7 (H7).** *Catalysts have a positive impact on project performance.*

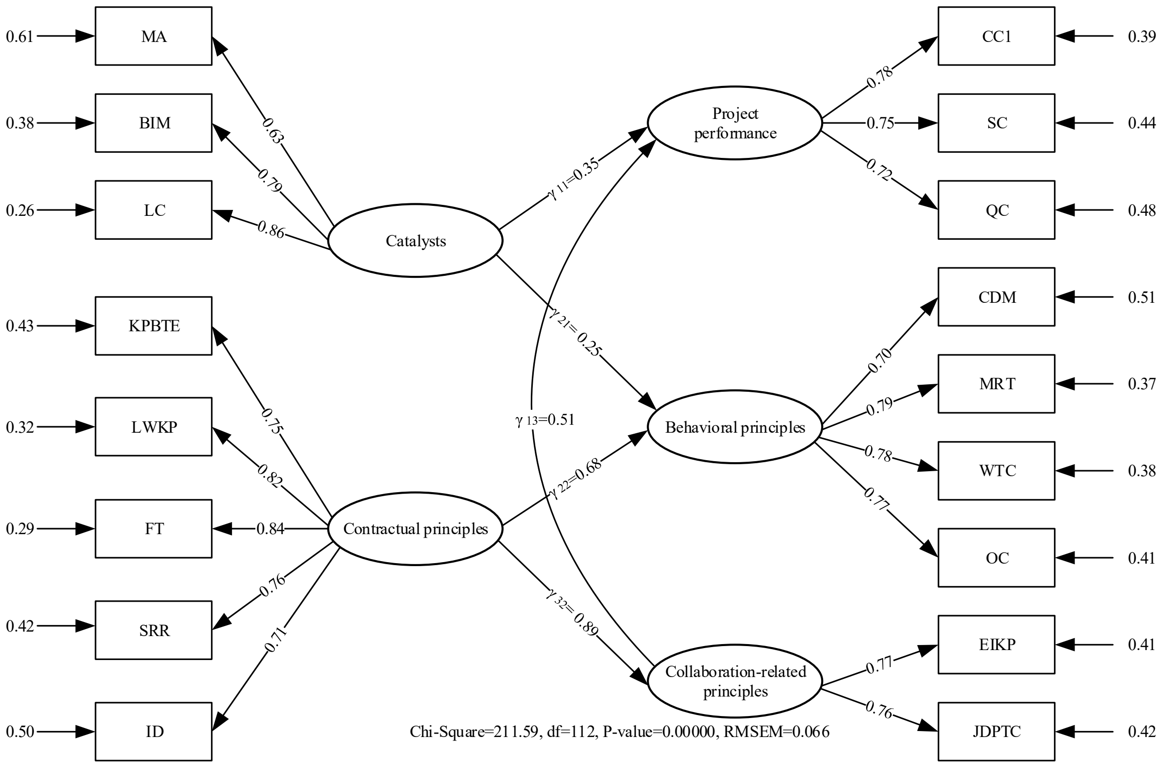
The category of catalysts includes multiparty agreements (MA), BIM, and LC. No matter what form of multiparty IPD agreement is chosen, it can support the application of IPD principles among all key project participants [26,62]. Since compensation is determined by the contributions of the participants, the success of MA depends on the collaborative work of participants who are committed to realizing team goals [6]. The close integration of MA project-based collaborative decision making and an incentive-compensation structure will improve project performance. Compared with traditional delivery projects, some case studies manifest that the integrated application of BIM and IPD widely recognized by practitioners has more potential to increase labor productivity, support the design of energy efficient buildings, obtain reliable and accurate cost estimates and budgets, save costs, improve build quality, shorten construction schedules, reduce coordination change orders and construction RFIs, and optimize facility management and maintenance [63–67]. Moreover, LC offers some innovations for project operating systems that reduce waste, shorten schedules, and increase labor productivity and project quality, resulting in many IPD projects accepting and implementing LC [68]. In addition to improving the overall efficiency of the IPD process and building a higher level of trust among stakeholders, stakeholders strongly believe that the lean IPD project delivery process is superior to the non-lean IPD project delivery process in terms of scheduling, costs, quality, and safety [26,45]. BIM application will intensively facilitate lean principles to expand project performance [69]. IPD, LC, and BIM had considerable effectiveness in terms of schedule performance and the combination of the cost performance index and the schedule performance index [70].

**Hypothesis 8 (H8).** *Catalysts have a significant positive impact on behavioral principles.*

With an integrated multiparty agreement among project team members, relationships become more reliable, cooperative, trusting, and respectful [8,11]. Even without a multiparty agreement, there is evidence that performing construction in a highly integrated environment promotes the achievement of superior project outcomes. Using different management tools represented by BIM, IPD can integrate different types of information, work processes, and activities into a single project boundary [44], supporting open communication and collaborative decision making. The lean mindset and a way of thinking that helps to promote behaviors that inherently improve project efficiency and collaboration.

### 3.4. Structural Model

The state of structural model fitting is judged by the fit indices; factors involved include $\chi^2/\mathrm{df}$, RMSEA, NNFI, CFI, GFI (goodness of fit index), AGFI (goodness of fit index), and NFI (normed fit index). Through the process of multiple structural model fittings and modifications, the best-fitting model $M_{A\text{-}7}$ is obtained and is shown in Figure 2. As shown in Table 3, the fit indices of $M_{A\text{-}7}$ meet the acceptable level. Consistent with hypotheses $H_2$, $H_4$, $H_5$, $H_7$, and $H_8$, the results indicate that all proposed path coefficients among the latent variables are statistically significant.




Note: $\gamma_{rc}$-the path coefficient; r-the result variable, when r=1,2,3, it shows respectively the project performance, behavioral principles and obligation principles; c-the causal variable, when c=1,2,3, it demotes respectively the optimization principle, liability principles and obligation principles.

MA: multiparty agreement; BIM: building information modeling; KPBTE: key participants bound together as equals; LWKP: liability waivers between key participants waivers; FT: fiscal transparency between key participants; ID: intensified design; SRR: shared financial risk and reward based on project outcome; CDM: collaborative decision-making; MRT: mutual respect and trust; WTC: willingness to collaborate; OC: open communication; EIKP: early involvement of key participants; JDPTC: jointly developed project target criteria; LC: lean design and construction; CC1: projects can be completed at agreed costs or at less cost; QC: all necessary expenses and economic losses incurred in failure to meet quality standards; SC: the project has not incurred all costs of taking appropriate measures to achieve the contract goal of schedule;

**Figure 2.** Best-fitting model M.

### 3.5. Path Analysis

This paper further analyzes the internal-influence relationship between IPD principles and project performance via path analysis (error term of collaboration-related principles: 0.21; error term of behavioral principles: 0.23; error term of project performance: 0.39; correlation coefficients of catalysts and contractual principles: 0.7; correlation coefficients of project performance and behavioral principles: 0.09). Let

$$\text{project performance} = f(CC1,SC,QC) \tag{1}$$

$$\text{Catalysts} = f(MA,BIM,LC) \tag{2}$$

$$\text{contractual principles} = f(KPBTE,LWKP,FT,SRR,ID) \tag{3}$$

$$\text{collaboration-related principles} = \text{f(EIKP,JFPTC)} \tag{4}$$

$$\text{behavioral principles} = \text{f(CDM, MRT, OC,WTC)} \tag{5}$$

It can be seen from the results of path analysis that:

$$\text{collaboration-related principles} = 0.89 \times \text{contractual principles} + 0.21 \tag{6}$$

$$\text{behavioral principles} = 0.25 \times \text{catalysts} + 0.68 \times \text{contractual principles} + 0.23 \tag{7}$$

$$\text{project performance} = 0.35 \times \text{catalysts} + 0.51 \times \text{collaboration-related principles} + 0.39 \tag{8}$$

Through the iteration of the Formulas (1)–(7), the project performance in Formula (8) can be expressed by the following equation:

$$\text{f(CC1,SC,QC)} = 0.35\ \text{f(MA,BIM,LC)} + 0.45\ \text{f(KPBTE,LWKP,FT,SRR,ID)} + 0.5 \tag{9}$$

## 4. Discussion

### *4.1. Similar Results to Previous Research*

The result of $H_2$ hypothesis testing indicates that contractual principles have a positive effect on behavioral principles, which is similar to the conclusions of other scholars [26,49,50,56]. By and large, contractual principles can be directly written into contracts or agreements. Expectations for collaborative behavior is set by contracts and realized when project participants negotiate to develop practices [71]. Due to the conversion into specific contract terms, there will be potential connections between contractual principles and behavior principles.

The result of $H_4$ hypothesis testing clearly reveals that collaboration-related principles have a significant positive impact on project performance. This result verifies hypothesis $H_4$ and is in line with the conclusions of other scholars [1,56,58,59]. Mutual commitments related to project performance are more likely to be met when the participants work closely with each other in the early stages of the project.

The result of $H_5$ indicates that contractual principles have a positive effect on collaboration-related principles. Hypothesis H5 is demonstrated to be true, supporting the ideas of El Asmar [60] and Teng et al. [72]. IPD places particular emphasis on the early involvement of participants, compliance with multiparty agreements, and shared financial risk and reward based on the project outcome.

The result of $H_7$ hypothesis testing makes plain that catalysts have a positive impact on project performance. The result verifies hypothesis $H_7$ and is consistent with the conclusions of other scholars [6,26,63,70]. There are four critical success factors required to implement IPD, including reform of contract law and adoption of appropriate IPD agreement forms, team building and management of the collaborative business process, early involvement and the enhanced role of key participants, and the improvement and utilization of BIM for the collaborative process of IPD [44]. The catalysts category ties the benefits of key participants and the overall project goal together via a multiparty agreement and uses BIM and LC technology as much as possible to improve the project's performance.

The result of $H_8$ indicates that catalysts have a significant positive impact on behavioral principles. The result shows that hypothesis $H_8$ is reliable, which supports the conclusions of other scholars [8,11,44,73]. There is a significant correlation between the catalysts and contractual principles (correlation coefficient: 0.7), indicating that they are interdependent. Contractual principles have a positive impact on behavioral principles. It can be seen indirectly that catalysts are related to behavioral principles. Apart from a few scattered scholarly accounts, there are no other writings that focus solely on the behaviors of participants based on catalysts. Alternatively put, such study remains terra incognita in academia.

### *4.2. Different Results to Previous Research*

The results of hypotheses testing for $H_1$, $H_3$, and $H_6$ are different from previous research, indicating that not all IPD principles will result in the improvement of project performance. The result of $H_1$ hypothesis testing demonstrates that behavioral principles have no positive impact on project performance. This result presents a clear inconsistency with the results of previous studies, namely, that mutual respect and trust, willingness to collaborate, open communication, and collaborative decision making will result in better project outcomes by generating more integrated and cohesive teams [1,2,47,56,74]. It can be argued that these inconsistent results may be due to several factors: First, mutual respect and trust, and open communication and willingness to collaborate, are necessary conditions for creating a collaborative management environment. At present, collaborative management in China exists only in theory (theoretical research). It may be difficult for the main participants driven by the pursuit of their own interests to reach a consensus of willingness to collaborate without a multiparty contract in China. Second, the information platform for construction projects is very important for open communication. Although BIM has been popular among construction practitioners in China, it has not been widely popularized for the current state of China's construction industry, meaning that truly open communication is still blocked. With that being said, goal definition, communication, mutual respect and trust, and decision making are still four necessary conditions for schedule performance, cost performance, defect identification, and change orders [15].

The results of $H_3$, $H_4$, and $H_5$ hypothesis testing reveal the undeniable fact that contractual principles can indirectly affect project performance through collaboration-related principles, which partially supports $H_2$. The timing of key stakeholder involvement, the level of team integration achieved in projects, and the existence of contractual relationships among key stakeholders can be highly influential on project performance [75,76]. Given that the quantitative research on the relationship between contractual principles and project performance is rare, these results provide an effective supplement for related studies. First, China lacks a perfect IPD contract structure. Second, although the contract itself advocates the equality of the parties, in practice, the owner is still dominant in project management. Considering the absence of a multiparty contract, and the fact that multiparty agreements are subject to moral standards, such a contract may not fully realize the key participants' equality. Third, the promotion of intensified design in the construction industry may face some challenges, such as requiring designers to possess sufficient professional ability, to change their traditional design thinking, and to advocate for the early involvement of key participants.

The results of $H_6$ hypothesis testing suggest that behavioral principles have no positive effect on collaboration-related principles, demonstrating that $H_6$ is not tenable. However, the key elements to successful IPD implementation include the skills, rewards, absence of obstacles, coordination mechanisms, trust, and interactions and information sharing with parties both inside and outside the project team [77]. Goal definition, communication, mutual respect and trust, and decision making are necessary for all performance areas [15]. The early involvement of key participants helps to infuse knowledge and experience into decision making. Even if the behavioral principles have no positive impact on the collaboration-related principles, their role in practical engineering cannot be ignored.

## 5. Conclusions, Implications, and Future Research

This paper examined the influence of IPD principles on project performance by means of a questionnaire survey and SEM. According to the obtained results and analysis, it can be argued that: not all IPD principles contribute to the improvement of project performance; the project performance is directly affected by collaboration-related principles and catalysts; and the contractual principles can exert positive impingement upon both behavioral principles and collaboration-related principles, while catalysts show a positive impact on behavioral principles. To this end, this paper contributes to the application of IPD research and practice from both the theoretical and practical perspectives.

### 5.1. Academic Implications

By engaging with the existing scholarship, this paper broadens the breadth and depth of IPD-related research, further supplementing the fundamental knowledge of project delivery system research.

(1) The research scope is extended beyond IPD as a delivery mode to IPD as a philosophy. A perusal of extant literature can quickly determine that most current studies are based mainly on pure IPD projects. However, the relevant research literature that queries whether IPD as a philosophy is conducive to improving project performance is insufficient. Since most projects are not purely IPD projects at present, the analysis of the influence of IPD principles on project performance will contribute to further the application and promotion of IPD.

(2) In terms of research depth, this paper looks beyond the influence results and burrows deep into the influence mechanism. Most of the previous studies have focused on whether and how to improve IPD project performance or results. For non-pure IPD projects, many IPD principles can be used, but it is difficult to implement them all at one time. Therefore, it is necessary to reveal the influence mechanism of IPD principles on project performance to find the most impactful IPD principles. Using these key IPD principles in construction projects will promote collaborative work, thereby improving performance. This paper also involves other aspects, including the classification of IPD principles in China; the demonstration of the positive impact of BIM, LC, and multiparty agreement on project performance; the measurement of the degree of influence of BIM technology and the LC method on project performance; and the determination of the indirect positive effect of contractual principles on the performance of projects through collaboration-related principles.

(3) This paper enriches the fundamental knowledge of project delivery system research by filling a research void. For countries or regions that cannot directly introduce the IPD delivery method, the research of IPD as a philosophy is limited, especially in terms of how to effectively and reasonably apply IPD principles to improve construction project performance. This paper found that not all IPD principles have a direct impact on project performance. This work concludes that the targeted application of IPD principles should be user-oriented and region-oriented, based on a detailed analysis of the internal-influence relationship among IPD principles.

### 5.2. Managerial Implications

According to formula (9), several management implications for how to use IPD principles to improve construction project performance are presented:

(1) This paper discusses some corresponding auxiliary measures for the potential benefits of fiscal transparency and liability waivers between key participants and shared financial risk and reward based on project outcome. These auxiliary measures include the establishment of collaborative work teams, the design of reasonable incentive-compensation mechanisms, and the usage of supplemental agreements.

(2) BIM and LC, as favorable improvements and supplements to traditional construction project management methods, should be more actively popularized by policymakers and other stakeholders to improve project performance. A multiparty agreement is encouraged as a supplementary form of related contract, bridging the collaborative management teams and increasing the possibility of collaborative behavior.

(3) Changing practitioners' thinking is of great significance to project management. The project managers should place more emphases on the impact of information technology and the scientific management methods of communication. The key participants should transform the traditional concept of obedience to the owners into the behavior of collaborative decision making based on the overall value of the project.

(4) The owner should encourage the participants to respect and trust each other and create a collaborative working environment to enhance the willingness to collaborate. In the actual construction process, participants should actively advocate brainstorming to make

colocation more than a mere formality. If allowed, intensified design should be considered, alongside the early involvement of key participants for the sake of developing inclusive project target criteria.

(5) IPD principles should be selectively used depending on the goal and actual situation of the project management. The participants should develop an IPD implementation strategy depending on their own priorities in performance areas, maximizing project performance given limited resources. A case-based guiding framework should be constructed to evaluate the type and level of the implementation of IPD. Careful consideration should be given to determining which IPD principles to implement in the project delivery phases via linking databases of past projects delivered using traditional delivery methods.

### *5.3. Further Research Suggestions*

This paper has its own limitations: (1) Our research only critically addresses the application of IPD principles in China; future work may conduct in-depth research on this topic in other countries. (2) Further work may consider the promotion of IPD benefits by the means of government incentive policies. To be more specific, the potential benefits of BIM and the owners' determination to use innovation can be taken into further consideration so that the impacts of the above factors can be properly considered. (3) It is acknowledged that each IPD principle may have a greater impact on one metric in some performance areas at a certain stage, but may exert little influence at other stages. In this vein, we can further study the impact of IPD principles on project performance according to project stage.

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