

Accepted version

Citation: Chang, C.Y., W.J. Pan and R. Howard (2017) *Impact of Building Information Modelling Implementation on the Acceptance of Integrated Delivery Systems: Structural Equation Modelling Analysis*, Journal of Construction Engineering and Management.

Impact of Building Information Modelling Implementation on the Acceptance of Integrated Delivery Systems: Structural Equation Modelling Analysis

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Abstract

In recent years, Building Information Modelling (BIM) has been increasingly employed by the Architecture, Engineering and Construction industry worldwide as a result of digital government initiatives. In spite of some promising early evidence on the benefits of BIM, the momentum of this “top-down” drive should build upon after-implementation empirical evidence. Through the structural equation modeling analysis of survey returns from 145 Chinese BIM-enabled projects, this research demonstrates that BIM’s degree of implementation can positively affect the acceptability of Integrated Project Delivery (IPD) in the future via increased perception of the need for supply chain incentivization and improved communication quality enabled by BIM. Rolling out BIM on a wider scale may yield an additional benefit in lowering the barrier to the implementation of IPD systems. This finding can serve as evidential support for government mandates that requires the compulsory adoption of BIM in public projects.

Keywords: integrated project delivery, building information modeling, structural equation modeling, collaboration, incentivization

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30 **Introduction**

31 In recent years, Building Information Modelling (BIM) has been enthusiastically promoted by
32 governments worldwide with the diffusion of BIM in fact driven primarily by means of
33 government mandates. For instance, the recent outgrowth of BIM in the United Kingdom can
34 be largely attributed to the government's target of having Level-2 BIM adopted in all central
35 government sponsored projects by 2016. Initially, this "top-down" drive for BIM
36 implementation was built upon the early evidence on BIM benefits including miscellaneous
37 cost savings (e.g., collision detection) or direct return on investment. However, such a drive
38 could lose momentum after a large-scale implementation without further evidential support. In
39 the initial stage, the high setup cost of BIM (hardware and software costs as well as training
40 costs) could not be justified by the benefits resulting from its deployment. Lack of a self-
41 sustaining economic case for individual users may result in resistance to increase the adoption
42 of BIM, which in turn will undermine the rationale of BIM mandates. In the policy cycle,
43 evaluation and feedback are the essential elements (HM Treasury, 2015). For a technology as
44 transformative as BIM, it is imperative to evaluate its benefit from the perspective of the
45 industry's long-term development. This research brings to light a hitherto unexplored benefit
46 from the widespread application of BIM as a result of government mandate: its ability to
47 increase BIM users' awareness of the significance of integrated delivery models which can, in
48 turn, precipitate the acceptance of these models moving forward. This cause-effect relation
49 evinces that the enabling function of BIM does not only result in quantitative changes (e.g.,
50 steady improvements in cost) to projects but also qualitative changes (e.g., greater employment
51 of integrated delivery systems) to the industry at large.

52 Integrated Project Delivery (IPD) aims to improve project outcomes through a
53 collaborative approach of aligning the incentives and goals of the project team via shared risk
54 and reward, contractor early involvement, and a multiparty agreement. Since both BIM and
55 IPD compel a dramatic increase in information sharing, these concepts have become
56 intertwined (Eastman, et al, 2011), with many going so far as to claim that IPD is pivotal to
57 BIM implementation (Sebastian, Haak & Vos, 2009). This provides a central piece of evidence
58 to understand the reinforcement effect of BIM on the evolution of integrated delivery
59 environments. Similar to the S-curve trajectory in the development of other technologies, the
60 diffusion of BIM has an uphill climb during the early stages (see the discussion section for
61 detail). Without strong driving forces, this "gravity" cannot be easily surmounted leading to
62 the slow diffusion of BIM. As well known in physics, the force required to move a still object
63 (i.e., static friction) is much higher than that necessary to maintain the speed of a moving object
64 (i.e., kinetic friction). This illustrates why a growing number of governments opted for a
65 powerful tool such as a policy mandate to set in motion large-scale BIM implementation in
66 hopes that its diffusion would be self-sustaining thereafter. Following such a mandated
67 implementation, resistance could primarily stem from BIM participants in circumstances where
68 their interests are not aligned and thus the application of incentivization measures could help
69 propel BIM participation. However, these measures could reach limitation if not embedded in
70 an integrated delivery system. As the implementation of incentivisation systems and delivery
71 systems involve a steep learning curve for all parties involved, according to the Technology
72 Acceptance Model user resistance could become a major hindrance to the realization of BIM's
73 full potential. The main intellectual contribution of this research lies in the discovery of a set
74 of statistically robust results to demonstrate that the compulsory adoption of BIM could lead
75 to a cycle in which the experience of using BIM translates into the momentum for ushering in
76 a desirable BIM delivery environment (i.e., IPD).

77 From May 2015, the Chinese government published a series of national
78 standards for utilizing BIM and regulations related to BIM implementation. In July

79 2014, the Department of Housing Construction issued the *Suggestion for Advancing*
80 *Construction Reform and Development* (as cited in Ni & Wang, 2015) which requires
81 promoting the use of information technology in the whole project life-cycle. This document
82 document also indicated that by the end of 2020, the ratio of projects using BIM in medium
83 and large public building projects, public green building projects and green demonstration
84 housing projects must achieve 90%. The overall adoption rate of BIM in China remains
85 considerably lower than that of developed countries (as cited in Cao et al., 2015). The use of
86 BIM in China to date is still limited principally to visualization. With the strong drive from the
87 Chinese central government, it can be expected that BIM will proliferate fast in the Chinese
88 Architecture/Engineering/ Construction (AEC) industry. Given the predominance of the
89 traditional design-bid-build delivery system in China, Chinese BIM users will come to realize
90 that BIM cannot reach its full benefit in improving project coordination without introducing
91 collaborative delivery systems. In this research, Integrated Project Delivery (IPD) is chosen as
92 the exemplar collaborative project governance owing to its strong influence in the US
93 construction industry. With survey returns from 145 Chinese BIM-enabled projects, this
94 research demonstrates statistically that the acceptance of IPD features increases with the use of
95 BIM applications through two channels: one via the improved awareness of incentivization
96 being a crucial element in governing BIM-enabled projects; the other by improved
97 communication quality affected by BIM. The value of this research can be seen in two aspects:
98 First, it has become an official practice that regulatory measures should be subject to a risk-
99 based assessment (Löfstedt, 2004; Organisation For Economic Cooperation and Development,
100 1997) by weighing up regulatory risks against the attendant benefits. This finding can be drawn
101 upon as an additional benefit by any government to justify the implementation of a new BIM
102 mandate or the broadening/deepening of an existing mandate. Second, this finding opens a new
103 frontier for BIM research as BIM's spill-over effect on IPD acceptance could ultimately be as
104 significant as the BIM benefits already reported within literature. Addressing this fact is a first
105 step to developing a life-cycle theory of BIM diffusion.

106 **Literature review**

107 BIM has the potential to be a game-changing factor in the industry for three reasons (Eastman
108 et al., 2011): First, it is a unique way of integrating information into design schematics. Second,
109 BIM can be easily standardized. Third, by accommodating all information into virtual models,
110 BIM provides an opportunity to improve quality assurance through the formalization of model
111 specifications. As a result, BIM can be perceived both as a “technology” and a “process”
112 (Tahrani et al., 2015). In pursuit of these benefits, several countries (e.g., Singapore, South
113 Korea, the United Kingdom, and the United States) have mandated the compulsory use of BIM
114 in public projects (Cao et al., 2015). However, BIM is just beginning to register significant
115 awareness and adoption within the industry at large. Eadie et al.'s (2012) recent investigation
116 show that contractors are less involved in BIM use than designers and many BIM practices are
117 limited to the design stage. While one can derive benefits from BIM in separate applications,
118 only when BIM is embedded in the process to generate the interoperable and interactive
119 workflow around it can the full potential of BIM be unlocked (Monteiro, Meda and Martins,
120 2014). This requires a new form of delivery system that supports collaborative procurement
121 processes (Australasia, 2012). It is widely recognized that IPD could be an organizational
122 solution (Australasia, 2012; McGraw Hill Construction, 2014). As argued by Succar (2009),
123 BIM development may go through three stages (object-based modeling, model-based
124 collaboration and network-based integration) before it reached the long-term goal of
125 embedding BIM in an IPD environment. Behind this evolution, there are three interlocking
126 driving forces at work, which are associated with policy, technology and process. Along the
127 similar line, Succar and Kassem (2015) develop five models for the assessment and

128 management of BIM diffusion (diffusion areas model, macro maturity components model,
129 macro diffusion dynamics model, policy actions model, and macro diffusion responsibilities
130 model). There is ample evidence from the US, UK, and China that project delivery systems
131 with a higher level of integration could lead to better project outcomes (Chen & Jiao, 2011;
132 Korkmaz et al., 2010; AIA, 2007). There is also a view that a BIM-enabled collaborative
133 environment could facilitate the implementation of IPD (Cohen, 2010). While IPD principles
134 have been promoted for over a decade, IPD projects remain uncommon (Kent et al., 2010). Ill-
135 devised legal frameworks, inadequate competencies, and lack of experience have all impeded
136 the adoption of IPD (Autodesk White Paper, 2008). Most existing IPD contracts include
137 elements that are designed to encourage teamwork for the success of the entire project rather
138 than any particular team member. Unlike traditional projects where all parties pursue own risk
139 minimisation, IPD combines the risks and rewards of all team members and correlates them
140 with common project goals (Kent et al., 2010). Generally, interest alignment holds the key to
141 the success of integration. As defined in Baddeley & Chang (2015), ‘incentivization’ refers to
142 the act of employing measures that help align the divergent interests of BIM participants.
143 Chang (2014) and Chang & Howard (2016) identified seven fundamental questions involved
144 in the design of a BIM incentivisation system and their theoretical foundations:

- 145 1) How to manage the coevolution of design and target cost?
- 146 2) How to fund the incentive pool?
- 147 3) On what basis to award compensation?
- 148 4) What weightings to assign to objective and subjective evaluation?
- 149 5) How to allocate risk through the choice of risk-sharing ratio?
- 150 6) How to choose the right compensation from between linear and non-linear plans?
- 151 7) How to set the threshold value for each incentive award band?

152 The current research adopts these BIM incentivization questions and previous research results
153 as the theoretical frame of reference.

154 Within the project environment, BIM’s greatest effects relate to communication (Mourshed,
155 2006). Trust and communication are critical to effective supply chain relationships (Baddeley
156 & Chang, 2015). The processes for the extraction, interpretation and communication of design
157 information from drawings and documents are frequently time-consuming and arduous
158 (Sebastian, 2010). However, BIM protocols can help facilitate this process. For example,
159 during the construction process, BIM can support communication among parties and locations
160 (e.g., the building site, the factory and the design office), which is crucial for efficient
161 prefabrication and assembly, as well as prevention of unexpected errors.

162 As maintained by Brennan (2011), effective communication, trust, and respect are
163 among the most important critical success factors (CSF) for team collaboration under an IPD
164 approach. Adding communication into the IPD acceptability model begs the fundamental
165 question of how to measure the quality of communication. As cited in Mohr and Spekman
166 (1994), communication quality is a critical aspect of information transmission, including issues
167 such as the accuracy, timeliness, adequacy, and credibility of the information exchanged. In a
168 recent study of trust in Chinese IPD teamwork, Wu (2012) identified communication as one of
169 the major indicators of project performance and measured it using three dimensions, including
170 communication effectiveness, accuracy and degree of involvement. By also reference to
171 Freeman, et al. (2006) and Pocock, et al. (1996), the current research takes a broader view by
172 defining communication quality as consisting of accuracy, timeliness, transparency, initiative
173 and frequency.

174 Large construction projects mostly span several years in which the interaction
175 between owner and contractor could be intense (Kadefors, 2003). BIM projects are
176 aimed to enhance collaboration by improving information sharing across business

177 boundaries and inter-disciplinary teams. In recent years, practitioners have become
178 increasingly aware that efforts should be made towards removing the barriers to collaboration
179 collaboration within the construction supply chain. Ertel, Jeff, & Laura (2001) explored the
180 the function of collaboration in multi-party agreements, finding that poor collaboration is the
181 most significant factor leading to the failure of project alliances. Respondents in a recent
182 investigation of BIM practices also observed mistrust and collaboration issues among
183 participants in their projects (Cao et al. 2015).

184 IPD is an emerging delivery system in which members' success depends on
185 collaboration and teamwork amongst main parties. Although research has demonstrated that
186 collaboration is a critical requirement for IPD, it is not solidly grounded in empirical evidence.
187 Only a few studies have focused on collaboration assessment and improvement. An example
188 is Abdirad & Pishdad-Bozorgi (2014) where the authors developed a framework of metrics for
189 measuring collaboration within IPD, including co-location (Brewer & Mendelson, 2003),
190 multidisciplinary work (Brewer & Mendelson, 2003), team productivity (Brewer & Mendelson,
191 2003), cost impact of collaboration (EI Asmar, 2012), training (Thompson & Ozbek, 2012),
192 immediate feedback (Brewer & Mendelson, 2003), real-time sharing of data (Moore et al.,
193 2005), methods of communication (Thompson & Ozbek, 2012), degree of interaction (Pocock
194 et al., 1996), individual human aspects (i.e. turnover) and BIM technology (Cohen et al., 2010).
195 This comprehensive list provides a sound basis for the selection of metrics used in the
196 measurement of collaboration in the current research.

197 Compared to the literature, the value of the current research can be seen in three aspects:
198 First, the focus of analysis is placed on to what extent mandated BIM implementation could
199 change the perception of the desirability of IPD features for BIM-enabled projects. This
200 provides a new angle for scrutinizing the benefits of BIM. The finding demonstrates that the
201 spillover effect of using BIM, voluntarily or not, could facilitate the acceptance of IPD. The
202 second distinguishing point lies in the empirical method used. For example, both of Succar
203 (2009) and Succar and Kassem (2015) are prescriptive and conceptual in nature. While the
204 framework of Succar (2009) is validated by a common qualitative approach, called
205 "triangulation," he also calls for researchers to use different methods in testing his framework.
206 By contrast, through the technique of *Structural Equation Modelling (SEM)*, the current
207 research can rigorously demonstrate that the more extensively BIM is deployed in the project,
208 the stronger the perception of the necessity of advanced IPD features for BIM-enabled projects.
209 This cause-effect relation suggests that BIM mandates could propel a more desirable delivery
210 environment for high-level BIM. The model also reveals that the momentum is generated by
211 the awareness of incentivization measures and the improvement in communication quality
212 enabled by BIM. While the effect of BIM on the transformation of construction management
213 work process is increasingly acknowledged (Hartmann et al., 2012; Monteiro et al., 2014), the
214 underlying forces remain under-studied. This research furnishes timely evidence to fill this
215 knowledge gap. Third, as elaborated in Succar and Kassem (2015), BIM diffusion could be
216 portrayed in various ways. In the development of a parsimonious lifecycle theory of BIM
217 diffusion, the two statistically significant constructs (incentivization and communication)
218 found in the SEM analysis can effectively sharpen the research focus.

219

220 **Research Design**

221 *Reasons for choosing SEM*

222 In recent years, SEM has emerged as a mainstream analytical tool in social sciences, with the
223 great strength of integrating confirmatory factor analysis (CFA) (Jöreskog, 1963) and path
224 analysis (Wright, 1934), which allows a latent construct measured by multiple observed
225 variables. Since several constructs (e.g., communication, collaboration and perceived need for

226 incentivisation) considered in Figure 1 contain multi-faceted dimensions, SEM is a suitable
227 method. The implementation of SEM below involves a two-stage procedure as suggested by
228 Anderson and Gerbing (1988): build a measurement model first for specifying the relationships
229 among measured variables that underlie the latent variables and then a structural model for the
230 relationships among the latent variables.

231

232 *The model and hypotheses*

233 Based on the literature review, the core model (see Figure 1) contains five variables, of which
234 four are latent variables (expressed by an oval), including perceived importance of BIM
235 incentivization, communication quality, collaboration quality, and the extent of IPD
236 acceptability. Each of these variables is comprised of several observable variables. As the scope
237 of BIM application in a project is determined at the outset, it is treated as the independent and
238 only exogenous variable (expressed by a rectangle). In summary, the model consists of six
239 hypotheses:

240 **Hypothesis 1 (H1):**

241 The degree of BIM application can raise the perceived importance of BIM
242 incentivization.

243 **Hypothesis 2 (H2):**

244 Perceived importance of BIM incentivization will have a positive effect on IPD
245 acceptability.

246 **Hypothesis 3 (H3):**

247 The degree of BIM application can improve the quality of communication.

248 **Hypothesis 4 (H4):**

249 Better communication quality will lead to greater IPD acceptability.

250 **Hypothesis 5 (H5):**

251 The degree of BIM application can improve the quality of collaboration.

252 **Hypothesis 6 (H6):**

253 Better collaboration outcomes can increase IPD acceptability.

254 *Questionnaire Development*

255 This research designed a survey to elicit experts' assessment of the five constructs in Figure 1.
256 Data was initially recorded by SPSS 19 and then entered into a structural equation model using
257 AMOS 17. Since the quantitative approach was considered appropriate to analyze individuals'
258 attitudes, main questions were measured on a 7-point Likert scale.

259 The first construct is concerned with the extent to which BIM was used in the
260 project, which can be measured by three dimensions (see Table1): level of the BIM
261 model (Level 0, 1, 2, 3), in which project phases the model was used, and what functions
262 BIM has assisted in serving. The four-level BIM maturity model originally developed
263 by Bew and Richards (2008) and further enriched by the UK Government Construction
264 Client Group (2011) has been employed in this research. This should ensure clear
265 articulation of the standard classifications and help respondents understand the
266 processes, tools and techniques involved in each of the BIM level defined in this model
267 (BIS, 2011).

268 As the three dimensions are nesting to each other, they cannot be used as parallel
269 constructs to form the variable. By capturing the combined effect of three dimensions
270 reflective of the differential degree of BIM use (depth (level of BIM), breadth (number
271 of stages applied) and scope (number of functions supported by BIM)), a multiplicative
272 index can provide a more reliable measure than a simple additive index for the extent
273 to which BIM has affected a project. For this reason, this construct is calculated by

274 taking the multiplication of the normalized score of each dimension (see Table1 for details).

275 The explanatory variable in the model is to what extent the acceptance of IPD features
276 features could change in response to the differing degree of BIM application in the project.
277 While most of the respondents were familiar with BIM, they were less familiar with IPD and
278 its relevant concepts. Given that there is no existing measurement of IPD acceptability, this
279 research first identified the common features of IPD based on the literature (Cohen, 2010), and
280 second developed the questions that can effectively elicit the respondent's view on the
281 necessity of IPD futures for BIM-enabled projects in the future. All the features adopted were
282 originated from IPD case studies reported in Cohen (2010). For ease of referencing, the fifteen
283 features and their measurements are grouped into three categories: contractual, managerial and
284 technological (see Table 2).

285 The second construct aims to assess the quality of collaboration. This construct is
286 measured using several metrics discussed in the literature for measuring IPD collaboration
287 (Brewer & Mendelson, 2003; Abdirad & Pishdad-Bozorgi, 2014; Moore et al., 2005;
288 Thompson & Ozbek, 2012; Pocock et al., 1996): aligned goals, centralized working place,
289 multidisciplinary knowledge, and real-time information sharing.

290 The third construct is to evaluate the quality of communication. Aside from the
291 traditional measures of communication quality by virtue of accuracy and timeliness (Mohr &
292 Spekman, 1994), three additional criteria are also included here: First, transparency reveals
293 another aspect of communication quality as information flow within the project may be
294 impeded by asymmetric information (Zaheer, McEvily, & Perrone, 1998; Kadefors, 2004).
295 Second, an initiative in participation is concerned with the degree of keenness in contributing
296 to decisions and goal formulation within the project (Mohr & Spekman,1994). Third,
297 communication frequency is meant to capture how actively parties have interacted with each
298 other in exchanging information (Mohr & Spekman, 1994; Pocock, et. al, 1996; Freeman et al.,
299 2006). The detail of three constructs can be found in Table3, including a brief explanation for
300 each construct, constituent elements of each construct, their measures and notations in the
301 model.

302 To fully understand the potential impact of BIM utilization on the prospect of IPD, it is
303 essential to include all three constructs in the model. The constructs "collaboration" and
304 "communication" both concern the actual impact of BIM on one of the 145 projects under
305 study in these two aspects, while "incentivisation" is evaluated via the respondent's perception
306 of the need for such an incentivisation system against his experience in a BIM-enabled project.
307 This is because while incentivisation measures are not widely adopted in practice yet, their
308 significance for efficiency improvement is well acknowledged in recent procurement reform
309 (e.g. (HM Treasury, 2013)) and thus the demand for incentivisation is expected to be a crucial
310 driver for ushering in integrated delivery systems in the future.

311 The data used to test the hypotheses was collected via three main methods: sending the
312 survey link hosted on Sojump (a pay-out service similar to SurveyMonkey) direct to 170 BIM
313 professionals (12%); posting the online survey link on social media interest group on Sojump
314 and Wechat (50%); and distributing 30 questionnaires in person (28%). In total, 163 returns
315 were received, 145 of which were complete and can be used in the analysis. The background
316 of the respondents spans six professions (owner, architect, engineer, general contractor, sub-
317 contractor, and consultant) which are representative of the composition of BIM participants in
318 China (see Table 4). The majority of respondents have 6-10 years of work experience (45.5%).

319

320 **Empirical Analysis**

321 *Summary statistics*

322 The result shows that the vast majority of projects have reached Level 1 (42.8%) and 2 (43.4%)
323 with similar proportions, meaning that a managed 2D and 3D environment has been built up
324 using BIM, but Level 3 BIM features (e.g., 4D construction sequencing, 5D (cost information)
325 and even 6D (life-cycle information)) are not utilized yet. As revealed in Figure 2, BIM has
326 been applied to various functions in the surveyed projects, more than 80% of which have seen
327 BIM used to assist in design and construction.

328 *Reliability & Validity Test*

329 First, the Cronbach's Alpha is used as a reliability indicator to check the internal consistency
330 of three constructs. The results show that all possess a score of over 0.8 (BIM Incentivization
331 Perception: 0.80; Communication Quality: 0.83; Collaboration Quality: 0.82), indicating good
332 reliability. The next step is to examine the validity of these constructs. In statistics, the use of
333 observed variables is based on the assumption that all these variable are valid and reliable.
334 Through the CFA, one can determine which set of observed variables share common variance-
335 covariance characteristics that define latent variables. The key test is to check if the sample
336 variance-covariance data can be fit well to the specified model. As each fit index only reveals
337 part of the model fit, it is useful to report a profile of complementary indices that cover three
338 model fit categories: absolute fit, incremental fit and parsimonious fit.

339 Absolute fit indices help examine how well the theoretical model can fit the data in
340 comparison to no model at all. The most fundamental index is the χ^2 and its p -value, which is
341 used to check whether the null hypothesis can be accepted that the sample covariance matrix
342 is equal to the fitted one. A good fit model must lead to accepting the null hypothesis (i.e., p -
343 value > 0.05), so χ^2 statistic serves as a "badness of it" measure (Kline, 2016). The magnitude
344 of χ^2 increases with the sample size, so χ^2 is normally reported as a ratio to the degree of
345 freedom (df). There is a consensus that χ^2/df should not exceed 3 (Kline, 2016). Apart from the
346 sensitivity of χ^2 to the sample size, the assumption of multivariate normality of this index could
347 result in the rejection of a well-specified model (McIntosh, 2007). Two complimentary indices
348 are also reported. RMSEA (Root Mean Square Error of Approximation) is an index sensitive
349 to the number of parameters estimated in the model, so it can help choose a parsimonious model.
350 An RMSEA below 0.08 shows a good fit (MacCallum et al., 1996). Another index is GFI
351 (goodness of fit index), which measures the proportion of variance that can be accounted for
352 by the model. A cut-off value of 0.9 is normally recommended (Shevlin and Miles, 1998).

353 Incremental fit indices allow researchers to compare a model's fit against a
354 baseline model that assumes that all variables are uncorrelated. Comparative fit index
355 (CFI) is a common choice. This index is in the range of 0 to 1. A value of greater than
356 0.9 can ensure a poorly specified model is detected (Hu and Bentler, 1999).

357 Finally, it is useful to examine whether a model is accepted as a result of
358 including unnecessary variables. The Parsimony Goodness-of-Fit Index (PGFI)
359 developed by Mulaik et al. (1989) is calculated based on the GFI by adjusting for the
360 loss of degrees of freedom, so it penalizes model complexity. As there is no consensus
361 threshold level for this statistic, it should be interpreted in conjunction with other
362 indices.

363 Figure 3a-c reports the result of validity test for the model. First, the loadings
364 (standard coefficient) of the observable items on the latent variable are all above the
365 acceptable value of 0.5. Second, the model fit is achieved compared to the threshold
366 value of each indicator suggested in the literature. The corroboration of the validity of
367 three constructs lays a solid foundation for the credibility of the statistical analysis

368 Last, the explained variable IPD Acceptability passes all the tests excepting the
369 loading of VA5 (open-book accounting) on the sub-dimension Contractual (Figure 3d).

370 Given its importance in the IPD model, VA5 is still kept in the analysis. As for reliability, the
371 Alpha scores of three sub-dimensions are all close to the acceptable level (0.79, 0.80 and 0.80,
372 respectively), so no further action was taken.

373 *Path Analysis*

374 The purpose of path analysis in SEM models is to test the statistical significance of the effect
375 of explanatory variables (BIM degree, Incentivization, Communication, Collaboration) on the
376 independent variable (IPD acceptability). The first step is to ensure that the Chi-square result
377 is not significant through some modifications, including building correlations between the
378 errors of VL1 & IPD management, VL2 & IPD acceptability, VM5 & Collaboration, VM1 &
379 VM2 as well as VM3 & IPD management. By way of this process, chi-square to the degree of
380 freedom ratio is improved, indicating that the conceptual model is a good fit to the real data.
381 This is also confirmed in other indicators of the model fit (see Table 4).

382 After estimation, it was found that the coefficient on each path, except for the one
383 between collaboration and IPD acceptability, is significant as hypothesized (see Table 5).
384 Specifically, a greater extent of BIM application in the project can lead to a stronger
385 appreciation for the significance of incentivization in strengthening BIM participation (H1) and
386 that will eventually translate into support for IPD (H2). If construction professionals recognize
387 the importance of having well-functioning incentive mechanisms in place, it will be more likely
388 for them to accept IPD contracts and their pain/gain sharing arrangements in the future.

389 Also, the greater use of BIM in a project can lead to improvements in the quality of
390 both collaboration (H3) and communication (H5). The effect of BIM degree on communication
391 can work its way to increase IPD acceptability (H4), while this is not the case for the impact of
392 BIM on collaboration (H6). The reason can be investigated through a mediation model (Figure
393 4). When modeled without including communication, collaboration has a statistically positive
394 effect on IPD acceptability ($W_c=3.570$, $p<0.001$). A possible reason why H6 fails is that the
395 two variables are completely mediated by communication (Baron & Kenny, 1986). This
396 conjecture is corroborated by the significance of the coefficient on the paths of collaboration
397 to communication ($W_a=0.907$, $p<0.001$) and communication to IPD acceptability ($W_b=3.193$,
398 $p<0.001$). This result means that collaboration positively affected IPD acceptability through
399 changing communication rather than affect it directly.

400 **Discussion**

401 Technically, BIM can provide a flexible modeling technique to visualize a design idea and
402 store it digitally as parametric objects, which could then be fed into other analyses within the
403 design (e.g., building services simulation) and facilitate collaborative working between project
404 parties throughout the project lifecycle. Like other information technologies, BIM adoption is
405 ultimately an investment decision so from a business perspective, the cost of BIM deployment
406 must be justified by the benefits accrued from it. The sources of benefit discussed in the
407 literature primarily concern the cost savings from early clash detection without paying much
408 attention to the qualitative changes BIM could bring about to the construction industry in the
409 long run. The current study represents the first attempt to take a forward-looking view on the
410 long-term benefit of BIM. It is found that the increasing use of BIM can considerably raise
411 practitioners' acceptance of the major IPD features which should then translate into support for
412 implementing this system in the future. This finding can provide a key stepping stone for
413 developing a lifecycle theory of BIM technology.

414 As an enabling tool, the realization of BIM's full potential depends on the readiness of
415 all parties concerned. To secure BIM-readiness, the AEC industry needs to make a lump sum
416 investment in hardware, software and training at the outset. The worthiness of this investment
417 bears upon how frequently the acquired capability can be reused. In the early stage (Stage I in
418 Figure 5), inhibited by lack of sufficient evidence in support of its benefit, the employment of

419 BIM is limited to the small group of early adopters. In cash flow terms, the additional cost
420 arising from BIM is high as most AEC companies have to build in-house capability from
421 scratch, which will naturally constrain the feasible scope of BIM application in the project. In
422 the environment of projects featured by a web of independent parties (designers, constructors
423 and suppliers), the benefit of BIM can grow exponentially as its application grows broader
424 (more lifecycle stages), deeper (levels of BIM) and more diverse (variety of analysis supported
425 by BIM). As a result, fragmented application of BIM can only realize a small fraction of its
426 potential. The gap in financial feasibility (Δ in Figure 5) is a fundamental problem hindering
427 the voluntary adoption of BIM. In economic terms, it can be regarded as a case of market failure
428 under which coordination mediated by the price signal cannot occur spontaneously, and that
429 gives a rationale for government intervention (Williamson, 1991). This could be the main
430 reason why mandating BIM deployment in public projects is widely embraced as a kick-start
431 strategy by governments. The nature of a government mandate is not much different than
432 regulation as both serve to restrict the range of allowable actions for public interests. In recent
433 decades, the pendulum of regulatory philosophies in Europe has swung to risk-based
434 assessment in which the cost of regulation are explicitly evaluated against its benefit (Löfstedt,
435 2004; Organisation For Economic Cooperation and Development, 1997).

436 When applying the same philosophy to the design of BIM mandates, the benefit is
437 significantly harder to evaluate than the cost because the latter involves a direct cash
438 expenditure while the former a delayed receipt of benefit. During the development stages, the
439 cost and benefit of BIM deployment will tend to converge as more companies upgrade to
440 “BIM-ready” (see Figure 5). To the left of the point where those two trajectories intersect, the
441 promotion of BIM is primarily driven by the “push” forces, such as BIM mandates. After the
442 benefit can cover the cost (to the right of the intersection point), then “pull” forces will
443 dominate. It is useful to understand this conversion from the perspective of the Nobel Prize
444 awarded Principal-Agent theory (Holmstrom, 1982). In designing an optimal contract, the
445 principal should first ensure compensation can more than cover the agent’s opportunity cost.
446 This so-called participatory condition can persuade the agent to take part but cannot induce
447 him to exert the best effort. This theory suggests that efficiency can be improved by holding
448 the agent accountable for the outcome of his action via risk-sharing arrangements. In the
449 promotion of BIM, mandating can “push” some owners to embark on experimentation with the
450 hope of driving industry BIM capability towards greater maturity through a “learning by doing”
451 process. The push force could only make BIM nominally deployed as an enhanced 3D
452 visualization tool, instead of giving participants strong incentives to explore the potential of
453 BIM. For this reason, after BIM deployment becomes financially viable, the “pull” forces
454 should be considered by way of various incentivisation measures (Chang and Howard, 2016).

455 When it comes to the development of BIM, the United States provides a unique case. It
456 is instrumental to make a demarcation between the model of a BIM leader (i.e., USA) and that
457 of BIM followers (e.g. UK, China) through the angle of a pair of contrasting concepts in
458 Transaction Cost Economics (spontaneous v.s. intentional institution) (Williamson, 1996). As
459 a leader for both BIM and IPD, the USA provides a desirable environment for both to cross-
460 fertilize each other. The early awareness of the reinforcement effect of BIM and IPD was well
461 documented in US literature (e.g., Cohen, 2010). This driving force nurtured an environment
462 for BIM to proliferate “spontaneously.” However, for most countries, IPD is a system not even
463 yet experimented with. Under the traditional design-bid-build system, key stages are separated
464 out by design which forces BIM to be applied in isolation. To expedite the diffusion of BIM,
465 an effective strategy for these governments is to impose “intentional institution” in the form of
466 BIM mandate. For this reason, the initial push force is essential. In a BIM mandate, the
467 government normally sets out requirements without providing much information about its

468 rationale. A good example is from the UK Government Construction Strategy (Cabinet Office,
469 2011):

470 *Government will require fully collaborative 3D BIM (with all project and asset*
471 *information, documentation and data being electronic) as a minimum by 2016. (p.14)*

472 In a follow-up report, several benefits were identified for BIM, including reduced lifecycle cost,
473 potential for higher whole-life value, expanded services to clients to raise the quality of their
474 outcomes, enhanced international competitiveness, increased offsite construction, and growing
475 Information and Communication Technology services in construction (Saxon, 2013). This
476 research demonstrates that utilizing BIM could have an additional benefit in raising
477 practitioners' awareness of the importance of IPD features and that helps increase the
478 likelihood of these features being accepted for the same project in the future.

479 **Conclusions**

480 In recent years, BIM has been feverishly promoted by governments throughout the world by
481 issuing mandates to force the adoption of BIM. The justification for these mandates is restricted
482 to current rather than long-term benefits. In addition to BIM, promoting IPD has also attracted
483 considerable government effort (e.g. (Cabinet Office, 2014)). While IPD is not yet piloted in
484 China, the awareness of its importance has emerged. For instance, more than half of the
485 respondents in Ni & Wang (2015) agreed that there should be a suitable delivery system to
486 support BIM. The statistical analysis of this research shows that potential cost savings aside,
487 BIM could also propel procurement reform in the long-run. This finding not only lends
488 empirical support to the BIM mandate in China but also predicts that the wider application of
489 BIM can facilitate the implementation of integrated delivery in the country. This evidence can
490 also be drawn upon by governments when considering enacting a new BIM mandate or
491 extending an existing one.

492 Using the data from 145 Chinese BIM-enabled projects, this research can further probe
493 the channels through which BIM application could have impacted IPD acceptability: first, the
494 first-hand experience of working in a BIM-enabled environment can make practitioners better
495 appreciate the importance of incentivisation and that perception can drive the acceptability of
496 IPD; second, observing the positive impact of BIM on communication quality can translate
497 into another drive to support IPD. It is hoped that these robust statistical relationships can spark
498 follow-on research to investigate the benefits of BIM in a wider context.

499

500 **Data Availability Statement**

501 Data analyzed in the study are available from the corresponding author by request.

502

503 **Acknowledgement**

504 The first author appreciates Project Management Institute for financial support from its 2015
505 Sponsored Research Program.

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Table 1. Measurement of degree of BIM application

BIM Level	In which Project Phases BIM was used?	What functions has BIM assisted in serving?
Level 0: Unmanaged CAD, in 2D, with paper or electronic paper data exchanges.	Feasibility, Concept Design, Detailed Design	<ul style="list-style-type: none"> • Visualization • Collaborative design • Space validation • Environmental analysis
Level 1: Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment and standardized approach to data structure and format. Commercial data managed by standalone finance and cost management packages with no integration.	Implementation Document Procurement Construction	<ul style="list-style-type: none"> • Model-based estimation • Digital fabrication • Clash detection • Construction simulation
Level 2: A managed 3D environment held in separate discipline BIM tools with data attached. Commercial data managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilize 4D.	Operation Maintenance	<ul style="list-style-type: none"> • Code checking • Facility Management
Level 3: Characterized by a fully integrated and collaborative process enabled by web services, and incorporating 4D construction sequencing, 5D cost information and 6D project lifecycle management information.		
Normalized score = number of level/4	Normalized score = number of phases assisted by BIM/6	Normalized score = number of functions served by BIM/10

Table 2. Measurement of IPD Acceptability

Categories	Dimensions	Representative Case	Measurement	Notation in the model
Contractual	Multi-party contract	Cathedral Hill Hospital	A new type of contract should be signed between key project stakeholders to realize co-management and promote multilateral collaboration.	VA1
	Incentive tied to goals	Edith Green Wendell Wyatt Federal Building	Financial incentives tied to goals (e.g. setting target cost) should be specified in legal forms that could incentivize collaboration on the specific projects.	VA2
	Liability waiver	SpawGlass Austin Regional Office	Appropriate liability waivers can positively affect the relationship between contracting parties and help to resolve the dispute.	VA3
	Integrated project insurance	Cathedral Hill Hospital	Integrated project insurance specific to the project should be used in the case of unbearable project loss that the relevant participants are not able to cover.	VA4
	Financial transparency	MERCY & Schiller Remodel	Fiscal transparency (no hidden profits, contingencies or allowance) can be accepted and should be achieved by open book documentation and reporting.	VA5
Managerial	Early involvement	Autodesk Inc.	Key project stakeholders should early involve in the project even without the contract in place for achieving collaborative attitudes and improve the accuracy in estimating.	VB1
	Full-time staffing	Edith Green Wendell Wyatt Federal Building Modernization	To increase the efficiency of problem solving, investment should be made to support full-time staffing.	VB2
	Intensified planning	Sutter Health Fairfield Office Building	The time-consuming process of intensified planning and team building to reach the aligned goals is worthwhile.	VB3
	Integrated group building	Cardinal Glennon Children's Hospital Expansion	A layered interdisciplinary team (e.g. Cluster Group) with open-minded members should be created to ensure cross collaboration and coordination between groups.	VB4
	Collaborative decision-making	Walter Cronkite School of Journalism	Increased number and frequency of meetings are necessary to deal with problems and assist collaborative decision making.	VB5
Technological	Co-location working	UCSF Mission Bay Medical Center	Co-location working has a positive effect on the BIM-enabled project in general.	VC1
	Necessity of BIM	St. Clare Health Center	BIM is a necessary tool for efficient sharing of information in an integrated project team.	VC2
	Lean construction	Sutter Health Fairfield Office Building	More Lean Construction techniques (e.g. Last Planner System and Target value design) should be applied in project implementation.	VC3

Standardized documentation	Cathedral Hill Hospital	Project documents should be standardized to facilitate sharing/transferring between project parties.	VC4
Information sharing platform	UCSF Mission Bay Medical Center	An IT platform (e.g. SMART board) should be used to enable information/document sharing in real time between project parties.	VC5

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Table 3. Measurement of the constructs “Collaboration”, “Communication” and “Incentivisation”

Key constructs	Dimensions	Measurement	Notation in the model
Collaboration Quality of collaboration, in terms of	Aligned goals	Team members have reached an agreement on the project goal and cooperate with each other throughout the life-cycle.	VL1
	Centralized working place	Each project party has worked in a relatively centralized place and organizes regular meetings.	VL2
	Multidisciplinary knowledge	Project members have possessed a certain degree of multi-disciplinary knowledge and are ready to collaborate with the professionals from different parties.	VL3
	Real-time information sharing	The project data was shared in real time among all relevant project parties	VL4
Communication Quality of real-time information sharing, in terms of	Accuracy	In the process of transferring information, there was no distortion or incomplete messages that would cause misunderstanding.	VM1
	Timeliness	Project related information could be transmitted timely through suitable communication platform.	VM2
	Transparency	Team members were fully informed about issues that affect their work, and information was not hidden by any individual or small group of people.	VM3
	Initiative in participation	Team members proactively participated in the goal setting activities, and they would like to provide/receive any information or suggestions that might help the other party.	VM4
	Frequency of communication	The frequency of communication is high enough to support the daily exchange of working information.	VM5
Incentivization Strength of motivation for pursuing the interest of the whole project	Monetary reward	Financial rewards can improve the effectiveness of BIM considerably better than non-monetary rewards.	VI1
	Group-based reward	Group based rewards will work considerably better than personal rewards in incentivizing contractor participation in BIM system.	VI2
	Objective metrics	Objective metrics are considered better than subjective ones as the basis for determining incentive rewards for BIM participants.	VI3
	Differentiated weightings to performance	It is necessary to assign different weightings to performance metrics in the determination of incentive rewards for BIM participants.	VI4
	Linear reward sharing rule	A simple linear reward sharing rule [e.g. reward linked to a fixed percentage of cost savings] will work considerably better than a more complicated non-linear reward sharing rule in incentivizing contractors to contribute to BIM.	VI5

Minimum amount of incentive	There is a minimum amount of incentive reward that can motivate contractors' full participation in BIM.	VI6
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Table 4 Profile of the survey respondents

Years of work experience	1-2	9.0(%)
	3-5	17.2(%)
	6-10	45.5(%)
	11-20	18.6(%)
	>21	9.7(%)
Roles	Owner/developer	10.3(%)
	Designer	32.4(%)
	Engineer	27.6(%)
	General Contractor	15.9(%)
	Sub-Contractor	3.4(%)
	Consultant	7.6(%)
	Others	2.7(%)

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Table 5 Model fit summary

	X ² /Df	P	RMSEA	PGFI	GFI	CFI
Default model	1.059	0.299	0.020	0.671	0.904	0.993
Criteria of good fit	Not significant	P>0.05	<0.08		>0.90	>0.90

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Table 6 Path analysis of six hypotheses

Hypothesis	Dependent Variable	Independent Variable	Estimate	S.E.	C.R.	P
H1 accepted	Incentivization	BIM degree	0.124*	0.045	2.730	0.006
H2 accepted	IPD acceptability	Incentivization	4.284***	1.030	4.160	<0.001
H3 accepted	Communication	BIM degree	0.095**	0.034	2.809	0.005
H4 accepted	IPD acceptability	Communication	2.207**	0.780	2.683	0.005
H5 accepted	Collaboration	BIM degree	0.192*	0.072	2.677	0.007
H6 rejected	IPD acceptability	Collaboration	-1.867	1.283	-1.455	0.146

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Note: *** p<.001, ** p<.005, *p<.05.

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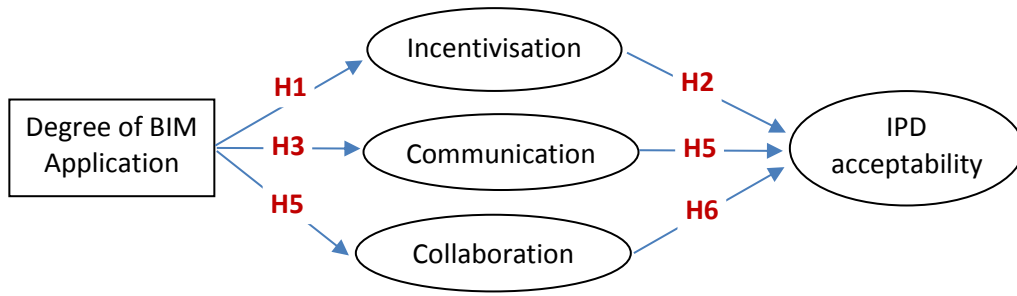
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736 Figure 1. A Model of IPD Acceptability

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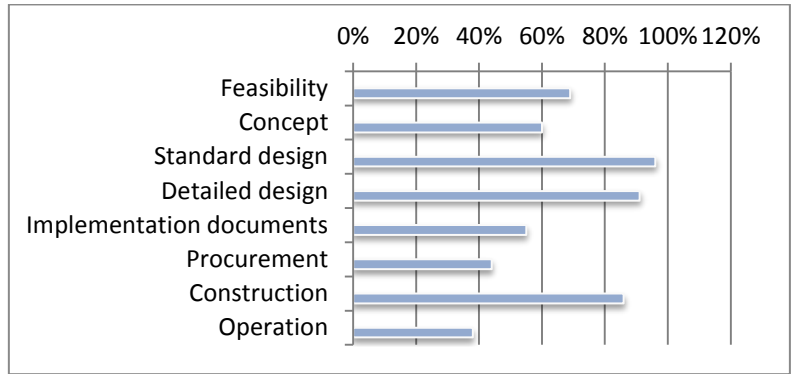


Figure 2. Project phases assisted by BIM

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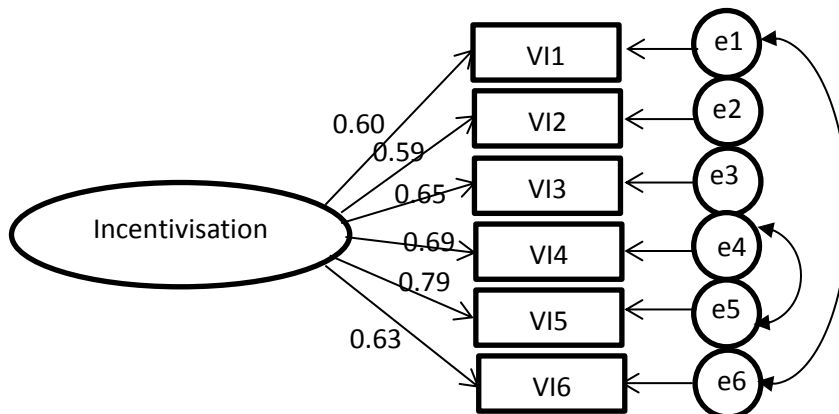
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	X ² /Df	p	RMSEA	PGFI	GFI	CFI
Default model	1.19	0.30	0.04	0.37	0.98	0.99
Criteria of good fit	Not significant	P>0.05	<0.08		>0.90	>0.90

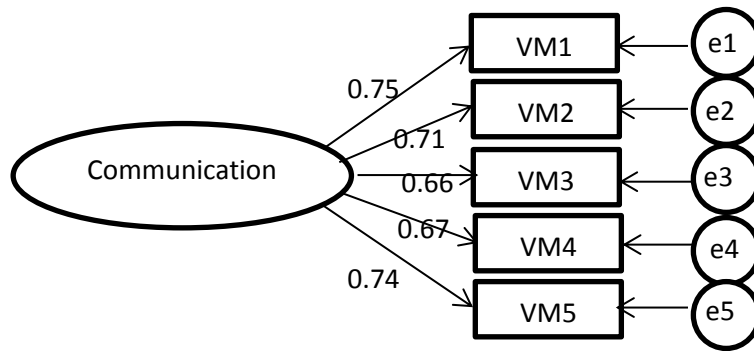
Figure 3a Construct Validity Test of "BIM Incentivization Perception"

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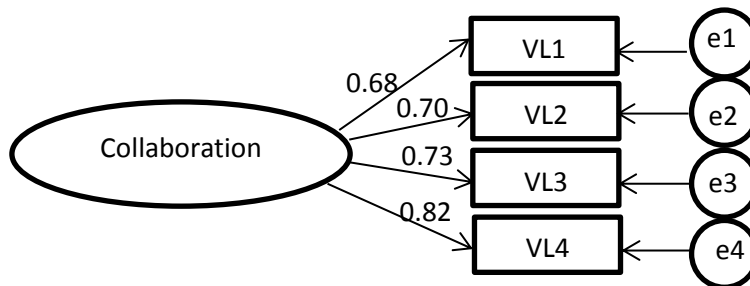


	X ² /Df	p	RMSEA	PGFI	GFI	CFI
Default model	2.17	0.06	0.09	0.32	0.97	0.98
Criteria of good fit	Not significant	P>0.05	<0.08	>0.5	>0.90	>0.90

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Figure 3b Construct Validity of “Communication Quality”

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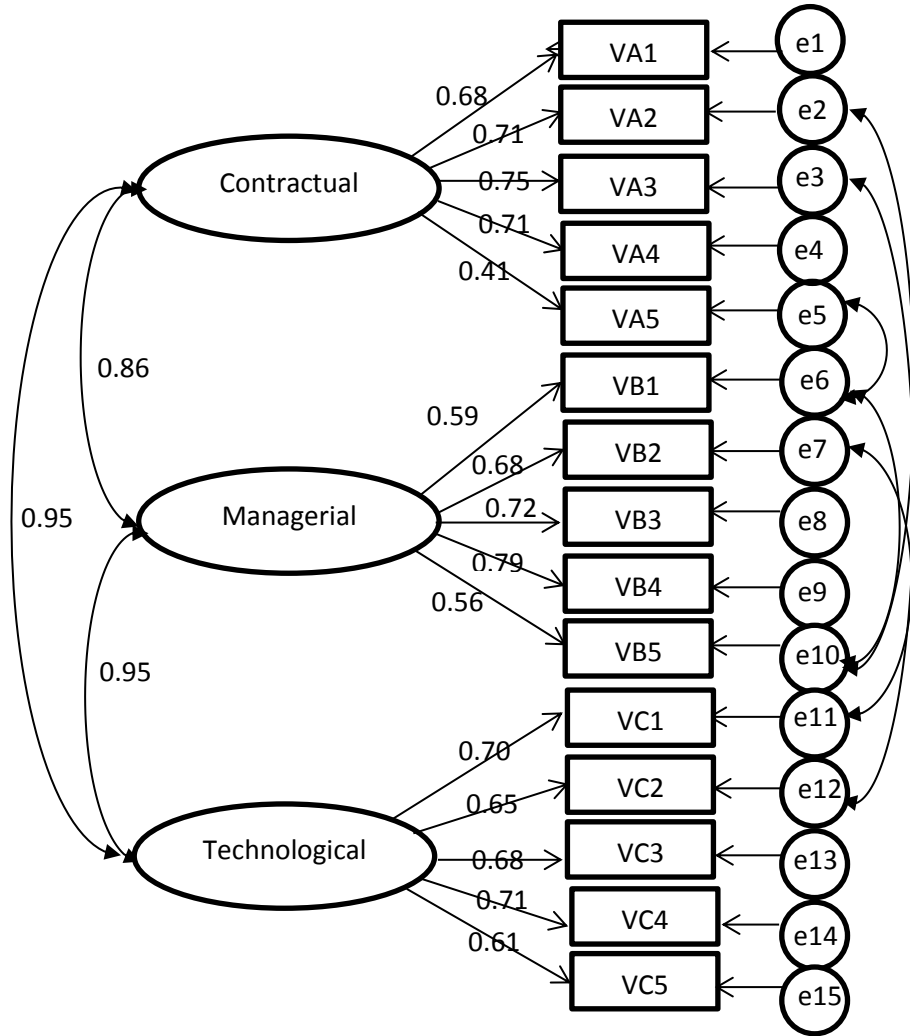


	X ² /Df	P	RMSEA	PGFI	GFI	CFI
Default model	1.00	0.37	0.01	0.20	0.99	1.00
Criteria of good fit	Not significant	P>0.05	<0.08	>0.5	>0.90	>0.90

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Figure 3c Construct Validity of “Collaboration”

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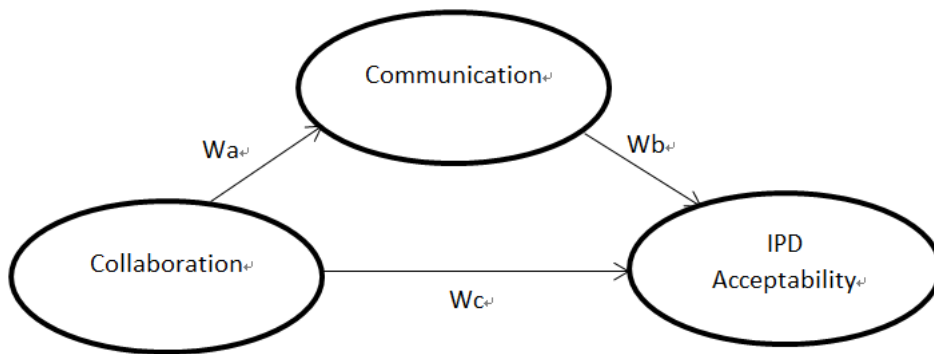


	X ² /Df	p	RMSEA	PGFI	GFI	CFI
Default model	1.059	0.299	0.020	0.671	0.904	0.993
Criteria of good fit	Not significant	P>0.05	<0.08	>0.5	>0.90	

Figure 3d The Construct Validity of “IPD Acceptability”

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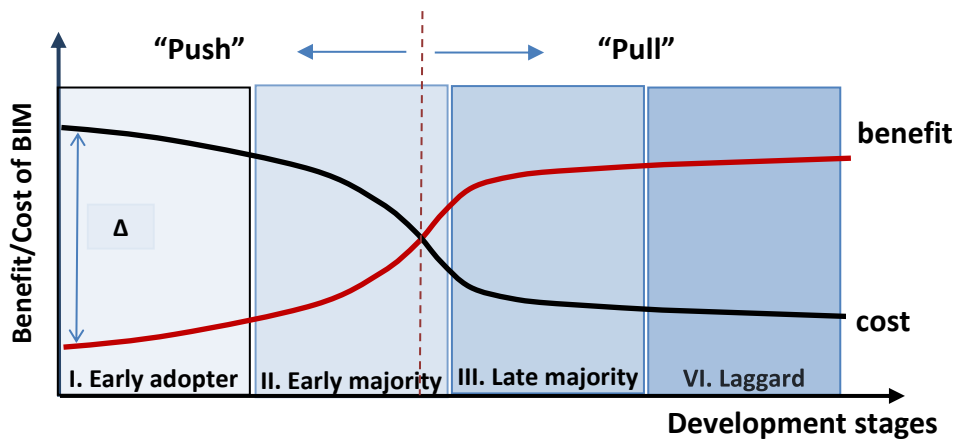
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Figure 4 The mediation model of “Communication Quality”

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Figure 5 Trajectories of the cost and benefit of BIM deployment over different development stages

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