Assessing the Influence of Virtuality on the Effectiveness of Engineering Project Networks: “Big Five Theory” Perspective

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Abstract: Engineering project networks (EPNs), as digitally mediated units whose team members are scattered across different organizations/locations, have become the norm for construction project teams. In EPNs, virtuality captures various forms of boundaries among team members and influences major dimensions of team functioning and outcomes. Despite this importance, investigating the role of virtuality on the functional performance of EPNs has remained an unexplored area. Through a multidisciplinary review of literature, a theoretical model has been created to conceptualize the fabric of links between virtuality and effectiveness in EPNs. The theoretical basis of the model is the Big Five theory of team effectiveness. The model has been evaluated using empirical data collected from 285 completed questionnaires, and analyzed through the use of partial least squares structural equation modeling (PLS-SEM) technique. Quantification of the model is the Big Five theory of team effectiveness. The model has been evaluated using empirical data collected from 285 completed questionnaires, and analyzed through the use of partial least squares structural equation modeling (PLS-SEM) technique. Quantification of associations reveals that virtuality significantly affects effectiveness in teams by manipulating several mediators. However, the level of influence of virtuality on these mediators, and eventually effectiveness, is much lower than previously assumed by current literature. This study goes beyond existing studies, presenting the first quantified model of virtuality applicable to any type of EPN in the construction context. DOI: 10.1061/(ASCE)CO.1943-7862.0001494. © 2018 American Society of Civil Engineers.

Author keywords: Engineering project networks; Virtual teams; Virtuality; Big Five theory; Effectiveness; Construction projects.

Introduction

Construction projects are collaborative ventures that are designed and constructed by construction project teams (Son and Rojas 2011). As defined by Buvik and Rolfsen (2015), construction project teams are “...a group of people responsible for complex tasks over a limited period, and are typically cross-functional, consisting of members who have complementary skills and come from different disciplines and functional areas in the organization.” For such teams, face-to-face collaborations are considered expensive, disruptive, and inefficient (Oraee et al. 2017). Consequently, the work is more often executed by geographically dispersed, digitally mediated teams of knowledge specialists who are organized into engineering project networks (EPNs) (Franz et al. 2017; Zelkowicz et al. 2015). Conducting business in the construction context relies on EPNs (Lobo and Whyte 2017; Niithiamyong and Skibniewski 2011). Hence, interactions among members and the way such interactions affect different features in respect of the functioning of EPNs have become areas of particular interest (Bussanino et al. 2014), especially in which the phenomenon of virtuality plays a pivotal role (Hosseini et al. 2016).

Virtuality is a key factor affecting every aspect of a team’s functions and members’ interactions (Foster et al. 2015; Peñarroja et al. 2013). It is dictated by several considerations that reflect the impact of boundaries, such as cultural, nationality and time zone differences, geographical distance, working for different organizations, and similar dividing characteristics present in the work context that team members have to bridge in order to interact and communicate (Zelkowicz et al. 2015).

Investigators such as Hosseini et al. (2016) identified perceived distance, task nature, difference in context, team tenure and maturity, dissimilarity of knowledge and skills, and team size as the factors that affect virtuality in EPNs. Yet, the weight and strength of their impact on virtuality remain unknown (Schaubroeck and Yu 2017). Moreover, findings of previous studies with regard to the impacts of virtuality on team functioning and outcomes are mixed (Marlow et al. 2017; Merschbrock and Munkvold 2015). In view of these considerations, investigating the impacts of virtuality on EPNs and the weight and strength of factors that affect virtuality are areas yet to be explored (Hosseini et al. 2016; Merschbrock and Munkvold 2014). Through the lens of the Big Five theory, this study aims at developing a model for virtuality for EPNs that answers two questions:

1. What are the weights and levels of influence of factors that affect virtuality in EPNs?
2. What are the major impacts of virtuality and its level of influence on the functioning of EPNs?
Background

The current manner in which teams work in the construction industry entails linking project members in EPNs electronically, as well as transferring and processing project data to and from these dispersed participants (Alin et al. 2013; Becerik-Gerber et al. 2012; Oraee et al. 2017). The use of EPNs is on the rise for several reasons. First, the business environment is changing while the construction workforce is becoming increasingly globalized (Iorio and Taylor 2014; Nithithamyong and Skibniewski 2011; Zelkowicz et al. 2015). In addition, economic fluctuations have resulted in fierce competition, which necessitates higher performance, access to global best talents, and international partnering (Chinowsky and Songer 2011; Zelkowicz et al. 2015). Moreover, due to the advent of technological innovations, including building information modeling (BIM) alongside virtual and augmented reality, virtual collaboration forms, such as EPNs are becoming mainstream (Oraee et al. 2017). Accelerated by technical advancements in Web and cloud computing (Petri et al. 2017), these have resulted in a rapid growth of EPNs on construction projects (Alreshidi et al. 2018; Merschbrock and Munkvold 2015; Mignone et al. 2016).

Virtuality

Members in EPNs have to cross several boundaries, such as organizational culture and practices, as well as geographic distance, to communicate and interact (Iorio and Taylor 2014; Mignone et al. 2016; Zhang and Ng 2013). These boundaries can be collectively conceptualized under the term virtuality as an attribute of such networks (Hosseini et al. 2016; Peñarroja et al. 2013; Schaubroeck and Yu 2017). Virtuality is the measure of proximity along a continuum in which one extreme is the traditional collocation of persons in a singular physical place, and the other extreme is where interacting persons do so from wholly mutually remote locations (Martins and Schipplzand 2011). As dichotomous as such a linear representation may appear to be—people are either physically near or not physically near—those elements that separate people or bring people together are in fact complex and multifaceted. Office arrangements and layouts; connective and communicative technologies; meeting, reporting, and work culture practices; among many other factors, all combine to enhance or detract from the effects of proximate work experience. Consequently, an examination of the singular concept of virtuality necessitates the actual examination of the multidimensional phenomenon (Dulebohn and Hoch 2017; Hosseini et al. 2015).

Factors Affecting Virtuality

Distance among members and the consequent increase in technology use has been treated as the key dimensions of virtuality (Dulebohn and Hoch 2017; Foster et al. 2015; Gilson et al. 2015). Yet, as asserted by Schaubroeck and Yu (2017), a variety of other factors, apart from distance, are influential. Six broad categories identified include temporal, cultural, spatial, organizational, work group, and relationship (Gilson et al. 2015). Indeed, a review of literature reveals that there is no agreement on what factors affect virtuality (Dulebohn and Hoch 2017). That is because virtuality is a context-specific phenomenon, hence factors affecting virtuality differ according to the context at hand (Ibrahim et al. 2013; Maynard et al. 2012).

In response to this disparity, Hosseini et al. (2016) identified the main factors that affect virtuality and customized them for the context of EPNs. Key factors were task nature, the number of team members (team size), and the skills and knowledge of these members. Other factors identified were disparity of context among members (termed as degree of dispersion), history of team collaboration (prior ties), and maturity of a team in supply chain relationships management. Hosseini et al. (2016), however, deployed a qualitative approach, thus the level of influence and strength of impacts of these factors on virtuality were not quantified. In fact, measuring the weight and strength of the factors that affect virtuality has remained an underresearched area in the literature (Schaubroeck and Yu 2017).

Impacts of Virtuality on Team Effectiveness (Big Five Theory)

Team effectiveness provides a holistic insight into how a team performs (i.e., how the team completed the team’s task), together with how the team interacted in achieving the final outcome (Franz et al. 2017; Salas et al. 2005). With this in mind, the Big Five theory of team effectiveness was used in the present study to conceptualize the impacts of virtuality on team functioning. The Big Five theory, as proposed by Salas et al. (2005), provides an appropriate theoretical lens to examine teamwork effectiveness (Kay et al. 2006). It was utilized in the present study because, according to Fransen et al. (2011), the Big Five theory is “[t]he best known framework for teamwork.”

The input-mediator-outcome (IMO) model incorporates all types of factors and mechanisms that link inputs to the effectiveness for teams (Mathieu et al. 2008) (Fig. 1). According to IMO, inputs represent the composition of a team, its structure, the organizational design, and the nature of the problem which provides the focus of activities for the team (Bosch-Sijtsema et al. 2011; Mathieu et al. 2008). The activities and interactions among team members, including their motivation, cognition, and affect make up the mediators that enable them to utilize the team’s resources synergistically (Bosch-Sijtsema et al. 2011). According to the Big Five theory, five key factors together with three supporting processes have active roles as mediators of team effectiveness. The five factors are leadership, backup behavior, mutual performance monitoring, team orientation, and adaptability. The three supporting processes are mutual trust, communication, and shared mental models (Salas et al. 2005). The Big Five theory is a theory applicable to all types of teams; however, the generic form of the Big Five theory is to be customized for specific contexts or particular types of teams (Fransen et al. 2011). Through a qualitative approach, Hosseini (unpublished data, 2016) provided a revised version of the Big Five theory for construction teams. According to this model, factors applicable to construction project teams were backup behavior, leadership, team orientation, and accountability. Supporting processes comprised communication, mutual trust, social interactions, and shared mental models.

Outcomes are the results expected of teams and cover a wide range of factors that are encapsulated in the concept of team effectiveness (Kozlowski and Ilgen 2006). The effectiveness of a team is measured by indicators such as (1) task-related indicators, namely, team performance (i.e., quantity, quality, timeliness, and customer satisfaction); and (2) affect-related indicators, such as team member satisfaction (Kozlowski et al. 2015). In the same vein, in their authoritative work, Mathieu et al. (2008) maintained that the team effectiveness framework should include “performance (e.g., quality and quantity) and members’ affective reactions (e.g., satisfaction, commitment, and viability).”

As a real-life example provided by Franz et al. (2017), establishing a common culture in a team can be seen as the input. Development of this team into a single working unit, however, is mediated through the level of integration achieved on the project (as a mediator). These contribute to final completion of the construction

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project on budget, schedule, and according to expected quality (overall performance, as an element of effectiveness).

Conceptual Model
The major factors affecting virtuality in EPNs were drawn from the study by Hosseini et al. (2016). As for the mediators (factors and supporting processes), the revised version of the Big Five theory for construction project teams (Hosseini, unpublished data, 2016) was utilized as the source. There were four factors: (1) leadership, (2) backup behavior, (3) team orientation, and (4) accountability. Similarly, there were four supporting processes: (1) mutual trust, (2) communication, (3) shared mental models, and (4) social interactions. Moreover, indicators of team effectiveness were encapsulated into two factors: performance and satisfaction of members, as recommended by Mathieu et al. (2008) (Fig. 2).

Research Methods
Factors that affect virtuality in teams are to be seen and measured as subjective phenomena (Siebdrat et al. 2014). As an example, deploying objective measures of distance as a factor affecting

Fig. 1. Conceptualizing the impacts of virtuality on team effectiveness.

Fig. 2. Conceptual model of the study.
vitality leads to misleading results (Siebdrat et al. 2014). That is because, “treating distance in purely objective terms provides an incomplete view of how people experience it” (Wilson et al. 2005). In the same vein, regarding the impacts of virtuality on team effectiveness, Laurey and Raisinghani (2001) proposed that “team member perceptions can be extremely valid predictors of the team’s effectiveness since team members are central to the work, and thus, they directly influence the team’s productivity and satisfaction.” Consequently, the aggregation of shared perceptions among team members is the major indicator for factors affecting virtuality and is the predictor of team outcomes and effectiveness (Siebdrat et al. 2014).

This distinction is not a trivial matter. If the distance of virtuality to be measured is a subjective one, then the method by which it is measured must correspond. In this regard, questionnaires, rather than direct quantitative approaches, are suitable. Here, the use of questionnaires is not merely a resort of practical expediency, but, rather, the most appropriate research tool for this study.

**Survey Design**

Survey is a robust, ubiquitous method used in the research field for the collection of perceptions from a population of interest. Thus, a questionnaire was deemed the best approach for testing the validity of the conceptual model. It comprised two parts, as illustrated in the Supplemental Data. The first collected demographic attributes of the respondents, while the second assessed factors affecting virtuality in EPNs along with impacts on virtuality that are associated with the effectiveness of EPNs.

Questions used were modeled on previous studies which, as indicated by Rowley (2014), is an efficient strategy for researchers attempting to measure complex and multidimensional concepts. A 7-point Likert scale (from 1 = very strongly disagree to 7 = very strongly agree) was used. This reduces skewness, improves normality, makes the data closer to interval-level scaling, while creating an adequate amount of variance (Blunch 2013). Pretesting was conducted with a group of 17 experts, and on the strength of the feedback received, the clarity of questions was strengthened with duplications eliminated; reducing the number of questions from 63 to 53.

**Sampling**

Survey Monkey was used as the online service for conducting the survey. Professional associations of construction practitioners in Australia (e.g., Master Builders, Australian Institute of Building, Civil Contractors Federation, and Australian Institute of Architects) were approached to distribute the questionnaire link. Similarly, building companies were contacted directly from website addresses and regulatory body lists. The kind of sampling chosen was stratified random sampling, with the stratified groups comprising architects, engineers, design consultants, contractors, facility managers, and project managers. As postulated by Robson (2002), “stratified random sampling can be more efficient than simple random sampling, in the sense that, for a given sample size, the means of stratified samples are likely to be closer to the population mean.”

The accumulated lists used for distributing the questionnaires included the contact details of 3,683 construction practitioners. The contacts belonged to 728 architectural companies; 1,308 contractors; 852 designing firms; and 795 construction management enterprises. In due course, 537 questionnaires were completed by the end of March 2015, with 475 of these completed to a sufficiently high level of 85%. Of the 475, 285 claimed previous involvement with EPNs, 76.5% of whom had more than 11 years of experience in the industry. Thus, these residual 285 questionnaires, showing a response rate of around 15%, formed the basis of the data set for the subsequent stages of data analyses. This was deemed acceptable given the novelty of the topic. Even so, response rates as low as 10–12% are not untypical of contemporary construction management research (Bing et al. 2005).

The professional areas in which respondents worked are illustrated in Fig. 3. This shows that the survey respondents covered a wide range of professions within the Australian construction industry. Thus, the views put forward are properly reflective of the general perceptions of practitioners working in construction project teams across the construction industry. As can be seen, the percentages are divided fairly equally between design practitioners (i.e., architects, civil/structural engineers, and quantity surveyors) and practitioners directly involved in on-site activities (contractors and building services).

**Structural Equation Modeling**

According to the test selection grid developed by Ho (2006), in circumstances in which the hypothesis falls within the category of relationships in which the nature of data could be regarded as interval, the method of analysis should be based on multivariate regression. On the other hand, in the present study, the main construct in the hypotheses was virtuality, which is an unobserved theoretical phenomenon that represents the degree of virtuality in teams, in which that virtuality is considered a latent variable (Ho 2006). Structured equation modeling (SEM) is capable of handling latent variables in multivariate regression analysis (Blunch 2013; Ho 2006) and is adopted in this study.

**Model Analysis**

**Constructing Parcels**

A common approach used to form SEM models involves aggregating two or more indicators into a parcel and using the parcel in lieu of individual indicators. First, forming parcels is a viable solution to the problems of both nonnormality when combined with the categorical nature of the data collated through Likert-scale questionnaires (Ho 2006). Second, using parcels instead of individual indicators for latent variables reduces the complexity of the model, facilitating greater stability of the parameter estimation (Blunch 2013). Thus, parceling is used, however, their reliability must be confirmed.

**Reliability Test**

The reliability of an instrument is associated with its consistency, which in turn has two major aspects, consistency over time and internal consistency (Ho 2006; Punch 2005). The present study meets the three key reliability requirements in creating parcels:

- Cronbach’s alpha coefficient value for the battery of measures for each concept is higher than 0.70 (Blunch 2013; Spector 1992).
- Corrected item-total correlation (the simple correlation between the item and the sum of the rest) is higher than 0.40 (Blunch 2013; Spector 1992).
- Squared multiple correlation [the coefficient of determination ($R^2$) when the item is regressed on the other items] is higher than 0.30 (Cronk 2014).
Validity Test
Exploratory factor analysis (EFA) is used to discover if a concept of interest is unidimensional or multidimensional (Spector 1992). Indicators were submitted to SPSS for analysis. Principal component analysis (PCA) with Varimax rotation was utilized to explore the underlying structure of each construct. All but two measures loaded cleared the minimum recommended (loading ≥ 0.5) (Spector 1992). Still, two of the eight measures for the concept of communications failed this test, and were, therefore, deleted from the battery of measures for the construct (Spector 1992). These were items measuring bidirectionality and sense of presence. The measures retained were considered sufficiently valid to form the basis for constructing the parcels in the present study.

Constructed Parcels
As mentioned, items were assigned to parcels on the basis of theoretical intended content of the parcel. In this approach, parcels represent concepts and their scores are calculated by summing the items assigned to that specific parcel (Spector 1992). Parcels were assembled using Eq. (1)

\[
\text{Parcel score}_i = \sum_{k=1}^{n} \text{items}_{ki}
\]

where \(i\) = observation number (\(i = 1\)–285); and \(k\) = number of items assigned to each parcel after validation of the items for that parcel. There is a strong underlying assumption regarding the multivariate normality of variables for SEM, with any deviation from this assumption resulting in incorrect interpretations. To test univariate normality in a data set, values for the skew index (SI) and kurtosis index (KI), with their standard errors, should be calculated. The ratio of the values of the SI and KI over the corresponding standard errors is a good measure as a \(z\)-test of the null hypothesis (Rose et al. 2015). Considering this, results of the test of normality for variables in the data set are presented in Table 1.

Values for SI/Standard error and KI/Standard error beyond ±1.96 suggest that distribution of a particular variable is not normal (Rose et al. 2015). As shown in Table 1, values above ±2.0 indicate that the variable distribution is very likely skewed, or has excess kurtosis, with few variables meeting the requirements of normality. The outcome of the analysis underscored the necessity of considering SEM techniques that are applicable to nonnormal categorical data.

Partial Least Squares Structural Equation Modeling
The two broad methods for conducting SEM are covariance based (CB-SEM) and partial least squares (PLS-SEM) (Hair et al. 2014). PLS-SEM is the most appropriate method when the nature of the study is more exploratory than confirmatory, with a less developed theoretical background. Therefore, PLS-SEM was used to test the model in the present study. A range of software packages for PLS-SEM are available, with SmartPLS, being one of the most common (Hair et al. 2014), and this package was used.

Model Specification
The model for SEM (Fig. 4) was developed according to the details shown in Fig. 2. Unlike software packages based on CB-SEM,
SmartPLS is able to analyze models in both formative and reflective forms. Since measures in the reflective form are viewed as representative samples of the possible items available in the domain of the associated concept, with the intention being that all measures are caused by the same concept, this approach was taken as the most appropriate. The assessment of PLS-SEM model generated follows a two-stage sequential procedure. This requires separate assessments of measurement models (indicators–constructs), and an assessment of the structural model, that is, between the constructs (Hair et al. 2014). Researchers then proceed to assessing the structural model after establishing the goodness of fit (GoF) of constructs of the specified model.

Table 1. Details of concepts in the model (constructed parcels)

<table>
<thead>
<tr>
<th>Concept</th>
<th>Number of items</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Skewness Statistic</th>
<th>Standard error</th>
<th>Kurtosis Statistic</th>
<th>Standard error</th>
<th>SI Statistic</th>
<th>Standard error</th>
<th>KI Statistic</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of dispersion</td>
<td>3</td>
<td>3.00</td>
<td>12.00</td>
<td>13.17</td>
<td>3.44</td>
<td>−0.679</td>
<td>0.144</td>
<td>0.628</td>
<td>0.288</td>
<td>−5.57</td>
<td>1.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maturity relationships</td>
<td>5</td>
<td>5.00</td>
<td>35.00</td>
<td>21.69</td>
<td>6.24</td>
<td>−0.278</td>
<td>0.144</td>
<td>−0.123</td>
<td>0.288</td>
<td>−2.17</td>
<td>−2.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Context disparity</td>
<td>5</td>
<td>5.00</td>
<td>33.15</td>
<td>22.60</td>
<td>5.02</td>
<td>−0.510</td>
<td>0.144</td>
<td>0.733</td>
<td>0.288</td>
<td>−3.07</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task nature</td>
<td>2</td>
<td>2.00</td>
<td>14.00</td>
<td>9.158</td>
<td>2.12</td>
<td>−0.959</td>
<td>0.144</td>
<td>1.534</td>
<td>0.288</td>
<td>−2.34</td>
<td>−0.37</td>
<td></td>
<td></td>
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<tr>
<td>Prior ties</td>
<td>2</td>
<td>2.00</td>
<td>14.00</td>
<td>8.77</td>
<td>2.51</td>
<td>−0.474</td>
<td>0.144</td>
<td>−0.008</td>
<td>0.288</td>
<td>−4.71</td>
<td>2.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KSAs</td>
<td>2</td>
<td>2.00</td>
<td>14.00</td>
<td>8.26</td>
<td>2.66</td>
<td>−0.214</td>
<td>0.144</td>
<td>−0.361</td>
<td>0.288</td>
<td>−1.92</td>
<td>−0.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of team</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>4.62</td>
<td>1.23</td>
<td>−0.803</td>
<td>0.144</td>
<td>0.566</td>
<td>0.288</td>
<td>−3.53</td>
<td>2.55</td>
<td></td>
<td></td>
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<tr>
<td>Backup behavior</td>
<td>2</td>
<td>3.00</td>
<td>14.00</td>
<td>9.15</td>
<td>2.34</td>
<td>−0.426</td>
<td>0.144</td>
<td>−0.324</td>
<td>0.288</td>
<td>−6.64</td>
<td>5.33</td>
<td></td>
<td></td>
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<tr>
<td>Leadership</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>4.42</td>
<td>1.24</td>
<td>−0.313</td>
<td>0.144</td>
<td>−0.660</td>
<td>0.288</td>
<td>−3.29</td>
<td>−0.03</td>
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<tr>
<td>Team orientation</td>
<td>2</td>
<td>2.00</td>
<td>14.00</td>
<td>8.83</td>
<td>2.43</td>
<td>−0.284</td>
<td>0.144</td>
<td>−0.245</td>
<td>0.288</td>
<td>−1.48</td>
<td>−0.12</td>
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<tr>
<td>Accountability</td>
<td>2</td>
<td>2.00</td>
<td>14.00</td>
<td>8.89</td>
<td>2.31</td>
<td>−0.295</td>
<td>0.144</td>
<td>0.035</td>
<td>0.288</td>
<td>−2.95</td>
<td>−1.13</td>
<td></td>
<td></td>
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<tr>
<td>Communications</td>
<td>6</td>
<td>10.00</td>
<td>42.00</td>
<td>27.11</td>
<td>6.49</td>
<td>−0.293</td>
<td>0.144</td>
<td>−0.301</td>
<td>0.288</td>
<td>−1.97</td>
<td>−0.85</td>
<td></td>
<td></td>
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<tr>
<td>Maturity trust</td>
<td>2</td>
<td>2.00</td>
<td>14.00</td>
<td>8.780</td>
<td>1.97</td>
<td>−0.069</td>
<td>0.144</td>
<td>0.165</td>
<td>0.288</td>
<td>−2.04</td>
<td>0.12</td>
<td></td>
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<tr>
<td>Social interactions</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>4.80</td>
<td>1.18</td>
<td>−0.337</td>
<td>0.144</td>
<td>−0.107</td>
<td>0.288</td>
<td>−2.03</td>
<td>−1.05</td>
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<tr>
<td>Shared mental models</td>
<td>2</td>
<td>3.00</td>
<td>14.00</td>
<td>9.42</td>
<td>2.12</td>
<td>−0.402</td>
<td>0.144</td>
<td>−0.305</td>
<td>0.288</td>
<td>−0.48</td>
<td>0.57</td>
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<td></td>
</tr>
<tr>
<td>Performance</td>
<td>4</td>
<td>4.00</td>
<td>28.00</td>
<td>16.96</td>
<td>4.32</td>
<td>−0.337</td>
<td>0.144</td>
<td>0.409</td>
<td>0.288</td>
<td>−2.79</td>
<td>−1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfaction of members</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>4.74</td>
<td>1.18</td>
<td>−0.444</td>
<td>0.144</td>
<td>0.193</td>
<td>0.288</td>
<td>−2.34</td>
<td>1.42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: SI = skewness statistic; KI = kurtosis statistic; KSA = knowledge, skills, and abilities.

Fig. 4. Specified model (based on model in Fig. 2) with initial estimation of loadings and path coefficients.
Assessment of Measurement Models

According to Hair et al. (2014), the assessment of measurement models comprises an estimation of (1) reliability of individual indicators; (2) composite reliability; (3) average variance extracted (AVE); and (4) discriminant validity.

Indicators in the model that show an outer loading below 0.40 should be eliminated from further analysis (Hair et al. 2014). Such indicators do not have much in common with other indicators captured by their common construct. In view of the results (Fig. 4), task nature, degree of dispersion, and size of team, as highlighted in Fig. 4, were eliminated from the battery of indicators for the virtuality construct, since the outer loadings were significantly lower than other indicators, and well below the threshold.

After the removal of these indicators, this process led to a revised model for the virtuality construct. The outer loadings for the revised model are presented in Table 2.

Prior ties also showed loadings below 0.40 in the initial model; however, the outer loading increased to 0.50 in the revised model and was within the acceptable range (Table 2), hence its removal was not necessary.

Due to the limitations of Cronbach’s alpha (sensitivity to the number of items involved), composite reliability (ρc) was used to assess the internal consistency (Hair et al. 2014). Values above 0.60 are acceptable (Hair et al. 2014), and since all constructs in the model met this threshold, all were accepted. AVE is a common measure used to establish the convergent validity of the constructs in the model with values greater than 0.50, indicating acceptable convergent validity. Again, all constructs met this test. Finally, checking the cross-loadings of indicators on constructs is a measure used to establish discriminant validity. Discriminant validity is established when an indicator’s loading on a construct is higher than all cross-loadings of the other constructs. This was established, with validity of all indicators confirmed (Table 2).

Assessment of the Structural Model

The next stage involved investigating the structural model to show whether it can be empirically confirmed, and to assess how well the empirical data supports the underlying theory of the study (Hair et al. 2014). The study’s structural model, including the relationships between the latent variables, was assessed using five features: (1) collinearity issues; (2) significance of path coefficients; (3) level of $R^2$ values; (4) the effect size ($f^2$); and (5) the predictive relevance ($Q^2$).

In the model, illustrated in Fig. 4, the factors and supporting processes constructs are both predictors of the effectiveness construct. A multiple regression was run with effectiveness as the dependent variable, and factors and supporting processes as independent variables. Tolerance values below 0.2, or variance inflation factor (VIF) values above 5, are indicative of unacceptable collinearity among the predictors. Both values were within the acceptable range and, consequently, there was no issue with collinearity.

The significance of path coefficients in PLS-SEM models is estimated using the bootstrapping method. The number of bootstrapping samples was set at 5,000, as recommended by Hair et al. (2014) for PLS-SEM models in a two-tailed test. Because all $t$-values were well above the threshold (2.57), the associations in the model all proved significant (significance level = 1%).

As recommended by Hair et al. (2014), adjusted $R^2$ is a preferred measure to assess the power of the model in predicting endogenous constructs, removing bias due to the complexity of the model. The adjusted $R^2$ values for endogenous constructs, that is, effectiveness, factors and supporting processes, were 0.71, 0.045, and 0.059, respectively. Effectiveness is strongly against factors and supporting processes, explaining at least 70% of the variance in effectiveness in EPNs. However, virtuality merely predicted 4 and 6% of the variations in factors and supporting processes, respectively, although these relationships were found to be significant.

The effect size, that is $f^2$, is used to assess whether a particular exogenous construct in the model has a substantial impact on endogenous constructs. SmartPLS is able to provide $f^2$ values for exogenous constructs in the model. Values for factors and supporting processes on effectiveness were above 0.15. On the other hand, values for virtuality on factors and supporting processes were around 0.02. Thus, as asserted by Cohen (2013), the effect size of factors and supporting processes on effectiveness was moderate, while the effect size of virtuality on factors and supporting processes was small.

Blindfolding analysis was carried out to assess the predictive suitability of the model. The omission distance was $D = 7$, with estimations provided by construct cross-validated redundancy, in accordance with the approach prescribed by Hair et al. (2014). Values of $Q^2$ larger than zero indicate that exogenous constructs in a model have predictive relevance for the endogenous constructs in that model. Because all $Q^2$ values were above zero, this indicated the predictive relevance of the model. However, virtuality, as the exogenous construct, only had small predictive relevance for factors and supporting processes, whereas factors and supporting processes had medium predictive relevance for effectiveness.

Model Interpretation

The loadings of the indicators (significant associations) in reflective measurement models are indicative of the relative importance of

### Table 2. Summary of the revised reflective measurement models

<table>
<thead>
<tr>
<th>Construct</th>
<th>Indicators</th>
<th>Loadings</th>
<th>Indicator reliability</th>
<th>Composite reliability ($\rho_c$)</th>
<th>Average Discriminant validity?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtuality</td>
<td>Context disparity</td>
<td>0.70</td>
<td>0.49</td>
<td>0.835</td>
<td>0.570</td>
</tr>
<tr>
<td></td>
<td>KSAs</td>
<td>0.89</td>
<td>0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maturity relationships</td>
<td>0.87</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prior ties</td>
<td>0.50</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factors</td>
<td>Accountability</td>
<td>0.83</td>
<td>0.69</td>
<td>0.917</td>
<td>0.735</td>
</tr>
<tr>
<td></td>
<td>Backup behavior</td>
<td>0.88</td>
<td>0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leadership</td>
<td>0.83</td>
<td>0.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Team orientation</td>
<td>0.89</td>
<td>0.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supporting</td>
<td>Communications</td>
<td>0.83</td>
<td>0.69</td>
<td>0.851</td>
<td>0.593</td>
</tr>
<tr>
<td>processes</td>
<td>Mutual trust</td>
<td>0.57</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shared mental models</td>
<td>0.87</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social interactions</td>
<td>0.78</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Performance</td>
<td>0.91</td>
<td>0.83</td>
<td>0.897</td>
<td>0.814</td>
</tr>
<tr>
<td></td>
<td>Satisfaction of members</td>
<td>0.90</td>
<td>0.81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the indicators with regard to their common factor (Hair et al. 2014). As shown in Table 3, the indicator members’ knowledge, skills and abilities (KSAs), with a loading of 0.89 on virtuality, was found to have the highest influence on virtuality. Contrariwise, the indicator prior ties (loading = 0.50) was the least important factor in association with virtuality. By the same token, team orientation was the most important indicator for factors (loading = approximately 0.90) and leadership was the indicator with the least level of influence on factors (loading = 0.828) in the model.

In terms of indicators associated with supporting processes, the indicator shared mental models was ranked first in terms of relative importance, while mutual trust was the least important of the four indicators. The indicators, satisfaction of members and performance, were found to be similar in terms of their relative importance, with loadings for both of close to 0.90.

A significant association between virtuality and effectiveness was observed (significance level = 1% due to t-value > 2.57); thus, an increase in virtuality is significantly and positively associated with a reduction in effectiveness. Nevertheless, the value of the path coefficient was found to be close to 0.22, indicating that the association between virtuality and effectiveness was weak. Converting this path coefficient by the amount of explained variance (R^2 = 0.22^2 = 0.048) shows that virtuality is responsible less than 5% of the variance in effectiveness in EPNs. In essence, 95% of the variations in effectiveness stem from factors other than virtuality. This clearly points to the small role virtuality plays with regard to changes in the effectiveness of EPNs. The total impacts of virtuality on the indicators of factors in the model are shown in Table 4.

### Discussion of Findings

The present study tested a revised version of the Big Five theory for EPNs. In so doing, it offered significant insights on the role of virtuality with regard to EPN effectiveness.

### Factors Affecting Virtuality in EPNs

As far as virtuality is concerned, the findings do not uphold the widely held view that the degree of dispersion, size of team, and task nature strongly impact the virtuality of EPNs. This study thus indicates a shift in the work culture of EPNs to one that is more accommodating and adapted to its usage. Previous seminal studies, such as those by Watson-Manheim et al. (2002) and O’Leary and Cummings (2007), have regarded the degree of dispersion as a pillar of virtuality for teams. The present study reveals rather that such findings have eroded with regard to EPNs. This is explicable in light of evolving remote work practices and the concept of “death of distance” (Yamin and Sinkovics 2006), in which, due to extensive experience with online internationalization, any form of disparity will likely erode. As a response to internationalization pressures, the construction industry is moving toward delivering

### Table 3. Relative importance of indicators in the model

<table>
<thead>
<tr>
<th>Association</th>
<th>Loadings</th>
<th>t-statistics</th>
<th>p-values</th>
<th>Rank (relative importance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSAs—virtuality</td>
<td>0.888</td>
<td>11.543</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>Maturity relationships—virtuality</td>
<td>0.866</td>
<td>12.324</td>
<td>0.000</td>
<td>2</td>
</tr>
<tr>
<td>Context disparity—virtuality</td>
<td>0.704</td>
<td>6.013</td>
<td>0.000</td>
<td>3</td>
</tr>
<tr>
<td>Prior ties—virtuality</td>
<td>0.497</td>
<td>3.301</td>
<td>0.001</td>
<td>4</td>
</tr>
<tr>
<td>Team orientation—factors</td>
<td>0.891</td>
<td>53.556</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>Backup behavior—factors</td>
<td>0.875</td>
<td>47.416</td>
<td>0.000</td>
<td>2</td>
</tr>
<tr>
<td>Accountability—factors</td>
<td>0.834</td>
<td>34.937</td>
<td>0.000</td>
<td>3</td>
</tr>
<tr>
<td>Leadership—factors</td>
<td>0.828</td>
<td>29.982</td>
<td>0.000</td>
<td>4</td>
</tr>
<tr>
<td>Shared mental models—supporting processes</td>
<td>0.868</td>
<td>51.225</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>Communications—supporting processes</td>
<td>0.825</td>
<td>31.453</td>
<td>0.000</td>
<td>2</td>
</tr>
<tr>
<td>Social interactions—supporting processes</td>
<td>0.781</td>
<td>25.568</td>
<td>0.000</td>
<td>3</td>
</tr>
<tr>
<td>Mutual trust—supporting processes</td>
<td>0.573</td>
<td>7.532</td>
<td>0.000</td>
<td>4</td>
</tr>
<tr>
<td>Performance—effectiveness</td>
<td>0.906</td>
<td>76.832</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>Satisfaction of members—effectiveness</td>
<td>0.898</td>
<td>67.373</td>
<td>0.000</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 4. Total impacts of virtuality on indicators in the structural model

<table>
<thead>
<tr>
<th>Structural model association</th>
<th>Path coefficient (1)</th>
<th>Measurement models’ associations</th>
<th>Loadings (2)</th>
<th>Total impacts’ association</th>
<th>Total impacts’ value (1) × (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtuality—effectiveness</td>
<td>0.206</td>
<td>Performance—effectiveness</td>
<td>0.906</td>
<td>Virtuality—performance</td>
<td>0.187</td>
</tr>
<tr>
<td>Virtuality—effectiveness</td>
<td>0.206</td>
<td>Satisfaction of members—effectiveness</td>
<td>0.898</td>
<td>Virtuality—saturation of members</td>
<td>0.185</td>
</tr>
<tr>
<td>Virtuality—factors</td>
<td>0.219</td>
<td>Team orientation—factors</td>
<td>0.891</td>
<td>Virtuality—team orientation</td>
<td>0.195</td>
</tr>
<tr>
<td>Virtuality—factors</td>
<td>0.219</td>
<td>Backup behavior—factors</td>
<td>0.875</td>
<td>Virtuality—backup behavior</td>
<td>0.192</td>
</tr>
<tr>
<td>Virtuality—factors</td>
<td>0.219</td>
<td>Accountability—factors</td>
<td>0.834</td>
<td>Virtuality—accountability</td>
<td>0.183</td>
</tr>
<tr>
<td>Virtuality—factors</td>
<td>0.219</td>
<td>Leadership—factors</td>
<td>0.828</td>
<td>Virtuality—leadership</td>
<td>0.181</td>
</tr>
<tr>
<td>Virtuality—supporting processes</td>
<td>0.249</td>
<td>Shared mental models—supporting processes</td>
<td>0.868</td>
<td>Virtuality—shared mental models</td>
<td>0.216</td>
</tr>
<tr>
<td>Virtuality—supporting processes</td>
<td>0.249</td>
<td>Communications—supporting processes</td>
<td>0.825</td>
<td>Virtuality—communications</td>
<td>0.205</td>
</tr>
<tr>
<td>Virtuality—supporting processes</td>
<td>0.249</td>
<td>Social interactions—supporting processes</td>
<td>0.781</td>
<td>Virtuality—social interactions</td>
<td>0.194</td>
</tr>
<tr>
<td>Virtuality—supporting processes</td>
<td>0.249</td>
<td>Mutual Trust—supporting processes</td>
<td>0.573</td>
<td>Virtuality—mutual trust</td>
<td>0.143</td>
</tr>
</tbody>
</table>
business in the form of e-commerce (Zelkowicz et al. 2015). This shift is associated with a diminution of the sense of dispersion for teams and companies (Yamin and Sinkovics 2006).

Also indicated is that for generic tasks assigned to EPNs, the size of a team does not impact perceptions of virtuality. Similarly, task nature also has limited impact. Complexity, the uncertainty of tasks, the involvement of a large number of organizations and disciplines, and the necessity of having skilled personnel from diverse locations are inherent to EPNs (Mignone et al. 2016). Simply, there is no perceived variance in task nature and size of teams associated with the level of virtuality among different EPNs.

Contrariwise, four factors were found to be influential on the level of virtuality in EPNs. As shown in Table 3, these are members’ KSAs; maturity of teams; context disparity; and prior ties. A few conceptual studies, such as Martins et al. (2004), have pointed out the likelihood of a link between virtuality and members’ KSAs. However, the findings of the present study have established the existence of a direct link between members’ KSAs and virtuality for EPNs. Likewise, the maturity of a team in handing supply chain relationships as a contributor to virtuality has been overlooked in the extant literature. Nevertheless, the concept of “team resiliency,” namely, the “ability to absorb high levels of change while displaying minimal dysfunctional behavior” (Hoopes 1999), is a direct outcome of team maturity.

The findings of the case study in the construction context by Mignone et al. (2016) identified the impacts of context disparity on a wide range of performance and effectiveness dimensions in EPNs. In this study, prior ties as a concept was found to be two dimensional, with its dimensions being (1) a history of collaboration prior to forming the current team, and (2) the time team members have spent together in the current team. Ortiz de Guinea et al. (2012) acknowledged the impacts of working in previous teams on virtuality. However, prior ties in the present study is conceptualized as the total amount of time that team members have worked together, whether in a previous team or only the current team.

**Impacts of Virtuality on Effectiveness of EPNs**

The findings reveal a number of original insights into the association of virtuality with the effectiveness of teams, as mediated through the Big Five theory factors and supporting processes. Principally, the findings spotlight that the negative impacts of virtuality found in previous studies are overemphasized. Even so, what negative impacts there are can be fully managed through alterations in team configuration (Eubanks et al. 2016). Moreover, as technology continues to improve and teams increasingly become iterations in team configuration (Eubanks et al. 2016). Moreover, as the total amount of time that team members have worked together in the current team. Ortiz de Guinea et al. (2012) acknowledged the impacts of working in previous teams on virtuality. However, prior ties in the present study is conceptualized as the total amount of time that team members have worked together, whether in a previous team or only the current team.

Leadership, as a dimension of factors (from the Big Five theory), is highly influential on the performance of EPNs. Nevertheless, change in the level of virtuality affects leadership only slightly. Self-leadership by far outweighs managers’ leadership at higher levels of virtuality owing to the lower influence of leaders on members working at a distance (Andressen et al. 2012) including EPNs.

Accountability as an area influenced by virtuality has remained unexplored within the extant literature. The present study’s findings reveal that accountability is indeed significant, albeit weakly associated with variations of accountability in EPNs. Lack of accountability may be the result of diminished supervision, feedback, and control (West 2012).

The present study’s findings also show an association between virtuality and the factors that reflect supporting processes. The direct association of shared mental models with the effectiveness of teams has also been recognized in previous studies (Jonker et al. 2011). The present study’s findings, however, reveal that the impacts of virtuality on shared mental models are higher than its impacts on communications. Contrary to the widespread perception that communication is the supporting process most negatively affected by virtuality (Hosseini et al. 2015), shared mental models is the process shown to have highest level of variance due to virtuality. Developing shared mental models thus requires extensive interactions between members, the exchange of rich information, combined with a history of cooperation between team members (Fransen et al. 2011).

Communication and interaction between members in EPNs are negatively affected at higher levels of virtuality (Nayak and Taylor 2009). Moreover, construction teams are inherently temporary (Rezgui 2007). The combined outcome of these points engenders shared mental models becoming the supporting process most affected by virtuality. Previous researchers (Martins et al. 2004; Peñarroja et al. 2013) have suggested that an increase in virtuality significantly diminishes communication, leading to a reduction in performance (Ferreira et al. 2012; Schweitzer and Duxbury 2010). Here, however, the impacts for EPNs are by far lower than previously asserted.

Researchers from the construction industry have endorsed the view that virtuality has a clear negative impact on levels of mutual trust (Peñarroja et al. 2013), while Bierly et al. (2009) have challenged this belief. This study confirms a strong association between virtuality and mutual trust for EPNs.

Moreover, virtuality was found to impact satisfaction of members and ultimately the effectiveness for teams. However, the impacts of virtuality on the satisfaction of members have remained unreported within the extant literature, particularly within the construction context. Few studies in the construction context, including that by Nayak and Taylor (2009), have been able to identify significant frustration among members working in dispersed teams.

**Implications for Practice**

With EPN use growing exponentially, this study’s outcomes could benefit organizations, construction firms, and managers by providing fresh insight into the nature of working in EPNs. Specifically, the findings provide guidelines to assess and develop essential competencies for working in EPNs, and could promote improved interactions and performance in EPNs. As such, the practical implications associated with the findings are summarized subsequently.

**Increased Awareness of EPNs**

The present study’s findings raise the level of awareness of managers and construction practitioners in dealing with potential issues inherent to EPNs, and in devising plans to deal with such challenges. Moreover, the quantification of associations provides a tool for generating predictions on the basis of level of virtuality.

**Implications for Training for EPNs**

The findings of the study could assist in providing training on effective styles of leadership for EPNs, backup behavior, and measures to develop trust and maintain communications. These areas are a few examples of what could be included within the topics for training prior to EPN involvement.
Design and Structure of EPNs

The present study’s findings lay a solid foundation for construction organizations, managers, and companies to make informed decisions on the adaptation of EPNs within the overall organizational structure of construction projects. In designing and arranging EPNs, the desired level of effectiveness could be achieved through the manipulation of influential variables.

Implications for Performance and Effectiveness in EPNs

The model of virtuality presented in this study illustrates the drivers and inhibitors of effectiveness and performance when it comes to implementing EPNs in construction projects. This leads to identifying the main variables and areas that require concentrated management interventions needed to facilitate a supportive workplace environment.

Limitations of the Study and Future Research

The findings are to be treated in light of the limitations of the study. The building blocks of the conceptual model deployed in the present study rely on the available literature on virtuality. This body of knowledge is, however, limited, being in its infancy and yet to reach maturity. This resulted in the inclusion of a number of concepts in the conceptual model (such as shared mental models and team orientation) which may be difficult to operationalize. In formulating the questionnaire, semistructured interviews were used to consolidate the content, and to fit the items to the construction setting. While the number of interviews was adequate for a qualitative study, the novelty of the concept of virtuality for industry practitioners may have interfered with informant responses.

A further limitation stems from the sampling strategy. In this study, interviewees and respondents were practitioners working in the Australian construction industry. Clearly, the perceptions of construction practitioners from other countries and in other contexts may differ. Therefore, generalizability of the findings is tentative. Nevertheless, further contexts and settings could serve as a basis for further research, with larger quantitative samples.

Of course, a further limitation lies with the reliance on data collected from questionnaire surveys themselves. Although the method is ubiquitous and indeed well suited to the collection of subjective perceptions of humans, as is the case here, they do attract the criticism that results are variable when tests are replicated. Nevertheless, the return of 475 usable questionnaires, with 76% having more than 11 years’ relevant experience, provides a benchmark against which further research into this area can be usefully compared and contrasted.

Conclusion

The present study conducted an empirical investigation on virtuality in EPNs within the construction context. It offers the first quantified model linking virtuality with the effectiveness of EPNs. In this regard, the study developed theories that were based on findings imported from information technology (IT), and management and business disciplines, modifying them through exposure to empirical data from the construction context. This facilitated “the transferability and applicability” of existing theories from other disciplines to the specific setting of construction.

Both the Big Five theory and the IMO model are well-known theoretical frameworks in the literature. However, the present study used virtuality as an input, connecting it with effectiveness in hybrid teams by synthesizing the IMO model and the Big Five theory. This presents a new interpretation of the associations of virtuality with effectiveness.

Furthermore, the present study provides an original insight into the phenomenon of virtuality through the use of contingency approaches. Contingency approaches provide an original understanding on a topic by bringing to light “what processes and practices apply in which contexts, what relationships hold or do not hold in which contexts and where do methods work and do not work or how do they vary in different contexts” (Boer et al. 2015). This refers to the findings of the study illustrating the specific factors that were not influential in the context of EPNs, as well as the items that were overlooked within the existing literature, yet were revealed in the present study.

Data Availability Statement

Data generated by the authors or analyzed during the study, along with created models, are available at https://figshare.com/s/40c40d257ede4aeb4aeb56f. Information about the Journal’s data sharing policy can be found here: http://ascelibrary.org/doi/10.1061/%28ASCE%29CO.1943-7862.0001263.

Supplemental Data

The questionnaire used in this study is available online in the ASCE Library (www.ascelibrary.org).

References


