

# BUILDING INFORMATION MODELLING (BIM) CAPABILITY AND DELIVERY SUCCESS ON CONSTRUCTION PROJECTS

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**Purpose:** Despite emerging research on Building Information Modelling (BIM) capability assessment, there is a general dearth of knowledge about the links between often pre-emptive capability measurement attributes and actual delivery success. More so, current studies have not considered success from the wider construction supply chain (CSC) perspective. So far, the perceived importance of capability metrics is not based on post-project evaluations of their contribution to BIM delivery success. This research identifies 28 relevant BIM capability attributes used for qualifying CSC organisations for projects, as well as investigates their relative importance and influence on some key aspects of BIM delivery success.

**Design/methodology/approach:** Based on heretofore validated set of BIM capability attributes from semi-structured interviews and a Delphi study, a survey of CSC firms on BIM-enabled projects was used to model the influence of BIM capability attributes on BIM delivery success. Multiple regression modelling was performed to ascertain the nature of the relationship between BIM capability attributes and key aspects of BIM delivery success as identified from the literature.

**Findings:** BIM *staff experience* and the *suitability of proposed methodology* prior to project commencement were identified as the most influential on BIM delivery quality, as well as delivery within schedule and on budget. Conversely, the *administrative and strategic* level capacities were found as the most influential in leveraging collaboration, coordination or integration of the CSC on projects through BIM.

**Originality/value:** This study provides a step change in prioritizing BIM capability criteria based on evidence of their contribution to delivery success in key performance areas rather than their perceived importance as capability metrics as widely practiced.

**Keywords:** Building Information Modelling (BIM), Construction Supply Chain (CSC), Delivery Success, Performance and Construction Projects

## **Introduction**

Building Information Modelling (BIM) has become a pre-requisite on many construction projects and is expected to eliminate information flow inefficiencies through virtual collaborative technologies (Arayici et al., 2012). The Construction Supply Chain (CSC) is expected to evolve in terms of their capacity and competencies in BIM-based processes and technology use in order to succeed in the delivery of projects. Despite the emergence of several frameworks for measuring BIM capability, it remains unclear which capability attributes are most relevant and responsible for successful delivery of BIM (Succar et al., 2012). In this study 'capability attribute' is used to describe criteria that denote the maturity and capacity to deliver BIM tasks competently and successfully. The assessment of BIM capability has often been pre-emptive with a general lack of empirical justification for selection of relevant capability criteria or attributes (Kam et al., 2013b; 2014; Smits et al., 2016). However, given an increase in the number of projects using BIM over the past decade (BIS 2013a; NBS, 2016), there is sufficient basis for examining the influence of the most widely used BIM capability measurement attributes on successful delivery of BIM. Furthermore, the success criteria examined must include important CSC performance resulting from BIM use on construction projects. This will enable the identification of potential differences and peculiarities across different CSC organisational and project profiles. In summary several different criteria have been promoted for use in evidencing the ability to deliver BIM in existing studies. None of these studies have, however, specifically looked at the influence of the proposed criteria on actual BIM delivery success of projects in order to aid more informed prioritisation of capability attributes during assessments.

To address the identified gaps, the most critical capability attributes being used to assess the BIM capability of firms were identified and prioritised. The prioritisation was based on the attributes' perceived contribution to the successful delivery of BIM with specific focus on supply chain success through BIM as well as BIM delivery quality, within schedule and cost. The assessment is based on the impact of these attributes on specific BIM delivery success areas identified from the literature and relating specifically to the CSC context of BIM use. In the following sections, a review of literature relating to BIM capability and delivery success is first presented. The research methodology applied in the study is then outlined. Subsequent to this, the research findings, their discussion and concluding remarks are presented.

## **BIM Capability and BIM Delivery Success**

According to Holt (1998) and Doloi (2009), the main premise on which an organisation should be selected for projects must be their likelihood to succeed or meet the project objectives. Thus, any efforts towards assessing BIM capability of a CSC organisation (for project pre-qualification or selection) must be premised on an understanding of the actual influence of the capability attributes measured on the likelihood of success (Mahamadu *et al.*, 2017). Project success is generally described as attainment or exceeding of project objectives (Takim and Akintoye, 2002). While some studies have explored the role

of BIM maturity in project performance generally (Smits *et al.*, 2016), there remain no studies specifically looking at BIM delivery success, especially in the CSC context. Emerging standards, frameworks and tools provide a basis for identifying appropriate BIM capability or qualification criteria for selecting CSC organisations on BIM-enabled projects (Succar, 2009; van Berlo *et al.*, 2012; NIBS, 2012; CIC, 2013a; Kam *et al.*, 2013a,b; Succar *et al.*, 2013; Du *et al.*, 2014; Giel and Issa, 2014; Azzouz and Hill, 2017). However, none of these initiatives provide relevant details about the influence of the BIM utilisation capacity measures on delivery success.

### **Capability Criteria and Success**

Doloi (2009) used multiple regression analysis to investigate the impact of 43 contractor capability criteria on project success. From the findings, technical expertise, past success, time in business, work methods and working capital emerged as the most influential on contractor's delivery success on a project. Arslan *et al.* (2008) proposed that capability criteria must be categorised based on their contribution to the attainment of quality, cost and time. Al-Zahrani and Emsley (2013) studied the impact of construction qualification related attributes on the success of completed projects. Based on logistic regression analysis, adequacy of labour ( $\beta = 1.284$ ) emerged as most influential on delivery on schedule and on budget, while size of past project completed ( $\beta = 0.893$ ) was most influential on delivery of quality on projects. Understandably, most construction pre-qualification and selection studies predate the recent mandates for BIM use in many countries, thus, criteria considered in such studies do not include BIM capability or BIM delivery success, more so, not in the CSC context (Mahamadu *et al.*, 2017). Recently, Smits *et al.* (2016) surveyed organisations in the Netherlands to identify the influence of BIM maturity elements on project performance. The maturity elements investigated in this study were strategy, BIM uses, process, information, infrastructure and personnel. Except for strategic level maturity attributes, which marginally predicted time, cost and quality performance of projects, this study found no statistically significant associations between BIM maturity and project success (time and cost). The findings were also inconclusive about the effect of BIM maturity on delivery of project quality. As a result, Smits *et al.* (2016) cautioned against over optimism in the expectations that BIM will improve project performance and success overall. Abdirad (2017) also reviewed existing approaches, metrics, and criteria used for assessing BIM implementation and revealed the lack of studies examining the role of BIM maturity in the attainment of delivery success. Mom *et al.* (2014) and Tsai *et al.* (2014) identified the following critical success factors of BIM implementation including organisational strategy; leadership; readiness; capabilities and resources; BIM application; BIM tools; BIM Business model; and BIM processes. These studies did not however distinguish between success factors and maturity elements. More recently, Antwi-Afari *et al.* (2018) performed a longitudinal review of BIM success factors and revealed the need for quality, effectiveness and efficiency in delivery. Despite the relevance of these studies, the factors

investigated related to project success and strategic implementation measures of success rather than success in the delivery of BIM itself or the CSC context of BIM use.

### **Success Factors in BIM Delivery**

A review of BIM benefits and performance assessment literature provides useful pointers to some of the most important indicators of success in the BIM and CSC context. Several studies highlight the applicability of the traditional view of success to BIM delivery. For instance, Mom *et al.* (2011) acknowledged the importance of quality, time and cost in the delivery of BIM value. Smits *et al.* (2016) relied on the *iron triangle* metrics (quality, cost and time) to assess the impact of maturity elements on project success. According to Atkins (1995) and Salmeron (2010), the traditional view of project success (quality, time, and cost) is a valid measure of the success of information systems. More specifically, the success of information systems in construction projects should be based on data accuracy, timeliness, control and auditability (Atkins, 1995). Saleh and Alshawi (2005), similarly, relied on timeliness of implementation and cost as a measure of success in the implementation of information systems in the construction industry. Du *et al.* (2014) developed a framework for benchmarking BIM modelling performance with emphasis on quality, time and cost efficiency related metrics for the BIM modelling process. According to Al-Zahrani and Emsley (2013), the iron triangle remains the most universally applicable success indicator in most construction project scenarios. Consequently, studies examining the successful delivery of information systems (Atkins, 1995) and BIM more specifically (Du *et al.*, 2014; Abdirad, 2017) in construction have adopted the 'iron triangle' for definition of success. As outlined in **Table 1**, key dimensions of success were adopted relative to the 'iron triangle' based on a review of BIM studies.

In addition to the iron triangle view of success, the other important dimensions reviewed were performance issues related to the integration of project supply chain through BIM. To identify these dimensions of BIM delivery success, the role of the construction supply chain was examined revealing four important dimensions: creating a focus on the CSC rather than a single organisation; creating an effective interface between SCM principles and the construction site; transferring activities from construction sites to the CSC; and focussing on the integrated management of the CSC (Khalfan *et al.*, 2015). Vrijhoef (2011) and Papadonikolaki *et al.* (2015a) highlight the importance of collaboration, integration and coordination to CSC success as well as the role of BIM in achieving these performance objectives. The benefits of the pervasive nature of BIM include transparency and communication, which further enhance collaboration in CSC (Papadonikolaki *et al.* 2015a). From a review of policy documents (BIS, 2011; 2013a,b) and other literature (Pryke, 2009; Lönngren *et al.*, 2010; Vrijhoef, 2011), three distinctive success areas are apparent:

*Collaboration:* The CSC often consists of a temporary setup for one-off projects resulting in instability and fragmentation (Dainty *et al.*, 2001). The levels of fragmentation can be reduced through open and honest communication that is facilitated by integrated BIM project environments (Vrijhoef, 2011).

*Coordination:* CSC is functionally characterised by fragmentation that prevents effective convergence of materials, goods and services on site efficiently (Manu, 2014). Thus, cross functional coordination is vital to achieving this with BIM-based communications regarded as central to enhanced operational planning through visualisation and virtual prototyping (Vrijhoef, 2011).

*Integration:* The CSC is also characterised by structural fragmentation. BIM, however, enables technologically seamless organisational structures (Papadonikolaki *et al.*, 2015 a,b). Thus, BIM-based centralised communication enables the disparate organisations to work better as a single unit (Vrijhoef, 2011). Based on the review of literature, the success indicators adopted for this study are summarised in **Table 1**.

**Table 1.**

### **BIM Capability Criteria Used in Existing Assessment Tools and Frameworks**

Succar *et al.*'s (2012) BIM competency framework provides a generic description of BIM capability attributes namely technology, process and policy. Technology attributes represent organisational attributes related to physical artefacts while process category represents resources, activities, workflows, products, services, leadership and management related attributes often used to evidence BIM utilisation capacity (Succar, 2010). Policy attributes refer to contracts, benchmarks and guidance for BIM implementation within organisational units (Succar *et al.*, 2012). Dib *et al.* (2012) categorised capability attributes as follows: planning and management of process and technology; team structure; hardware; process definition; and information management abilities. The Pennsylvania State University BIM guide (CIC, 2013a), on the other hand, relies on the following distinctive areas of BIM capability: strategy; BIM uses; process; information; infrastructure and personnel. Different criteria have been promoted for use in evidencing the ability to deliver BIM. None of these studies have, however, specifically looked at the influence of the proposed criteria on actual BIM delivery success on projects in order to aid more informed prioritisation of capability attributes during assessments. Overall, these studies have focused more on the aspects of BIM that give an indication of the extent of BIM maturity achieved by an organisation, but do not provide empirical basis for BIM delivery success on projects. BIM delivery success on projects might arguably require more than just achieving a state of maturity based on technology, processes and policy as from the CSC perspective, these have to be mobilised together to achieve the collaboration, integration and coordination requirements which are perhaps more predictive of BIM delivery success on projects especially with regards to CSC objectives. Thus, this study aims to bridge this gap through an empirical enquiry of the influence of BIM capability on BIM delivery success.

## Research Methodology

Based on a pragmatic philosophical position, the influence of 28 previously validated BIM capability criteria (Mahamadu et al., 2017) on selected BIM delivery success indicators, was modelled based on a survey of BIM enabled projects ( $n = 64$ ). The 28 BIM capability criteria were validated through interviews with BIM experts ( $n = 8$ ) and a two-round Delphi study ( $n = 25$  [round 1] and  $n = 30$  [round 2]) of experienced BIM practitioners in Phase 1 of the study which has been reported in Mahamadu et al. (2017) as presented in **Table 2**.

### Phase 1 (Interviewees and Delphi Study)

Semi-structured interviews were conducted with BIM experts to explore relevant BIM capabilities given the relative novelty of BIM capability as a subject. This was to solicit their expert opinion about BIM capability attributes that are currently being used in practice to consolidate the list of attributes identified from literature. Phenomenological principles were relied on to satisfy the requirements of the qualitative parts of the study. This is as a result of the need to investigate construction experts' personal perspectives on BIM capability criteria based on their experience of working on construction projects. Similar methods have been applied in the exploratory phase of mixed method research (Manu, 2012). Furthermore, according Adriaanse (2007) and Navendren *et al.*, (2014) digital technology research in construction requires such initial qualitative explorations due to its novelty to provide sufficient context for further investigations. Interviewees comprised of BIM managers, digital engineers, commercial managers and quantity surveyors with extensive industry and BIM experience. All interviewees had management roles in the BIM implementation of major construction projects and organisations. Interviews were transcribed verbatim for analysis. The interviews, which lasted up to 40 minutes on average, represented the exploratory phase of the mixed method research strategy adopted. Interviews were terminated after the eighth interview as a result of saturation as suggested by Guest et al. (2006).

After the identification of BIM capability attributes, a Delphi survey was then used to establish the most relevant. The Delphi technique was first developed by Dalkey and Helmer (1963) as a method for achieving convergence of opinion among groups of experts. Delphi has gained popularity within construction management studies recently and is regarded as a strong approach for the determination of capability or competence criteria (Hallowell and Gambatese, 2010). Delphi has been adopted for contractor selection criteria (Hatush and Skitmore, 1997), as well as BIM competence criteria prioritisation for owner organisations (Giel and Issa, 2014). The Delphi survey of 30 construction practitioners resulted in 25 valid final Delphi round responses. This phase was used to validate the list of capability attributes generated from the interviews and literature as well as reduce it to a concise number consisting of only the most critical attributes being used within industry for evidencing BIM capability of CSCs.

## Phase 2 (Survey)

A survey was then used to solicit senior project participant's independent evaluation of the BIM delivery performance of a CSC firm on a project, as well as evaluate the extent of their BIM capability and its influence on the success indicators investigated (Table 1). According to Yin (2003) surveys are appropriate for the exploration of relationships between personal or perception-based variables on samples wider than those covered by qualitative strategies. A survey research strategy was therefore adopted to enable investigation of research propositions from the earlier phases among a wider group of respondents (i.e. projects). Surveys are the most associated strategy with the conduct of quantitative research including several BIM studies as well as evaluation of the influence of capability on delivery success (Kam *et al.*, 2014; Smits *et al.*, 2016). The survey consisted of practitioners on BIM enabled projects ( $n = 64$ ) and was thus used to establish the influence of the 28 critical BIM capability criteria on various aspects of BIM delivery success in the CSC context. The survey was used to solicit senior project participant's independent evaluation of the BIM delivery performance of a CSC firm on a project, as well as evaluate the extent of their BIM capability and its influence on the success indicators investigated (Table 1).

## Data Analysis

### Phase 1 (Interviews and Delphi Study)

Thematic analysis was deemed appropriate contextualisation of capability attributes proposed from the interviews and literature (see Thomas and Harden, 2008; Navendren *et al.*, 2014). Thematic analysis allows systematic data structuring to adduce patterns relevant to the phenomenon being investigated (Creswell, 2007). Based on the coded responses, interviewee's opinions on BIM capability attributes were further categorised into distinctive but related concepts, leading to the development of a three-tier hierarchy of BIM capability attributes presented in Table 2.

The Delphi study was used as a validation of interviews and to develop a more parsimonious list of capability attributes. Critical attributes were determined through statistical determination of consensus with the aid of the interrater agreement ( $r_{wg}$ ). Based on the analysis of the  $r_{wg}$  values and mean ratings, all criteria that recorded acceptable ( $r_{wg} \geq 0.750$ ), as well as a mean scores equivalent or above 'agree' were retained. This was based on the five-point rating scale used in the Delphi survey (1 = Strongly Disagree, 2= Disagree, 3 = Neither Agree or Disagree, 4 = Agree, 5 = Strongly Agree). From the principles of mathematical approximation, BIM qualification criteria with mean values  $\geq 3.5$  were accepted as critical provided there was consensus among participants (i.e.  $r_{wg} \geq 0.750$ ). Delphi studies involve iterative rounds of data collection which is terminated when there is stability or insignificant changes in responses between rounds. Spearman's correlation test



coefficient ( $\rho$ ) was adopted to assess stability between Delphi rounds considering the ordinal nature of the data gathered from the questionnaires (Field, 2013). The correlations tests between Delphi rounds resulted in statistically significant correlations hence no significant shift in participant opinion thus leading to reliance on data from round two of the process.

## Phase 2 (Survey)

Both descriptive and multivariate analysis were employed to explore the data. Descriptive statistics are often used to uncover the patterns, distribution and simple deviations within sample data (Denscombe, 2010). Measures of central tendency (means) were used to identify response points on the questionnaire scales (Denscombe, 2010). Standard Deviation (SD) was used to assess the measure of spread within data. Multivariate statistical modelling techniques were then used to model the relationship between the BIM capability attributes and key BIM delivery success indicators in the CSC context. This was achieved through Multiple Linear Regression (MLR) analysis of survey data. This process involved the construction of an index of BIM capability attributes and success variables. Thus, an index of the eleven main BIM capability attributes (consisting constituent 28 capability attributes) were modelled as independent variables on success indicators representing the dependent variables. Two dimensions of success indicators were drawn from the literature (Table 1). The first dimension was '*BIM modelling success*' representing the traditional *iron triangle* view of success. This dimension of success consisted of criteria measuring the quality of BIM, delivery of BIM on schedule (time) and delivery of BIM within budget (cost). The second dimension was '*CSC success through BIM*' representing the attainment of strategic CSC/SCM objectives through the application of BIM namely collaboration, coordination and integration. This study relied on modelling several observational measures and latent variables from a survey thus making MLR and Structural Equation Modelling (SEM) the most suitable analysis techniques (Field, 2013; Hair *et al.*, 2010). The choice of MRL over SEM was due to a couple of reasons. SEM is more suitable where there is very complex relationships between variables, however the relationships examined in this study were less complex thus making MLR adequate (Anvuur, 2008). Furthermore, SEM is recommended to overcome problems associated with MLR analysis where there is prevalence of issues such as multicollinearity and spurious suppression (Field, 2013; Hair *et al.*, 2010). None of these were, however, observed from preliminary analysis of data to determine non-violation of primary assumptions of MLR. The key assumptions that had to be met for effective application of MLR were: linearity of the relationship between outcome and predictor variables; constant variance of the error terms; independence of the error terms: normality of the error term distribution. All these were met after examination of residuals from the MLR and test of normality of variables used. Another key factor which made SEM undesirable was the fact that SEM requires often large cases of data for effectiveness (i.e. more than 300) (Anvuur, 2008). Thus, MLR was the most suitable statistical

modelling technique for the dataset in this study. The choice of MLR is also consistent with the principle that simple and minimally sufficient statistical analysis are most appropriate to avoid over interpretation (Best and Smith, 2005).

Pearson's correlation coefficient ( $r$ ) was also used to establish linear relationships between variables in order to check intra-variable relationships as a pre-cursor to the MLR analysis (Field, 2013). A parametric test ( $r$ ) was chosen given variables studied were composite variables from the construction of an index of variables thus assumed normal distribution and making parametric test suitable. Based on classical MLR modelling, the relationship between the predicted outcomes  $Y_p$  and predictor variables ( $X_1, X_2, X_{k-1}, X_k$ ) were assessed. The MLR was used for the development of predictive models for BIM delivery success through BIM capability attributes (as the predictor variables). The stepwise method in MLR was adopted in this study to support development of optimum regression models containing only the most relevant predictors after iterative rounds of analysis (Brace *et al.*, 2003).

***The Capability Criteria Adopted in Survey:*** Table 2 presents a summary of the 28 critical BIM capability attributes adopted from literature and interviews and subsequently validated by the Delphi survey (Mahamadu *et al.*, 2017). These BIM capability attributes are most suitable for the study of influencers of success given they incorporate all attributes relied on in BIM project pre-qualification and selection, thereby providing a wide range of criteria as well as opportunities for understanding relative importance of criteria relative to selecting firms most likely to succeed prior to project commencement.

Table 2.

### *Recruitment and Sampling*

As cited by Denscombe (2010), decisions on selecting research participants can be as precise when based on familiarity and good judgment. Preliminary enquiries about major BIM-enabled projects was performed through internet searches, published case studies and industry event discussions. Interview and Delphi experts were subsequently recruited with the total number of subjects commensurate with past qualitative studies ( $n=8$ ) and Delphi studies ( $n=25/30$ ) in BIM literature (Navendren *et al.*, 2014; Giel and Issa, 2014). Similar methods were used to identify expert and experienced BIM professional respondents working on BIM projects who were targeted through for random distribution of surveys both online and in paper versions. In order to determine a suitable sample size, the Creative Research Systems (2003) formula was applied leading to a recommended sample size of 480. This led to the posting of the online version of surveys to identifiable internet groups with construction professionals and in institutions that use BIM. This included LinkedIn, google and yahoo groups restricted to various BIM and construction professionals. The LinkedIn professional group pages contacted included 'BIM4SME', 'RICS', 'CIOB', 'ICE' 'BIM Experts', and 'BIM Architects', among others. These groups have memberships ranging from 330 to over 10,000. Furthermore, 160 questionnaires were directly distributed

to individuals in the generated contact list from the internet searches and solicitation of contacts from BIM events. The survey resulted in 13.3% ( $n = 64$ ) response rate, which is acceptable based on a review of similar construction management studies (Ankrah, 2007).

## Results

The survey was used to ascertain the perceived influence of the 28 critical BIM capability attributes (Table 2) on the six dimensions of success reviewed (Table 1). The majority of survey respondents were BIM Managers or Technicians (31.4%), with a substantial proportion possessing between 11-15 years of industry experience (46.7%) or 4-6 years of BIM or other virtual digital construction technologies experience (35.9%). In relation to academic qualifications, 42.2% of respondents were holders of a Bachelor's degree as their highest qualification with a good number of post-graduate degree holders (Masters - 29.7% and Doctorate - 7.8%) This is indicative of a substantially experienced and knowledgeable group of respondents.

In relation to the background of projects assessed, 19.3% were large scale with estimated project values above £50 million. Though the majority of projects (80.7%), were less than £50 million in value, more than half were above £25 million. Most of the projects surveyed reported middle tier CSC involvement in their BIM implementation or strategy, though a much less proportion (1.6%) reported lower tier CSC involvement in BIM processes. The projects assessed in the survey were mostly building projects (90.3%) as summarised in **Table 3**.

Table 3.

## Modelling the Impact of BIM Capability Attributes on Delivery Success

*Staff Experience* (Mean = 3.883) emerged as the most important attribute, with a positive influence on overall BIM delivery success. The other important influencing attributes were *Specific BIM Modelling Capacity* (Mean = 3.426), *Organisation's Experience* (Mean = 3.399) and *Technology Readiness* (Mean = 3.354). The constituent attributes regarded as most highly influential on BIM delivery success were: *Technical Staff BIM Experience*, *Suitability of Proposed BIM Execution Plans for Project (BEPs)*, *Awareness of BIM Benefits*, *Organisation's BIM Training Arrangements*, *Managerial Staff BIM Experience*, *Key BIM Software Experience* and *Past BIM Project Experience*. The rest were *Quality of BIM Implementation Strategy*, *Software Availability*, *BIM Standards*, *Data Classification and Naming Practices* and *LOD/LOI (level of detail / information) Capacity*. The remaining attributes had arithmetic means between 1.5 and 2.5 representing 'Slightly Influential' on the scales. These were *BIM Vendor Involvement and Support* and *Reputation (in relation to performance on past BIM projects)* of CSC organisation. Despite their reported low level of influence, they remain influential with none of the

attributes assessed reported as not influential on BIM delivery success on projects. This is summarised in **Table 4**.

**Table 4.**

From the analysis the area within which assessed firms performed best overall, was the delivery of BIM within budget (Mean = 4.656). This was followed by the delivery quality of BIM (Mean = 4.297), delivery within schedule (Mean = 4.094) and then use of BIM to achieve collaboration (Mean = 3.922) within the project CSC. Respondents were of the opinion that coordination (Mean = 3.469) and the integration (Mean = 3.313) were not attained to similar extents as the other success factors. While the high standard deviations (SD = 0.946 - 1.123) could be indicative of high level of variability in the performance assessment, Cronbach's Alpha (0.810) was indicative of highly reliable scales for assessing success. The results are summarised in **Table 5**.

**Table 5.**

### **Association between BIM Capability Attributes and BIM Delivery Success Indicators**

Based on Pearson's correlation coefficients ( $r$ ), all capability attributes were found to have a positive association with BIM delivery success overall. *Professional and Academic Qualifications* recorded the most significant level of association ( $r = 0.520$ ;  $p < 0.01$ ,  $n = 64$ ) with BIM modelling success while *Cost* recorded the least ( $r = 0.283$ ;  $p < 0.05$ ,  $n = 64$ ). Most of the BIM capability attributes were found to influence the delivery of quality in comparison with the rest of the success indicators. *Cost* charged for BIM services was the only attribute that did not record association with quality delivery of BIM ( $r = 0.144$ ;  $p > 0.05$ ,  $n = 64$ ). The capability criteria with the most significant association with quality was *Staff Experience* ( $r = 0.602$ ;  $p < 0.01$ ,  $n = 64$ ).

A total of five capability attributes were found to have a significant degree of associations with the delivery of BIM on schedule with *Proposed Methodology* ( $r = 0.475$ ;  $p < 0.01$ ,  $n = 64$ ) recording the highest degree of association. Furthermore, seven of the capability attributes recorded significant degrees of associations with the delivery of BIM within budget. *Administrative and Strategic Capacity* recorded the highest level of association ( $r = 0.482$ ;  $p < 0.01$ ,  $n = 64$ ) followed by *Staff Experience* ( $r = 0.404$ ;  $p < 0.01$ ,  $n = 64$ ). In relation to the delivery of CSC success through BIM, only four of the capability attributes recorded statistically significant levels of associations with *Administrative and Strategic Capacity* emerging with the highest degree of association ( $r = 0.507$ ;  $p < 0.01$ ,  $n = 64$ ). *Administrative and Strategic Capacity* emerged with significant correlations across all three areas of CSC success through BIM ( $r = 0.374$ ;  $p < 0.01$ ,  $n = 64$ ). Coordination through BIM had a weak but statistically significant correlation coefficient ( $r = 0.377$ ;  $p < 0.01$ ,  $n = 64$ ) while integration through BIM recorded an appreciable correlation ( $r = 0.522$ ;  $p < 0.01$ ,  $n = 64$ ).

## Modelling the Impact of Capability Attributes on BIM Delivery Success

Two MLR models were developed to ascertain influence of capability attributes on the two dimensions of delivery success (BIM modelling success and CSC success through BIM). With regards BIM modelling success, the outcome variable consisted of respondents' assessment of CSC performance in relation to BIM modelling quality, BIM delivery on schedule, as well as BIM delivery within budget on a current or recently completed project. The multiple regression modelling resulted in a statistically significant regression equation ( $F [2, 61] = 18.629; p < 0.05$ ) with an  $R^2$  of 0.379. The adjusted  $R^2$  of 0.359, denotes 35.9% of the variation in the BIM modelling success due to predictor variables. Based on the findings BIM modelling success can thus be predicted from Equation 1.

### Equation 1: Regression Equation for Predicting BIM Modelling Success

$$\text{BIM MODELLING SUCCESS} = 0.857 + 0.483 (\text{Staff Experience}) + 0.447 (\text{Proposed Methodology})$$

From this regression equation, BIM delivery success on a project increases per 0.483 unit increments in level of *Staff Experience* and 0.447 unit increments in the level of suitability in relation to *BIM Proposals* submitted by firms prior to commencement of projects. Both *Staff Experience* ( $p < 0.05, n = 62$ ) and *Proposed Methodology* ( $p < 0.05, n = 62$ ) were significant predictors of overall BIM modelling success as summarised in **Table 6** and **Figure 1**.

Table 6.

Figure 1

The Durbin-Watson test recorded value of 1.383 indicative of no independence of the error term. The variance inflation factor (VIF) were within acceptable range (1.179 for *Staff Experience* and 1.179 for *Proposed Methodology*) (Hair *et al.*, 2010). Further residual analysis revealed no violations of MLR assumptions.

With regards to CSC success through BIM, the outcome variable consisted of ratings of performance outcomes in relation to collaboration, coordination and integration of the CSC through BIM on the projects assessed. The MLR exercise resulted in a significant regression equation ( $F [1, 62] = 21.489; p < 0.05$ ), with an  $R^2$  of 0.257. Adjusted  $R^2$  was 0.245 implying that the predictors in the regression model accounted for 24.5% of the variation in CSC success through BIM. From the analysis overall CSC success through BIM can be predicted from Equation 2.

## Equation 2: Regression Equation for Predicting CSC Success through BIM

OVERALL SUPPLY CHAIN SUCCESS THROUGH BIM = 1.483 + 0.595 (Administrative and Strategic Capacity)

From this analysis, administrative and strategy related capacities are the most significant predictors of performance related to collaboration, coordination and integration of the CSC through BIM. **Table 7** and **Figure 2** is a summary of the key parameters of the regression model for predicting CSC success through BIM.

Table 7.

Figure 2.

The Durbin-Watson test for MLR model for CSC success through BIM was 2.059, indicating that the residuals errors were not correlated unduly. This is indicative of no evidence of first-order autocorrelation. The VIF of the significant predictors was 1, thus, within acceptable range (Hair *et al.*, 2010). This is indicative of highly satisfactory results in relation to the violation of collinearity assumptions. Further residual analysis revealed no violation of the principle MLR assumptions.

### Mediating and Moderating Effect of Project and Organisational Characteristics

Mediation in a regression model refers to the elucidation of the mechanisms that underlies an observed relationship between independent and dependent variables (Kenny, 1986; Hayes, 2009). Mediator variables, thus, clarifies the nature of the relationship between the predictors and outcome variables (Kenny, 1986). This is often done through the investigation of the influence of mediating variables in the regression modelling (Hayes, 2009). In this study, mediation analysis was undertaken to identify whether or not project complexity mediated the influence of capability attributes on delivery success. If significant changes occur in the model parameters, this is indicative of a mediating role of the additional variables (project complexity characteristics). The three principal dimensions of complexity measured were project size, BIM complexity and supply chain complexity. Project size was based on the value of the projects surveyed and categorised within the following ranges: < £25 million; £26-50 million; £51-75 million; £76-100 million; and > £100 million. BIM complexity accounted for BIM Task responsibility of the CSC organisation, project BIM model complexity (including BIM maturity level) and product or facility complexity (in terms of design). Supply chain complexity included the level of CSC's involvement in the BIM process and the extent of the use of BIM across the CSC of the project. MLR was re-run with the inclusion of mediator variables revealing only marginal decrease in the adjusted R<sup>2</sup> from 0.245 to 0.229 with evidence of additional significant predictor, *Project Supply Chain Complexity* ( $\beta = 0.423$ ;  $p < 0.05$ ,  $n = 62$ ) for CSC success through BIM. *Administrative and Strategic Capacity* ( $\beta = 0.754$ ;  $p < 0.05$ ,  $n = 62$ )

remained a strong predictor despite an overall drop in the variance accounted for in the entire regression model. No project characteristic was found to influence attainment of BIM modelling success.

Moderation in regression is used to describe the relationship between two variables when they are dependent on a third variable called the moderator (Kenny, 1986). The relationships between the predictors in the regression models for BIM modelling success and CSC success through BIM was tested through a moderation analysis with the aid of PROCESS software for SPSS (Hayes, 2016). Using a path analysis framework, the PROCESS tool provides a moderation analysis through an estimation of the coefficients of a regression model (Hayes, 2016). None of the project and organisational characteristics were found to have a moderating effect ( $p > 0.05$ ).

### **Validity and Reliability of Analysis**

The  $R^2$  values (25.7% and 35.9%) recorded in the regression models were highly acceptable from a review of the  $R^2$  values of other construction management studies, employing similar methods (4.0% - 26.0%) (Omoriege, 2006; Ankrah, 2007). According to Harris (1985) reliance on the ratio of number of predictor variables (' $p$ ') to observations (' $N$ ') is most appropriate method for establishing sample size adequacy in regression modelling. From a review of empirical studies, Howell (1997) suggests that ' $N$ ' is adequate when it exceeds ' $p$ ' by between 40 and 50. Following Harris (1985) and Howells (1997), the ratio of observations to predictors in this study satisfies the requirements for conduct of regression analysis. Furthermore, Cronbach's Alpha values (0.810 - 0.93) were indicative of highly reliable scales (Field, 2013) for both success and BIM capability variables, respectively.

### **Discussion of Findings**

A review of the relationship between the significant predictors of BIM modelling success and constituent success indicators revealed that *Staff Experience* has a higher degree of association with BIM modelling quality and delivery within budget, while suitability of *Proposed Methodology* is more associated with BIM delivery within schedule. With regards to CSC success through BIM, *Administrative and Strategic Capacity* emerged as the only capability attribute with a meaningful contribution albeit dependent on the level of CSC complexity (i.e. large, multi-layered CSC characterised by substantial lower tier BIM involvement or use). The results suggests that BIM is likely to influence collaboration, integration and coordination on projects with more complex supply chains. *Administrative and Strategic Capacity* was also found to influence the attainment of integration more when compared to coordination and collaboration of the CSC.

According to Du *et al.* (2014), the key performance expectations of BIM include, information quality, as well as timely and cost effective delivery. This includes the accuracy of data in models and generally, the extent to which modelling conforms to requirements. From the findings, individual skills at developing BIM models as well as appropriate execution planning, are found to constitute the most critical capability attributes that influenced successful delivery of BIM.

In circumstances where the traditional view of success (quality, schedule and budget) is a concern, individual competencies should be the most important consideration. According to Succar *et al.* (2013), such individual BIM skills should be both procedural and applied or conceptual knowledge. While there are multiple areas of performance, Succar *et al.* (2013) have not advocated the specific areas within which experience is most likely to influence success. This study, however, reveals that individual experience influences tangible performance expectations of BIM, specifically, in relation to the quality of modelling, delivery within budget and on schedule. Smits *et al.* (2016), on the other hand, found strategic capability as the most influential on project cost, time and quality performance. This contrast may, however, be explained by the fact that Smits *et al.* (2016) investigated the influence of BIM maturity on project level success factors rather than the success in the delivery of BIM itself on the project.

While planning has always been recommended for the attainment of project objectives, no empirical studies have explicitly investigated the impact of BIM execution plans on successful delivery on projects. However, the ability to develop an effective plan or method in response to a project brief or need is identified as key to BIM modelling success, more specifically delivery within schedule. Standards documents such as the CIC protocol (CIC, 2013b) and PAS1192:2 (2013) have promoted the concept of BIM Execution Plans (BEP). Other studies have highlighted the importance of BEP to project success (Al-Ahbabi and Alshawi, 2015). However, no study has sought to establish the relationship between proposed methodology (project specific BEPs) and delivery success in practice especially through an empirical assessment. From the findings suitable *Proposed Methodology* (e.g. a BEP) is mostly associated with delivery within schedule. This study aligns with a wider view within construction that effective planning and allocation of CSC resources affect timely deliveries of BIM output (Murphy, 2014). The delivery of quality BIM models within budget is mostly associated with higher levels of staff experience. This also aligns with the views that construction organisations are able to conform to requirements better, when workforce possess adequate levels of procedural skill and knowledge (Arditi and Gunaydin, 1999). The finding further supports the notion that years of repetitive usage of BIM or related technologies aid individuals to develop core or domain competencies that assure value. This value is mostly evident in the quality of the deliverables and their ability to deliver BIM within cost but not as much for timely delivery. Furthermore, staff expertise



and proposed methodology have featured among the most important predictors of success in construction studies in general (Doloi, 2009).

*Administrative and Strategic Capacity* emerged as the single most important influencer of CSC success through BIM. This variable provides evidence of effective vision, planning, development and management of resources in BIM implementation within an organisation. While other studies have highlighted strategic factors as important to BIM capability overall (Murphy, 2014; Giel and Issa, 2015), this study indicates, it primarily influences the attainment of collaboration, coordination and integration in the CSC context. The attainment of CSC success through BIM was, however, mediated by the level of complexity of the project CSC. Consequently, more complex supply chains present more opportunities for achieving collaboration, coordination and integration through strategic implementation of BIM (Vrijhoef, 2011; Manu, 2014; Papadonikolaki *et al.*, 2015a).

According to Giel and Issa (2014), strategic capacity refers to factors that impact on an organisation's ability to plan and develop courses of action for BIM execution. Administrative capacity also refers to how organisations manage resources to meet desired goals associated with their internal BIM execution strategies (Giel and Issa, 2015). Similarly, the following factors constituted administrative and strategic capacity: *IT Vision and Mission, Quality of BIM Implementation Strategy* and *BIM Research and Development*. It is still not clear the extent to which the construction industry is leveraging BIM to achieve CSC objectives, however, this study highlights the importance of strategy and administrative issues on attaining these objectives. The findings suggest that strategic objectives of the CSC must be incorporated in the long-term planning activities as well as allocation of resources in BIM implementation in order to attain success. According to Papadonikolaki *et al.* (2015a), CSC BIM performance is underpinned by strategy that is normally linked to effective long-term and commercially driven factors. Thus, while there are operational benefits of BIM use, its success in the CSC is largely dependent on the overarching strategy, as well as management of BIM implementation resources. Consonant with these assertions, Manu (2014) recommended the incorporation of BIM capability criteria in performance management of the CSC. According to Manu (2014), this improves the strategic management of the CSC, which currently focusses mostly on factors such as health and safety performance, financial health and programme compliance.

Evidence of BIM research and development (R&D) within an organisation is a likely indicator of ability to leverage BIM for the attainment of CSC objectives (Succar, 2010). The findings, therefore, support a notion that the success of BIM application for CSC operations is not dependent on procedural, process, or technology related capacity but rather management and strategy level factors. Thus, it can be inferred that BIM enhances strategic functions of the supply chain much more than operational areas which arguably is still at the infancy of BIM application (Papadonikolaki *et al.* (2015a). This finding is consistent with the findings of Smits *et al.* (2016) that strategic BIM process

maturity influences project level performance rather than the performance in the attainment of BIM deliverables themselves.

Respondents recounted that the attainment of CSC success through BIM was generally not as high as the levels of BIM modelling success (quality, schedule and budget). This confirms existing evidence that CSC and CSC management objectives are not solely met by the use of technologies like BIM but also other commercial and structural imperatives (Cerovsek, 2011; Antwi-Afaria *et al.*, 2018).

## **Conclusions**

The findings provide empirical evidence on the need for the prioritisation of BIM capability attributes based on their relative influence on desirable success indicators. Thus, the prioritisation of criteria during capability assessments must be based on their relative contribution to all relevant areas of success in order to provide a holistic view. Prioritisation of criteria in existing frameworks are, however, based only on the relative importance of such criteria as capability metrics rather than their relative contribution to various areas of success as investigated in this study. Furthermore, capability or maturity only denotes the basic abilities to perform BIM-related tasks efficiently, rather than the actual attainment of the objectives expected from BIM deployment.

This study has provided insights about the influence of key capability attributes on other BIM deployment objectives such as: the quality of BIM; delivery of BIM on schedule, delivery of BIM within budget; collaboration, coordination and the integration of CSC through BIM. While some studies have sought to explore influence of BIM maturity elements on project success in general no studies have investigated influence of CSC BIM capability on the successful delivery of BIM itself. This is, however, a more meaningful measurement given overall project success is presumably influenced by many other factors.

### *Study Implications for Practice*

The main implications of the research findings for practice are two-fold: development of BIM capability and maturity; and development of procurement policies. These are elaborated as follows.

#### *BIM Capability and Maturity Development*

- The BIM capability attributes and their priority rankings would enable organisations to self-examine their internal capacity and maturity for the purposes of performance management and improvement. This would aid the identification of areas of strength, weaknesses and opportunities for consolidating BIM capability within construction industry organisations

overall. Furthermore, these organisations can identify BIM implementation areas that require prioritisation such that there is efficient allocation of investment in BIM capacity building. On this note, this research has demonstrated the need for prioritising administrative and strategic capacity for supply chain BIM use success and on the other hand, staff experience and project execution planning (i.e. methodology) for more efficient BIM delivery performance.

### *Procurement Policy Development*

- Despite Government mandate for adoption of BIM, particularly, in UK and more recently across Europe, Asia and the Middle East, there remains no policy directives regarding capacity building. The research findings, however, have implications for BIM implementation on projects particularly in relation to procurement. Clients, main contractors and principal suppliers can prioritise selection criteria such that they are consistent with the research findings. This is important given relevant documentations for procurement such as British Standards Institution (2013) PAS 91:2013 and the Pennsylvania State Planning Guide (CICa, 2013), which do not prescribe selection criteria priority weightings for selection of organisations on BIM projects.
- From the findings the key determinants of success from supply chain integration perspective has been established to be Strategic and Administrative BIM process maturity. This distinction is critical to current efforts for the adoption of integrated procurement methods such as Integrated Project Delivery (IPD) (Porwal and Hewage, 2013) which promises to integrate supply chains more effectively through BIM.

This study provides an empirically supported justification for propositions about the role of BIM capability in BIM delivery success as espoused within literature. It further shows the multidimensional nature of this relationship, which hitherto has been viewed as a unilateral and technologically deterministic concept. It brings into focus the need for prioritising BIM capability criteria based on their contribution to delivery success. The findings debunk the hard technology centric nature of BIM capability discourse. Criteria relied on for assessing BIM capability in most existing frameworks are often hard technology centric. Thus, most capability frameworks align with a hard technological deterministic view of BIM, where the technology artefacts and resources are primary determinants of BIM capability and delivery success. While this study acknowledges the importance of technological capacities, such as hardware and software, it places more emphasis on the role of specific information process maturity and collective knowledge, skills and attitudes within a CSC organisation.

### *Limitations and Implications for Future Research*

Future studies could adopt more longitudinal approaches to explore the evolution of BIM maturity and how that influences delivery success over longer periods as opposed to the cross-sectional focus of this study. A review of the survey respondent's backgrounds revealed many of the CSC organisations assessed were design consultants, as well as main and sub-contractor organisations with high-level design responsibility and between middle to the top tier of the CSC. This is largely due to reported lack of usage of BIM by lower tier CSC organisations that often have less design responsibility and digital technology expertise. Future studies could, however, focus on the lower tiers of the CSC especially when BIM adoption increases in this segment of the market. Lastly, some key BIM delivery success factors have been examined, albeit in a supply chain and project model delivery perspective. Future studies could consider other dimensions of success especially at project level with consideration of other non-BIM capability indicators.

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Table 1. Review of BIM Delivery Success Factors for Construction Supply Chain

BIM Delivery Success	References *														Success Variable Description	
BIM Modelling Success																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N		
Quality				X		X	X	X	X	X					X	Overall conformance to technical requirements [i.e. client or project and specifications (including accuracy, usability of data or BIM models)].
Schedule (timeliness)				X		X	X	X	X	X					X	Attainment of BIM deliverables within time [i.e. as set out in project programmes, data drop agreements or Master Information Delivery Plans (MIDP)].
Budget (Cost/economy)						X	X	X							X	Attainment of BIM deliverables within budget.
Supply Chain Success through BIM																
Collaboration	X	X	X		X	X					X	X	X	X		Trust-based relationship and commitment for the attainment of common business objectives through transparent and effective communication
Coordination	X	X	X	X	X	X					X	X	X	X		Effective operations and resource alignment and control for the attainment of project objectives through communication, transparent and effective project data management.
Integration	X	X	X		X						X	X	X			Functional coupling of fragmented CSC organisations into an integrated project delivery team(s)
*References - A = Pryke (2009); B = Lönngren et al. (2010); C = Vrijhoef (2011); D = Kam et al. (2012); E = BIS (2013b); F = CIC (2013a); G = Keavney et al. (2013); H = Du et al. (2014); I = Mom et al. (2014); J = Tsai et al. (2014); K = Khalfan et al. (2015); L = Papadonikolaki et al. (2015a); M = Papadonikolaki et al. (2016); N = Abdirad, (2017)																

Table 2. Critical BIM Capability Attributes and Review of Relevant Frameworks (Adapted from Mahamadu *et al.*, 2017)

Critical BIM Capability Attribute			Interview	Literature - Relevant BIM Capability Frameworks *					Delphi Validation
				A	B	C	D	E	
Competence	Professional and Academic Qualifications	Key Technical Staff BIM Qualification	X	O	X	X	O	O	√
		BIM Staff Availability for Project	X	O	X	O	X	-	√
		Organisation's BIM Accreditations and Certifications	X	X	O	X	O	X	√
		Organisation's BIM Training Arrangements	X	X	X	X	X	X	√
	Staff Experience	Managerial Staff BIM Experience	X	X	X	O	O	X	√
		Key Technical Staff BIM Experience	X	X	X	X	X	X	√
	Organisation Experience	BIM Software Experience	X	X	X	X	X	X	√
		Past BIM Project Experience	X	O	O	O	X	O	√
		BIM Experience on Similar Project	X	O	O	O	X	O	√
Internal Use of Collaborative IT Systems		X	X	X	O	O	X	√	
Capacity and resources	Administrative and Strategic Capacity	IT Vision and Mission	X	O	X	O	X	O	√
		Quality of BIM Implementation Strategy	X	X	X	X	X	X	√
		BIM Research and Development	X	X	X	X	O	X	√
	Technical (Physical) Resources	Software Availability	X	X	x	X	X	X	√
		Data Storage (suitability and capacity)	X	X	x	O	O	X	√
		Network Infrastructure Availability	X	X	X	X	O	X	√
	Specific BIM Modelling Capacity	BIM Standards	X	X	X	X	X	X	√
		Data Classification and Naming Practices	X	X	X	O	X	X	√
		Model Maturity Expertise/Capacity	X	X	X	X	X	X	√
		LOD/LOI Expertise/Capacity	X	X	X	O	X	X	√
	Proposed Methodology	Suitability-BEP's for Project	X	-	X	O	X	O	√
		BIM Vendor Involvement and Support	X	O	O	O	O	-	√
	Culture and Readiness	Reputation	Reputation -Performance on Past BIM projects	X	-	O	-	O	-
Technology Readiness		Attitude Towards New Technology/Willingness	X	X	X	O	X	X	√
		Awareness of BIM Benefits	X	-	O	O	X	O	√
		Extent of IT Support to Core Business and Processes within Firm	X	O	X	O	O	O	√
Organisational Structure		Organisational Structure (Level of Decentralisation)	X	X	X	X	X	O	√
Cost	Cost/Price of BIM Service	X	-	-	-	X	-	√	
<b>Interview and Literature:</b> (x) = largely considered, (o) = somewhat considered, (-) = not considered/proposed *A =Quicksan TNO (Sebastian and van Berlo, 2010); B = VDC Scorecard (Kam <i>et al.</i> , 2014); C = BIMMI (Succar, 2009); D = University of Pennsylvania CIC (2013a); E = Owners Competence Framework (Giel and Issa, 2014)									

Table 3. Background of Surveyed Projects

		Frequency	%	Cumulative %
<b>Project Size</b>	Less than £25M	30	48.4	48.4
	£26 - £50M	20	32.3	80.6
	£51M-£75M	6	9.7	90.3
	£76M-£100M	3	4.8	95.2
	Over £100M	3	4.8	100.0
<b>Supply Chain Involvement in BIM Process</b>	Only Top Tier	5	8.1	8.1
	Some Middle Tier	38	61.3	69.4
	Significant Middle Tier	18	29.0	98.4
	Lower Tier	1	1.6	100.0
<b>Project Type</b>	Civil	6	9.7	9.7
	Building	56	90.3	100.0

Table 4. Descriptive Analysis of Influence of BIM Capability Attributes on Overall Delivery Success

Variables (BIM Qualification Criteria)		Statistics					Degree of Influence*		
		N	Range	Rank	Mean	Std. D	SI	I	VI
Competence	<b>Professional and Academic Qualifications</b> (Mean = 3.067)								
	Key Technical Staff BIM Qualifications	64	4	21	2.938	1.067		√	
	BIM Staff Availability for Project	64	4	14	3.344	0.946		√	
	Organisation's BIM Accreditations and Certifications	64	4	28	2.391	1.229	√		
	Organisation's BIM Training Arrangements	64	4	7	3.594	1.065			√
	<b>Staff Experience</b> (Mean = 3.883)								
	Managerial Staff BIM Experience	64	4	10	3.563	1.125			√
	Key Technical Staff BIM Experience	64	3	1	4.203	0.858			√
	<b>Organisation's Experience</b> (Mean = 3.399)								
	BIM Software Experience	64	3	5	3.656	0.781			√
	Past BIM Project Experience	64	3	7	3.594	0.921			√
	BIM Experience on Similar Project	64	4	19	3.016	1.076		√	
	Internal Use of Collaborative IT	64	4	15	3.328	0.977		√	
Capacity and Resources	<b>Administrative and Strategic Capacity</b> (Mean = 3.333)								
	IT Vision and Mission	64	4	18	3.156	0.979		√	
	Quality of BIM Implementation Strategy	64	3	7	3.594	0.849			√
	BIM Research and Development	64	4	16	3.250	1.084		√	
	<b>Technical (Physical) Resources</b> (Mean = 3.068)								
	Software Availability	64	4	11	3.500	0.960			√
	Data Storage	64	4	24	2.828	0.901		√	
	Network Infrastructure	64	4	23	2.875	0.951		√	
	<b>Specific BIM Modelling Capacity</b> (Mean = 3.426)								
	BIM Standards	64	4	6	3.625	1.266			√
	Data Classification and Naming Practices	64	4	11	3.500	1.039			√
	Model Maturity Capacity	64	4	22	2.891	1.143		√	
	LOD/LOI Capacity	64	4	4	3.688	1.125			√
	<b>Proposed Methodology</b> (Mean = 3.149)								
	Suitability of Proposed BIM Execution Plans for Project	64	3	2	3.844	0.801			√
BIM Vendor Involvement and Support	64	4	26	2.453	1.181	√			
Culture and Attitude	<b>Reputation</b> (Mean = 2.453)								
	Performance on Past BIM Projects	64	4	26	2.453	1.181	√		
	<b>Technology Readiness</b> (Mean = 3.354)								
	Attitude Towards New Technology/Willingness	64	4	13	3.359	1.060		√	
	Awareness of BIM Benefits	64	3	3	3.734	0.802			√
	Extent of IT Support to Core Business and Processes	64	4	20	2.969	1.098		√	
	<b>Organisational Structure</b> (Mean = 2.781)								
Level of Decentralisation	64	4	25	2.781	1.105		√		
<b>Cost</b> (Mean = 3.188)									
Price Charged for BIM Service	64	4	17	3.188	0.906		√		

\*Influence scales: SI –Slightly Influential=2; I –Influential=3; VI – Very Influential=4. NB: Please note that no means scores corresponded with NI (Not Influential at all=1); and EI (Extremely Influential=5) thus not shown in Table for brevity.

Table 5. Level of Attainment of BIM Delivery Success by CSC Organisations

Variables	Statistics						Extent of Attainment on Project		
	N	Range	Min	Max	Mean	Std. D	Fair	Good	Very Good
Budget (cost)	64	4	2	6	4.656	0.946			√
Quality	64	5	1	6	4.297	1.079		√	
Schedule (time)	64	5	1	6	4.094	1.123		√	
Collaboration	64	5	1	6	3.922	1.088		√	
Coordination	64	5	1	6	3.469	1.038	√		
Integration	64	5	1	6	3.313	1.111	√		

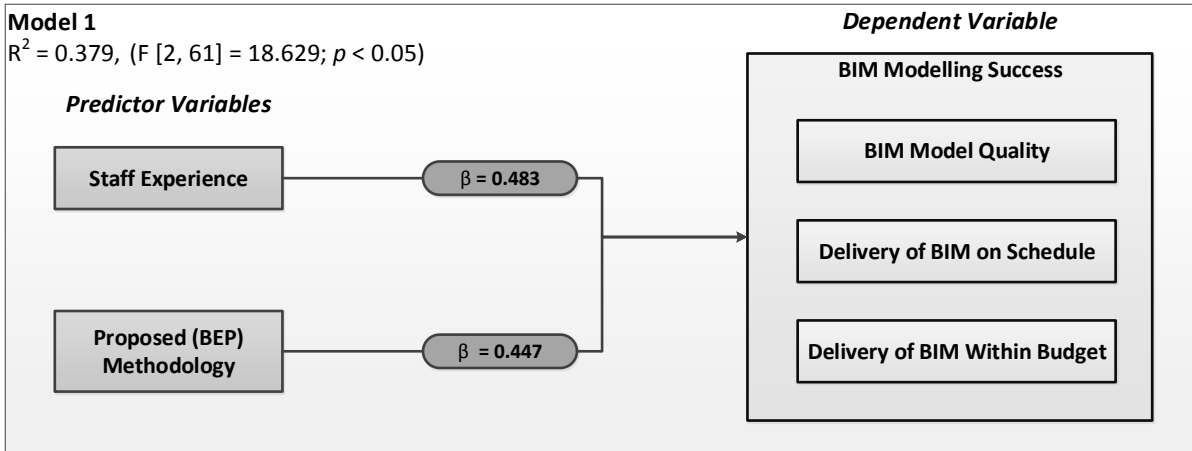
Scales: Not at all=1; Poor=2; Fair=3; Good=4; Very good=5; and Excellent=6

Table 6. Regression Analysis Results for BIM Modelling Success

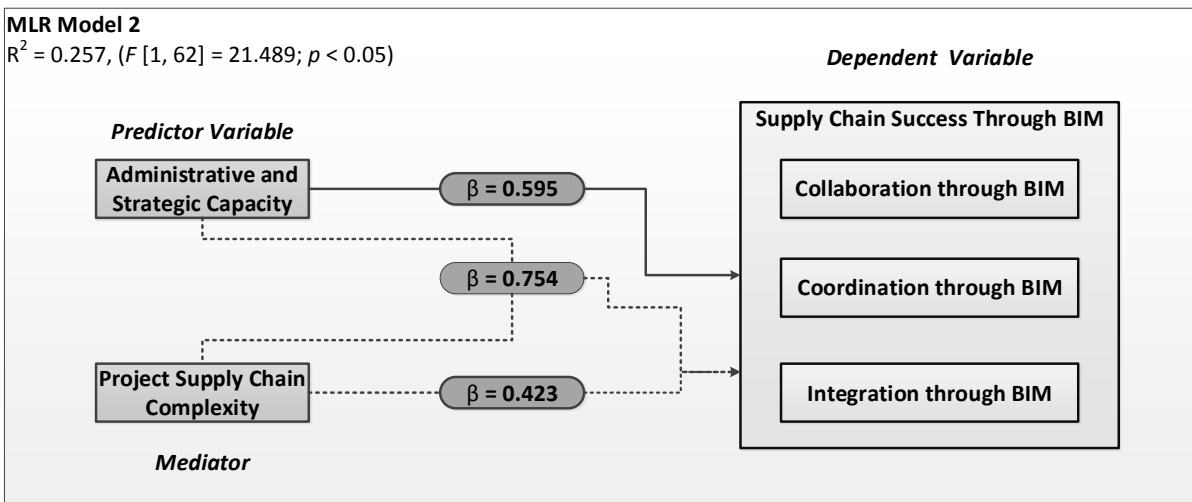
Variables in Equation							
	$\beta$	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	0.857	0.563		1.521	0.134		
Staff Experience	0.483	0.140	0.377	3.441	0.001	0.848	1.179
Proposed Methodology	0.447	0.135	0.362	3.301	0.002	0.848	1.179
Std. Error = 0.711; Durbin-Watson = 1.383							
ANOVA ( $F(2,61) = 18.629, p = 0.000$ )							

Table 7. Regression Results for Overall Supply Chain Success through BIM

Variables in Equation							
	$\beta$	Std. Error	Beta	t	Sig.	Tolerance	VIF
(Constant)	1.483	0.440		3.366	0.001		
Administrative and Strategic Capacity	0.595	0.128	0.507	4.636	0.000	1.000	1.000
Std. Error = 0.781; Durbin-Watson = 2.059							
ANOVA ( $F(1,62) = 13.120, p = 0.000$ )							



**Figure 1.** Summary of Regression Analysis for BIM Modelling Success



**Figure 2.** Summary of Regression Analysis for Supply Chain Success through BIM Modelling

