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Assessing supplier capabilities to exploit building information modelling

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Abstract

Purpose: A number of governments are making building information modelling (BIM) a mandatory requirement for all public works construction projects. While main contractors may be ready to comply with such requirements, the supply chain as whole may be vulnerable as lower-tier suppliers may not be able to adopt BIM. There is currently no objective approach to assessing BIM maturity, hence we develop a new approach to determine suppliers' current vision and execution based capabilities to exploit BIM and their capacity to reach a higher maturity level.

Method: Based on United Kingdom government BIM maturity levels, we exploit a unique data set made available by a main contractor, to determine a data-driven approach, using K-means, to assess the capabilities and vision of its supply base.

Findings: We find a direct comparison between our suggested K-means clusters and the UK government's BIM maturity levels. However, in interrogating specific cases, we find that using a subjective approach would have wrongly categorized certain companies. We also determine what capability and strategic developments are required for companies to move to a higher level.

Research implications: Our method aligns with the existing UK BIM Maturity Model and enhances the model by determining the likelihood of a supplier in progressing to a higher level of maturity. Our research was with a single case company, exploiting their existing survey instrument and data. A more comprehensive study could be adopted with a generic survey questionnaire.

Practical implications: The research may be exploited by companies to take a strategic approach to assessing suppliers in BIM adoption and to establish supplier development mechanisms.

Originality: Our data-driven approach avoids ambiguity of categories and mis-categorizing suppliers.

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1. Introduction

Finding suitable information technology (IT) systems to support the unique characteristics of the construction industry has been a challenging endeavor (Brière-Côté et al., 2010). Advances in digital engineering have led to model-based approaches, which appear likely to replace traditional engineering drawings and virtual collaboration (Rezgui et al., 2011, Merschbrock et al., 2015).

An emerging approach to managing these issues is Building Information Modelling (BIM). Different from traditional design approaches, such as computer aided design (CAD), BIM transforms the paradigm of the construction industry from 2D-based drawing information systems to 3D / 4D object-based information systems (Arayici et al., 2011a). This allows clear visualization and integration of data early in the design process to an extent that was difficult to achieve previously. Hence, BIM enables the synchronization of information with construction practices starting from design, execution, operation, and through to maintenance and renovation; as well as provide information for decision-making throughout a project life cycle. Therefore, it breaks the silo effect among various participating organizations in a construction supply chain and connects fragmented processes in a more integrated manner. As a result of this increased connectivity and accessibility, multiple benefits are reported such as cost savings due to early clash detections between design and construction teams, increased accuracy on cost estimation, reduced errors and better customer service (Bryde et al., 2013).

Recognizing the importance of BIM, the UK government announced that use of BIM on publicly-funded projects is mandatory since 2016, reflecting its ambition to take on a global leadership role in BIM exploitation and enhance UK construction competitiveness (UK Government, 2012). Further, the mandate required all centrally procured projects to achieve Level 2, requiring building information in the specified standard digital format, which can be stored in separate BIM platforms integrated via middleware or proprietary interfaces (UK BIM Task group, 2011).

Two recent UK surveys find that progress towards achieving BIM targets has been slow (NBS, 2016, Withers, 2014). This is particularly the case for subcontractors, where only 10% believe that the construction industry is ready to deliver on it, with a quarter feeling they lack the skills and knowledge they need (NBS, 2016). While implementing BIM may be less of an issue for large contractors, which usually have sufficient in-house resources and expertise, this may not be the case for suppliers, in particular for small-medium sized enterprises (SMEs). The annual National BIM Survey (NBS) report has revealed that this problem persists in all previous years (2011-2017); "*...we've seen a clear divide between the awareness and adoption of BIM between small practices and larger firms. In all measures, smaller practices were lagging behind their larger counterparts by around two years, with cost still being seen as a major barrier to adoption (McPartland, 2015)*". The most recent national survey (NBS, 2017) finds that smaller companies are still lagging behind their larger counterparts.

The challenge for SMEs and specialist subcontractors in adopting BIM has been noted by researchers (Arayici et al., 2011a, Poirier et al., 2015). A recent study finds that 42% of Australian SMEs use BIM in Level 1 and Level 2 with only around 5% have tried Level 3, and the main barriers stem from the risks associated with an uncertain return on investment (Hosseini et al., 2016). A regular explanation for the lack of success by smaller companies in adopting IT is the combined gaps arising from strategic intent (vision) and implementation capabilities (execution) (Nguyen et al., 2015) with such a gap highlighted as worthy of further study within a BIM context (Murphy, 2014).

Many of the discourses surrounding BIM seek to classify and benchmark progress in terms of BIM levels (Sebastian and van Berlo, 2010, McCuen et al., 2011, Barlish and Sullivan, 2012, Khosrowshahi and Arayici, 2012). Maturity Models have been debated at length in the literature, both in terms of general application, and in specific application to design automation in engineer-to-order industries (Becker et al., 2009, Wendler, 2012, Neff et al., 2014). What is clear from the latter work, and that of Willner et al. (2016), is that maturity models must be appropriate for the context in which they are applied and developed in a robust way. At present, we perceive a lack of critical, and empirical, investigation of the maturity of BIM adoption for SMEs and specialist contractors, and the way that it is assessed.

To address the aforementioned challenges we aim, firstly, to determine the level of BIM maturity within the contractors' existing supplier base, and secondly, to develop a strategic approach for assessing and benchmarking suppliers in BIM adoption according to vision and execution-based capabilities. Consequently, our original contribution is in developing a new procedure to objectively establish construction suppliers' current capabilities in exploiting BIM, as per the BIM Maturity Model, and also to determine their likelihood of progressing to a higher level of maturity.

2. BIM background

A number of working definitions have been offered for BIM. It can be viewed as a set of interacting policies, processes and technologies which enhance coordination between various stakeholders of a project, facilitating the capture of required information throughout the whole project life cycle (Succar, 2009, Sacks et al., 2010). A practical definition is offered by the Construction Project Information Committee (CPIC) UK: "'Building Information Modeling is digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition (Snook, undated)". For a more detailed overview of BIM technology, one can refer to the work of Succar (2009).

With an increasing take-up of BIM technology in the UK, the national Government's BIM adoption strategy was launched in June 2011 having been referenced in the preceding Low Carbon Action Plan and Government Construction Strategy. The strategy outlines how Government will mandate the delivery of intelligent data to client organizations and required fully collaborative 3D-BIM as a minimum by 2016 (UK Government, 2012). In addition, a government BIM working group also developed a maturity model in 2011 outlining the evolutionary path for companies and has been widely accepted as a benchmark model by the UK construction industry. Those levels are defined as;

- Level 0, Unmanaged CAD probably 2D, with paper (or electronic paper) as the most likely data exchange mechanism
- Level 1: Managed CAD in 2/3D format using British Standards 1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by stand-alone finance and cost management packages with no integration.
- Level 2. Managed 3D environment held in separate discipline BIM tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as proprietary-BIM (pBIM). The approach may utilize 4D and 5D elements. Any CAD software that companies used must be capable of exporting to one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange).
- Level 3. Fully open process and data integration enabled by web services compliant with the emerging IFC/IFD (international framework dictionary) standards, managed by a

collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes. This level of BIM will utilize 4D, 5D and 6D elements.

Such a mandate poses a significant influence on how a main contractor and its suppliers will develop their capabilities to meet government requirements. Therefore, the UK's construction sector provides us a unique opportunity to examine supplier capability of BIM deployment.

The challenges and opportunities of BIM adoption has also been addressed in the academic literature. According to a recent literature review by Volk et al. (2014), architects, engineers and main contractors played a major role as early adopters of BIM technology and still dominate the elaboration of BIM functionalities and dissemination. This finding was further confirmed by Ghaffarianhoseini, et al. (2017) who pointed out that contractors play a significant role in promoting/demoting the adoption of BIM. They further warned that we would start to see structural 'BIM inequalities' in the market place to be reinforced as large, successful expert BIM adopters may become even more successful, leaving those less capable behind.

As discussed in Section 1, the limited capability of SMEs in adopting BIM hinders its further diffusion. In the UK, the construction sector is dominant with SMEs in various parts of a project lifecycle, in particular during the construction stage with limited process and technical maturity and capability (Rezgui, et al. 2013). Yet the importance of understanding and developing suppliers' BIM capability has not received due attention. For example, Sebastian (2011) acknowledges that the key to a successful integrated project delivery is tight collaboration between the client, the architect, and the main contractor, yet neglects the fact that suppliers are also part of the integrated project community. Successful BIM adoption and implementation processes require an inclusive consideration and effective development of multiple stakeholders', particular SMEs', competences (Murphy 2014; He, et al. 2017).

Although there are various studies emphasizing the importance of BIM collaboration among supply chain actors as summarized by Oraee et al. (2017), the critical issue of structural inequalities mentioned above has not been properly addressed. Our study aims to fill this gap by using a data driven approach to assess suppliers' existing capability, thus laying the foundation for organizations to develop effective instruments/schemes to further improve their competence later.

3. Assessing supplier BIM capabilities

A regular explanation for the lack of success by companies in adopting IT, and especially by smaller businesses, is the gap between strategic intent, often referred to as vision, and the capabilities to actually implement the technology, that is, the ability to execute the technological implementation. Not only is there a disconnect but companies can also be lacking in both dimensions (Nguyen et al., 2015).

3.1 Execution capability

Although the UK government is optimistic that mandating the use of BIM will help to improve the overall competitiveness of UK's construction sector in a global market, such optimism may not yield the desired results without due consideration of the capability of execution in industry. Furthermore, it is likely that suppliers' capability in implementing BIM will vary, given different natures and sizes of their businesses. Companies may compete in the same environment and deploy the same technology, yet some perform better than others. The differences in performance lie in the strategic capabilities they have or have tried to develop (Johnson et al., 2011). These capabilities can serve as a catalyst in transforming IT-related resources into higher value for a firm (Rush et al., 2007, Doherty and Terry, 2009). If the government and/or main contractors are to put measures in place to help industry prepare for Level 2 BIM, it is also important to have a deep understanding of how capable suppliers are in use of BIM. One-size-fits-all approaches to influence BIM adoption is unlikely to work.

According to Chen and Popovich (2003) and Wang et al. (2011), a systematic assessment of current execution ability needs to focus not only on technical ability but also people (skills and readiness) and existing processes. The rationale is that a successful technological deployment will depend on the alignment of these three core elements (Arayici et al., 2011b, Khosrowshahi et al., 2012). Getting people 'on board' will determine the ultimate success or failure in using BIM. Having the right process is essential to enable the required transformational changes to take place. Selecting the right technology will have a large impact on financial and organizational performance.

3.2 Strategic vision

While many scholars tend to concentrate solely on assessing firm's strategic or dynamic capability in technological adoption (Smart et al., 2007, Teece, 2007, Ambrosini and Bowman, 2009, Rai et al., 2012), we believe that for BIM to be effectively taken up by the construction industry, we also need to examine firms' vision for the future. Drawing from Institutional Theory, we argue that there is potentially a high risk that BIM implementation will take place only at a superficial level if suppliers are purely in response to coercive pressures. This is evidenced in other sectors, for example, Bhakoo and Choi (2013) applied institutional theory to investigate IOS mandatory implementations across different tiers of the healthcare supply chain in Australia and they found that strong coercive pressure if exerted on an organization tends to generate a cosmetic response at the administrative level. Equally alarming, the studies of (Devaraj and Kohli, 2003, Lai et al., 2006) claim that organizations may only respond to the regulatory and endogenous pressures in a ceremonial fashion and not make real usage of the technology. Assessing suppliers' future vision and strategy will help us to understand how committed a supplier is to exploit the use of BIM and collaborate with its clients.

If companies lack long-term vision in reaping the potential benefits BIM might offer, it is unlikely technological take-up at industry level will be sustainable. For instance, suppliers may see an increase in cost (such as the cost of purchasing software applications) to meet the mandating requirement and may see limited benefits to their own other than fulfilling the minimum requirement imposed by the government and/or customers. This may lead to a limited expectation of benefits in BIM adoption in the future. Any resource-constrained organization needs a strategy and vision that defines boundaries and set up the boundary of medium- and long-term objectives and actions (Collis, 2016). Having a BIM strategy and vision defines the type of value the companies intend to expect from BIM and guides the scope of its BIM investment and deployment process choices. Strategic vision influences and guides execution (Sull et al., 2015).

Management literature has long argued the importance of strategic orientation and intent to competitive advantages (Hamel and Prahalad, 2005). Firms with a strategic intent usually set out stretch targets, which force themselves to compete in innovative ways in order to build dynamic capabilities for a sustained growth (Hamilton et al., 1998). While current capabilities help firms to compete in today's market, their strategic vision guides them to overcome empirical limitations to the future and is a powerful predictor of their future success (Aragón-Sánchez and Sánchez-Marín, 2005, Zhou and Li, 2010). Assessing both core capabilities of execution and strategic vision of a firm's potential on BIM is therefore a more systematic approach to gain insights on BIM adoption. The next section reports how we use this approach to interrogate a unique data set of a BIM survey from a leading construction company's top 150 suppliers.

4. Research Method

4.1 Research Design and Context

Our study is rooted in the context of the UK construction sector and was conducted at the time when UK government mandated BIM use at Level 2 for large publicly procured projects. Whilst there have been a lot of sensemaking among the industry because of the mandate, it was those large contractors that were seen to have sufficient expertise and resources to lead the BIM adoption and diffusion. Seeing BIM level 2 as the order qualifier for bidding large government projects, these companies actively seek ways to improve their BIM capabilities as well as their suppliers'. We have has a long-term collaboration with one of those companies, hereafter known as CASE BIMP, a BIM pioneer and early adopter. CASE BIMP is a well-established main contractor specializing in large infrastructure projects, employing 4000+ people and with an annual turnover of £1.7 billion. The company has a clear strategy on BIM, appointed a BIM senior manager and tried to establish an understanding of its supply chain capability on BIM. This offered us a great opportunity to gain access to its supplier base.

Hence, we adopted a single case study as the focal perspective within our study. A case study approach is particularly suitable for investigating complex problem in its real-life context (Benbasat et al., 1987) and when the research is exploratory in nature (Yin, 1994). Within this single case we included an embedded unit of analysis, which relates to the BIM capabilities of individual suppliers. This aligns with Yin's (1994) single case study with multiple embedded units of analysis design, since the data includes multiple suppliers. Our quantitative analysis is based on a dataset collected by the case company's BIM manager, who developed a series of questions to survey BIM capability of the firm's preferred 150 suppliers.

For the single case, we held regular meetings and calls with the BIM manager and Innovation Manager to help guide and interpret the data, as well as understand the context of BIM initiatives at the organization. For the embedded unit of analysis, we utilized the data obtained by the BIM manager. This data was then coded in order to develop Vision and Execution based capability scores and analyzed to determine maturity scores, as explained in detail in section 4.2. To exemplify and illustrate different configurations of BIM capability, we sampled a selection of suppliers at the boundaries of different maturity levels to ensure that there was a valid difference between their characteristics, as well as to explain some of the underlying reasons as to why certain companies were placed in certain levels. These are presented as a series of supplier vignettes, building on the questionnaire data, to help characterize different maturity levels. Vignettes are frequently used in social science to represent illustrative cases, presented in narrative form (Pendleton et al. 2002) and have been exploited in supply chain settings (Williams, 2007).

4.2 Data Exploration, Mobilization and Analysis

We were able to obtain usable capability information for 41 of the suppliers (27.3%) including material suppliers, suppliers of significant structural elements, and those that assume responsibility for 'work packages', e.g. internal fittings. The survey consisted of 28 questions as given in Appendix A. We then categorized the questions in line with the theoretical dimensions of vision and execution, as discussed in Section 3.

Execution related questions were divided into: basic information, interoperability and compliances, current level of conformance to government standards, and current provision of process, people and technology. Under the vision dimension, questions focused on suppliers' understanding of BIM benefits, whether any strategies were in place to support BIM adoption and level of commitment and willingness to collaborate with the case company to sustain BIM development. To support our interpretation of the dataset, we also attended the case company's BIM system demonstrations, BIM meetings and workshops with suppliers, as well as obtained archival information on the company's BIM practices. In addition, we kept abreast of the BIM developments in the sector by attending BIM related industrial conferences and analyzing reports/news released by government and industrial bodies. These activities helped us to understand the wider context of BIM adoption in the UK's construction sector.

A scoring method was used to transform the answers to each question into numerical values based on a three-point Likert-scale. Given that most of the questions are quite straightforward, demanding a 'yes' or 'no' questions, this simple scoring method is sufficient for converting the answers into numerical categorization – namely yes (3), no or don't know (1). For a small number of questions (such as questions 5, 10, 11) that asks 'which' and 'how many' information, this scoring method is also adequate as we are able to set up our evaluation criteria into such as 'substantial (3), some (2) and little (1), and then assign a score based on individual answers. Full justifications for the scoring of each question is provided in Appendix A. All the criteria are benefit criteria, i.e. the higher the values are, the better it is as to BIM execution or having a vision for exploiting BIM. We then sum up all the numerical values obtained for each company for each of the two dimensions: execution and vision. We also created the maximum and minimum possible scores attainable and used these to normalize the data for clustering purposes, so as to have a scale from 0 to 1.

Table 1
Filtering criteria – based on government maturity model

Filters	Questions in the survey	Filtering criteria
Filter 1:	Do you have BIM, yes or no	If yes, then classify as level 1; no, as level 0
Filter 2:	Are your BIM systems/processes BS1192 compliant?	If yes, then classify as level 1; no, as level 0
Filter 3:	ERP and 3D	If yes, then classify as level 2; no, as level 1

We adopted two approaches to estimating where the suppliers were categorized according to the UK government's maturity model. Firstly, based on the definitions given of each maturity level, as per the literature review in Section 2, we simply looked for the attributes given e.g. adherence to BS 1192:2007 (therefore, Level 1 or above) and/or evidence of 4D program data (Level 2 or above). Table 1 outlines this filtering approach. The problem with this approach is that it was not easy to determine the existence of all attributes due to the vagueness of the definitions (National Federation of Builders, 2015). For instance, using ERP to determine level 2 is problematic, as not all businesses would need ERP to integrate. We then repeated the categorization using the execution and vision scoring and determined clusters using the K-means method (MacQueen, 1967). This latter approach is purely based on an objective function and is not so prone to subjectivity regarding the existence of certain attributes as per the maturity definitions. While the K-means approach may be modified, for example, to allow for automatic selection of the optimum number of clusters (Affify et al., 2007), or alternatives clustering approaches selected (Brusco et al., 2012) in its classic form it still has considerable utility due to its ease of use and simplicity (Ratrout, 2011) and is particularly pertinent to data sets such as ours, where which we wish to partition through establishing virtual cluster centers (Brusco et al., 2012).

5. Supplier Capability Analysis

5.1 Analysis of Vision and Execution Scores

Figure 1 presents the Execution and Vision scores for each of the suppliers plotted onto a chart. These are further coded by the existing government levels. It shows that out of the total of 44 suppliers, 20 are at level 0, 17 are at level 1, and 7 are at level 2. Hence the majority of suppliers are at the government's levels of 0 or 1. For completeness, the minimum and maximum possible values for vision and execution are also indicated.

As expected, there is a steady upward progression in vision and execution scores for each of the government level averages. But what is also evident is that some organizations at one maturity level are in close proximity to the means of a higher / lower level of maturity. Hence, the maturity levels do not seem to be good indicators of organizations' capabilities. In addition, this indicates that the boundaries for different levels are fuzzy.

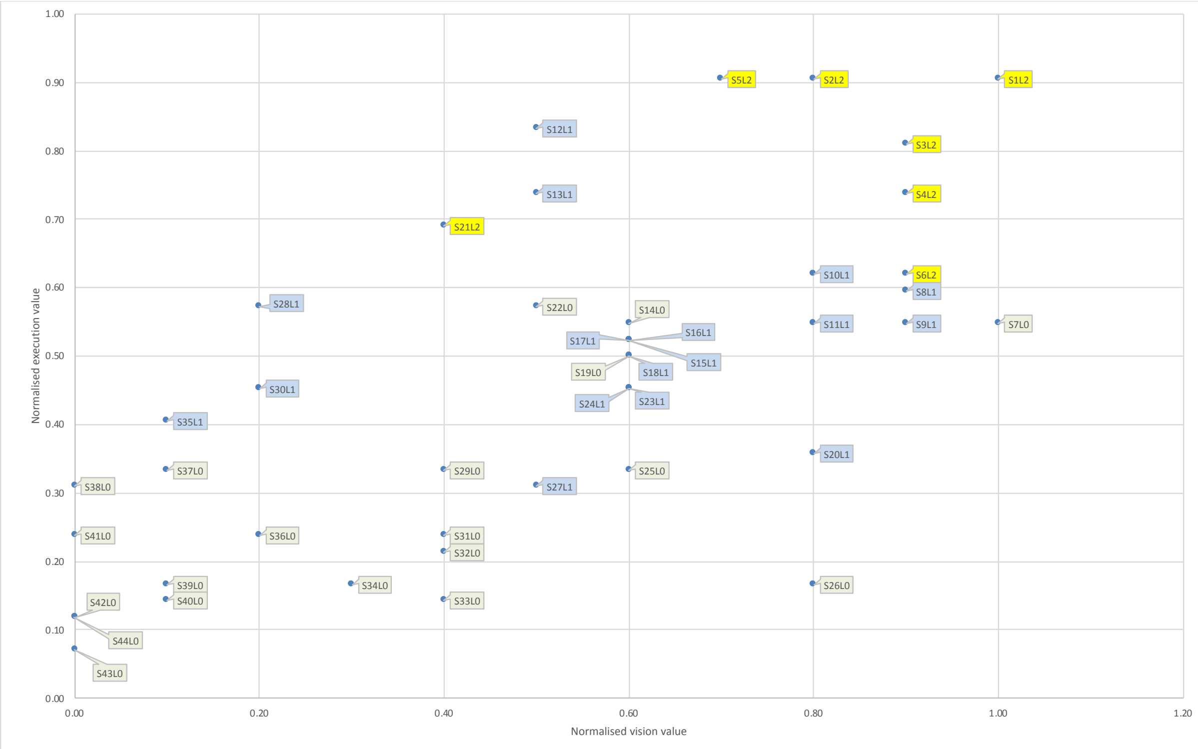

Figure 1: Vision and Execution clusters coded by Government Maturity Level (note, S_iL_j, where S=supplier number, L = maturity level)

Using the K-cluster approach, we can make a direct comparison between suggested K-clusters and our analysis of government levels. Figure 2 presents a comparison of these clusters and means. Also, Table 2 gives the comparison of the alternative governmental definition and data-driven approaches.

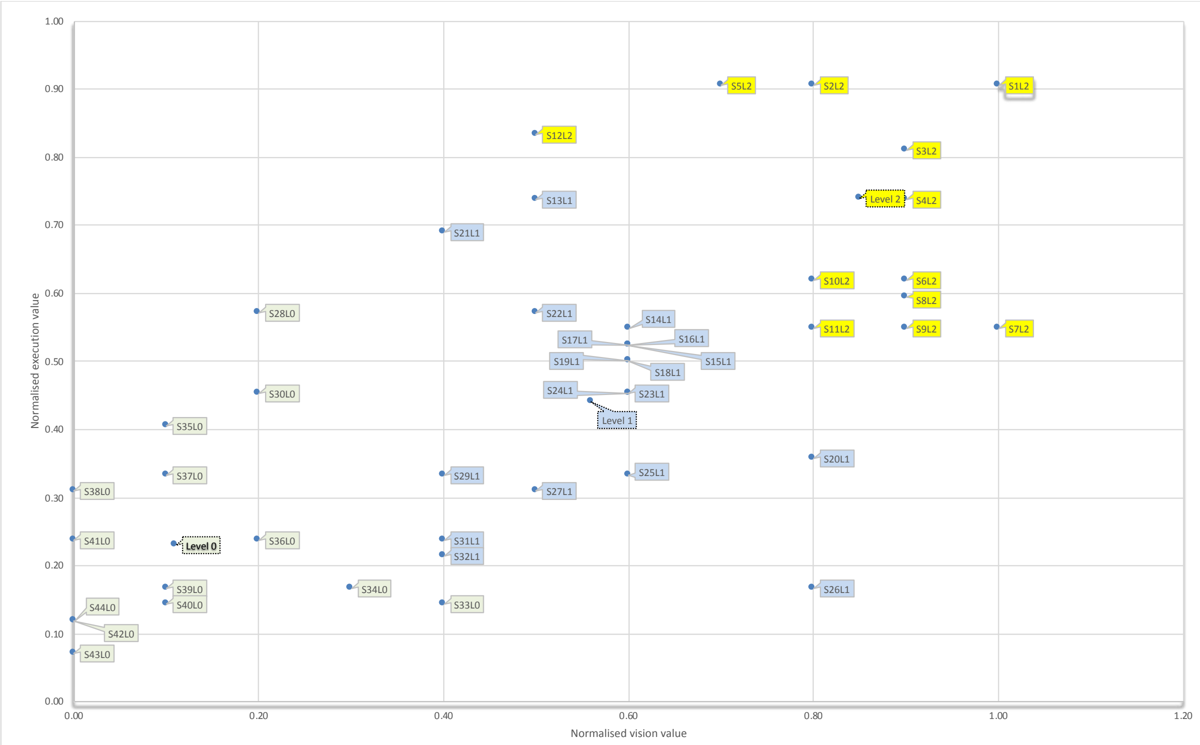

Figure 2: Vision and Execution Clusters using Data-driven approach (note, S_iL_j, where S=supplier number, L = maturity level)

Table 2
Results of clustering using two different approaches

	Number of Suppliers in Levels		
BIM levels	0	1	2
Government approach	20	17	7
Data-driven approach	14	18	12

Level Change	Number of suppliers
0 → 1	5
1 → 2	5
0 → 2	1
1 → 0	3
2 → 1	1

5.2 Illustrative vignettes

We select a number of suppliers to indicate the typical BIM attributes, for both capabilities and vision, of various companies. The selection takes examples from each level including those suppliers which identify strongly with a particular level and those that have changed levels. Table 3 shows the suppliers selected, with brief descriptions, their vison and execution scores, and some significant characteristics, which we describe in more detail.

Table 3 Illustrative Suppliers

Supplier Number	Government Maturity Level	Data-driven Level	Company - Trade	Employees	Turnover (£000)	Execute Score	Vision Score	BIM technologies	Investment	External integration
1	2	2	Engineering Consultancy, Project and Program Management, Design and Construction	742	166,365	0.90	1.00	Compliant with BS1192, ISO15926, integrate advanced technologies	Invests in and uses BIM extensively, has specialists and champions	Enthusiastic and keen to support clients
21	2	1	Structural steelwork design, detailing, erection	55	10,548	0.69	0.40	COBie2, IFC,	Has BIM software, provides staff training but has limited budget	Has clear vision but not many clients asking for BIM capability
13	1	1	Structural Steelwork and Bridge Construction	594	68,282	0.74	0.50	AutoCAD, StruCAD, COBie2, IFC, bespoke information systems, Engineering Data Management System	Uses BIM in-house for some projects but budget for BIM development lacking and tools are not integrated.	Wants to support clients but lacks investment
15	1	1	Design Consultant	167	8,061	0.52	0.60	ProjectWise, Buzzsaw, asset management systems, Geographical Information Systems, COBie2, IFC	BIM used in-house in most projects. Has a dedicated budget to support BIM deployment.	Reluctant to share BIM files due to intellectual property issues
14	0	1	Switchgear Design & Manufacture	-	-	0.55	0.60	COBie2, IFC	Has limited BIM adoption in projects. Passive 'wait & see' approach.	Needs main contractor / client support
43	0	0	Brick, stone and scaffold contractor	36	23,635	0.07	0.00	MS Excel	No BIM adoption.	Has no strategy.
7	0	2	Internal dry lining, ceilings and facades	500+	45,000	0.55	1.00	COBie2, IFC, MS Excel	Educates employees via industry fora. Dedicated budget in place.	Proactive to work with clients / contractors.

Supplier 1 is an exemplar at level 2 with core expertise in engineering and design consultancy. Further, the company is large and can invest in BIM as required. They use BIM routinely, and perceive BIM as value-add value to projects. They are conversant with BS1192 and international standards (ISO15926). They are able to utilize fully functional BIM software. All projects use some BIM tools and approaches, and a few projects use most of their BIM tools and processes. It has technical specialists and champions to provide in-house training and advice. It has been able to integrate advanced technologies (e.g. GIS) with BIM and can provide BIM information in the format required by clients and contractors. In terms of vision, Supplier 1 is enthusiastic to support the BIM strategy of clients and contractors. They have internal processes, strategy and budget to support future BIM deployment.

Supplier 21 is a small structural steelwork company with design engineering expertise. It has appropriate BIM software tools in place, and perceives BIM adds cost, but also provides value. Most of the projects use a few BIM tools/processes and the BIM information is available upon request. The reason why it is not very aggressive in adopting BIM is that, at present, they do not see many clients asking for it. They have provided appropriate in-house training to staff, and are able to provide BIM and COBie2 information in the format required by clients such as IFC. It is willing to support the BIM strategy of clients and contractors, but it does not have a strategy and budget in place to facilitate its own future BIM deployment.

Interestingly there is a discrepancy between the level assigned based on the government maturity model (level 2) and our data-driven approach (level 1). Their lack of vision plays a large part in this difference. While the government maturity model is entirely based on current capability, our model takes into consideration their future vision. Vison and strategy depict which direction the organization will go in the future and fundamental decisions are made about medium- and long-term objectives and activities. This will then in turn influence the investment and commitment of resources in BIM deployment and the likelihood of modification of existing supply chain processes, relational and informational practices. Given the fast-developing landscape of BIM and increasing need for digitalization in the construction sector, companies without an appropriate BIM strategy for the future may risk falling behind and lose their competitive advantages. Lack of strategic thinking and planning is indeed a common issue within SMEs (Stonehouse and Pemberton, 2002, Kyobe, 2004). Research also suggests that the focus on short-term business objectives is an important factor in the high failure rates commonly encountered among SMEs (Stonehouse and Pemberton, 2002). In addition, lack of skills and knowledge, lack of internal resources and project uncertainty may well contribute to the short-term orientation in BIM adoption by SMEs.

Supplier 13, a structural steelwork and bridge construction company, is classified at BIM level 1 under both approaches. The company uses BIM in house and provides BIM tools and share files with no extra cost. It perceives that BIM does add value to the business but also increases cost. Currently the company carries out a few projects using limited BIM tools and processes. It provides appropriate BIM training via seminars and specific supply chain workshops. It uses different commercial software such as AutoCAD and StruCAD to aid the design of 3D models. The company is also capable of providing the government mandated COBie2 Information in an IFC file, however only less than 25% of their work is COBie2 compliant. It has a few bespoke information systems such as customer relationship management system and Engineering Data Management System but these are not internally integrated. In terms of vision, as with Supplier 21, it is willing to support the BIM strategy of clients and contractors, but it is yet to have a strategy and budget in place to facilitate its own future BIM deployment. Different from Supplier 21, Supplier 13 is a large company. Therefore, affordance may not be a significant barrier to BIM deployment. The lack of strategy and vision may help to explain its stagnation in BIM adoption.

Supplier 15, a design consultancy, is classified at BIM level 1 under both approaches. The company uses BIM in-house and provides BIM tools and share files with no extra cost. As with Suppliers 21 and 14, they also perceive BIM does add value to the business but also increases cost. The depth of BIM deployment is better than Supplier 13, as they carry out a few projects using most of their BIM tools and processes. It has an intensive range of information systems in place that are able to provide BIM information, for instance various data management systems such as ProjectWise, Buzzsaw, asset management systems such as Ellipse and Maximo and Geographical Information Systems such as ESRI, Bentley Map and GeoWeb. The company promotes the deployment of BIM by increasing its day-to-day use of BIM for projects and has a mentoring scheme to support its less experienced staff in order to equip them with appropriate skills and knowledge.

However the company is currently unable to work out how much of their work is compliant COBie2 and whether it provides an IFC file upon request. This indicates that technically the company might be quite capable in deploying BIM but lacks the willingness to share information due to intellectual property and commercial sensitivity concerns, a barrier to BIM take-up previously identified (Samuelson et al., 2012). This example highlights the ambiguity of the maturity model in assessing BIM capabilities - the company is capable but unwilling to integrate hence will score low. In terms of Vision, the company does have budget, processes to support BIM deployment, and sees value in supporting the BIM strategy of clients and contractors.

Supplier 14 is a specialist supplier of switchgear systems (Tier 3 Supplier/Subcontractor) in the project delivery cycle. The company claims not to use BIM but a closer examination of the survey answers reveals that the company does carry out a few projects using some BIM tools. It does acknowledge positively the potential benefits of using BIM i.e. it saves cost and adds value.

This example again reveals the complex issue of BIM deployment and there seems to be a different interpretation of what BIM is in practice, further reflecting the ambiguity associated with the government maturity model. Overall, the company seems to have been in a passive wait-and-see mode. The status was evidenced by the comments from the survey respondent "it is our experience to date that the collaborative working/design interface between Tier 1/2 & Tier 3 Contractors/Subcontractors, is only now gathering momentum". The company is capable of providing COBie2 information if "the main contractor help us and supply a template." It estimates that 25-50% of its work is compliant with COBie2 and is able to provide an IFC file upon request.

In terms of vision, it currently has no process, strategy or budget to support BIM deployment. But the management team has become aware of the increasing importance of BIM to their business, therefore it has committed and planned to engage with its clients in order to establish the scale and timeframe for the introduction of BIM interface with subcontractors. It plans to make provision in their future budgets for tools, training and new processes associated with the introduction of BIM, which will then form part of a quality management system. Although being a large organization it identified many deficiencies, such as, appropriate metrics, information about BIM process, how to manage interfaces between companies and individuals' skill sets and competencies to implement BIM.

Supplier 43, an SME, is a brick, stone and scaffold contractor. It does not have the resource or inclination to gain BIM expertise. The company currently does not use BIM nor does it have any strategy, process or budget in place for BIM adoption. Its overall IT adoption is low, only using basic data management application (Microsoft Excel) for project management. Due to the nature of the business, the company does not use 3D models for their work, therefore sees the use of BIM of little relevance to them. Therefore, this example is clearly at level 0 under both approaches.

Supplier 7 specializes in internal dry lining, ceilings and facades and is one of the largest drywall specialist contractors in the UK. This example is the most provocative in our analysis. It is at BIM level 0 according to the government maturity model but is in Level 2 under our data-driven approach. When asked whether they use BIM, the respondent says no but further questions do provide evidence that they carry out a few projects using limited BIM tools. This highlights the same problem associated with the government maturity model, as identified in Supplier 14.

Supplier 7 educates it employees via industry seminars and product suppliers on BIM. It currently does not have any commercial software packages on enterprise resource planning and risk management to integrate with BIM but has its own version on Excel. In terms of engineering data management, the company follows suit with main contractors. Some mechanical data analysis was conducted externally due to lack of expertise in-house. The company is capable of providing COBie2 information but requires help from main contractors. Currently less than 25% of work is compliant with COBie2 and it cannot provide IFC files. It is a supplier where there is some BIM capability but requires external support to progress in its BIM journey.

In terms of vision, the company is keen to deploy BIM, and perceives benefits in both cost savings and value-add. It has strategy and budget in place to support future adoption. It identified barriers in projects as of lack of objectives, guidance and understanding of the implications of workflow. A well-articulated strategy and vision is evident, setting it apart from its peers, explaining why it is being clustered at level 2 under the data-driven approach.

6. Discussion and conclusion

Our aims were to determine the level of BIM maturity within the contractors' existing supplier base, and to develop a strategic approach for assessing and benchmarking suppliers in BIM adoption according to vision and execution-based capabilities. We applied two different approaches in assessing suppliers' BIM capabilities to a dataset relating to the suppliers of a large UK engineering contractor: the UK government maturity model approach and a data-driven approach.

Our analysis reveals the potential pitfalls in relying on interpreting the government maturity level definitions and its sole focus on technical capability of using BIM. For example, when assessing the maturity level of Supplier 7, the attributes of that supplier suggested a Level 0, especially because the organization claimed that it did not have BIM capabilities. On closer examination, there is evidence of a number of projects that utilized BIM tools, such as AutoCAD, although in a limited and fragmented manner. Also, the company has a clear strategy for developing BIM and has invested for the future, particularly through training. In contrast, the data-driven clustering analysis has identified Supplier 7 as a Level 2, considering actual capabilities, rather than the company's own perceived lack of tools and knowhow, and clear vision. Another evidence is that the data-driven approach has helped to reduce the ambiguity on clustering created by the government maturity approach. For instance, Supplier 19 and Supplier 18 were very close to each other in Figures 1 (government approach) and 2 (data-driven approach) but were assigned into two different clusters by the former, whilst were grouped into the same cluster by the latter. The same applies to Suppliers 14 and 16.

6.1 Practical implications

Assigning suppliers into clusters will help main contractors to establish a portfolio of its supply base, and devise the appropriate supplier development mechanisms accordingly, as it is unlikely the 'one size fits all' approach will be effective (Dyer et al., 1998) Our data-driven approach proves to be a more robust way to divide suppliers into meaningful groups so that tailored action plans such as development and provision of education, training and knowledge transfer around collaborative working practices, contractual arrangement and performance measurement can be developed to help them in accelerating the BIM adoption. This is in line with the creation of supplier associations, as happens in the automotive sector (Hines and Rich, 1998), used by large organizations to help develop their supply base.

For suppliers in cluster 0 (laggards) with limited capabilities and vision, the main contractor needs to center efforts on further awareness raising, education and training programs. The main contractor may also need to improve awareness of the benefits and clearly communicate the requirements for implementation of BIM among the suppliers. Those suppliers need a much hands-on project based support from the main contractor. Once seeing the need and benefits of using BIM, suppliers will then need to put a structured change management program in place for further take-up on BIM. However it may well be possible that main contractors perceive suppliers in this cluster as demanding too much investment and will simply choose not to involve them in future projects. Instead they may favor those from cluster 2 (some of whom may not be fully capable yet but are fully committed and have strategic intent to deploy BIM).

Suppliers with both good capability of execution, as well as vision for the future, also fall into cluster 2. With those companies, a main contractor need not provide much technical support or training, nor to spend time raising the awareness of BIM benefits. Instead they may consider those as their 'preferred suppliers' (for example, see the supplier classification in Gosling et al., 2015) and actively engage them in a variety of projects. They may also set up stretch targets and explore more innovative use of BIM, which potentially leads to sustained BIM performance in the future.

For suppliers in cluster 1, the main contractor may need to set up clear contractual terms depicting expectations, information sharing and process integration protocols, and measurement/reward on

BIM performance. There is also a need to look in more detail barriers to their capability development. As discussed in Section 5, there are various inhibiting factors on BIM use, such as fear of information sharing and lack of BIM strategy. Main contractors may consider incentivizing collaborative behaviors about sharing information. Knowledge transfer type of activities on best practices may help suppliers looking into long-term strategic approach to harvest the BIM benefits and routinise the use of BIM.

6.2 Limitations and future research

Though our data-driven approach proves to be more effective in assessing suppliers' BIM capabilities, it is not without limitations. As we rely on a dataset designed by the case company not by ourselves, the survey could be more systematically designed, for instance more questions can be asked on 'vision for future', and on suppliers' current BIM performance. A more systematically designed survey would also allow us to conduct more complex statistical tests and gain further insights into the phenomenon examined. The current clustering analysis does not make use of weightings. There might be some items that are more important than others when assessing supplier capabilities. A qualitative empirical research may help to understand whether there are 'must-have' factors, or factors that are optional.

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Appendix A

Category	No	Question	Rating		
			3	2	1
Execution capability					
Basic information	1	Do you use BIM in your company	Yes		No
	2	Do you provide BIM tools and share files	Yes, routine	Yes, sometimes	No
Interoperability and Compliance	4	Are your BIM systems/processes BS1192 compliant?	Yes		No or Don't know
	5	Which National or International standards do you work to (if any) ?	Most	Some	None
	25	Can you provide COBie2 Information	Yes (in IFC or excel)	Yes (if given a template)	No or Don't know
	26	How much of your work is compliant with COBie2?	Lots	Some	None
	27	Can you provide an IFC (.ifc format) file?	Yes		No or Don't know
	28	How much of your work is in IFC format?	Lots	Some	None
Process, Scope and scale of current BIM uptake	6	Do you have processes in place that support BIM deployment?	Yes		No or Don't know
	10	Which BIM processes do you use? Please tick all that apply	Substantial	Some	Little
	11	To how many projects do you apply BIM processes and/or tools?	Substantial	Some	Little
People	12	How do you educate your people in the benefits of BIM?	Effective	Basic	Lacking
	13	How do you educate your people in the use/application of BIM tools and processes	Effective	Basic	Lacking
BIM software	9	How is your BIM data hosted?	Internally	Externally	Don't know
	16	Typically, if you use 3D modelling, how do you create your models?	Advanced model	Concept modelling only	NA or do not use 3D
	17	Which CAD software do you use?	Yes		None
	21	Which Engineering Data Management System do you use (CAD data management)?	Yes		None
Data management					
Planning, ERP and risk (basic level)	18	Which planning/programme management system do you use *(if any)*?	Yes		None or Don't know
	19	Which ERP (Enterprise Resource Planning) system do you use*(if any)*?	Yes		None or Don't know
	20	Which Risk Management software do you use *(if any)*	Yes		None or Don't know
Assets, Analysis and GIS	22	Which Asset Management software do you use *(if any)*?	Yes	Use other system for	None or Don't know

(advanced level)				asset mgt	
	23	Which Analysis (FEA or CFD) software do you use *(if any)*?	Yes		None or Don't know
	24	Which GIS software do you use *(if any)*?	Yes		None or Don't know
Strategic vision					
Understanding of BIM benefits	3	What is your perception of BIM?	Beneficial (save cost and add value)	Beneifical (add cost but provide value)	Just add costs or no relevance to business
Strategies in place	7	Do you have a BIM Strategy?	Yes		No or Don't know
	8	Do you have a budget in place to support BIM?	Yes		No or Don't know
Management commitment and willingness to collaborate	14	How would you like to help your client improve BIM performance?	Helpful	Some	Don't
	15	Would you like to help your client develop its BIM Strategy	Yes		No or Unsure