



# Accelerating BIM adoption in the supply chain

Final Project Report March 2017 (Revised)

Project team: Dr. Yingli Wang<sup>1</sup>, Dr. Jon Gosling,  
Dr. Maneesh Kumar and Prof. Mohamed Naim  
Cardiff Business School, Aberconway Building, Colum Drive, CF10 3EU

---

<sup>1</sup> Corresponding email: [wangy14@cardiff.ac.uk](mailto:wangy14@cardiff.ac.uk)

# Executive summary

Given the UK Government's mandatory requirement, from April 2016, for Building Information Modelling (BIM) adoption, our research set out to explore whether construction supply chains can achieve the targets set and what actions are required to accelerate BIM adoption in the supply chain. To establish an in-depth understanding of the current state of BIM awareness, capabilities and uptake in supply chains, we have consulted a wide range of stakeholders, including clients, main contractors, Tiers 2/3 suppliers (large and small, and including suppliers and material / equipment suppliers), technology service providers, academics and consultants.

Our research identified several barriers to BIM adoption beyond Tier 1 level; including interoperability issues, BIM sold as a technology solution, lack of knowledge on how and where to start BIM adoption, and a lack of leadership from main contractors and clients to provide clear guidelines and support for BIM implementation. With regards to current BIM capabilities, we found that large main contractors are usually quite capable of using BIM and tend to have sufficient in-house expertise and resources for deployment, albeit yet to devise an effective mechanism to engage with their suppliers. Supplier BIM capabilities vary significantly. Some are early adopters, proactively seeking innovative ways of using BIM and have developed a good degree of confidence in using BIM, while others are lagging and still trying to make sense of what BIM means for them. Small-Medium Sized (SME) suppliers are particularly struggling, constrained by a number of issues such as limited financial, human and technical resources, and overwhelmed by a plethora of publicly available information on BIM.

In terms of BIM leadership, the majority of participants would suggest that the main contractor is best positioned to take the lead in BIM adoption, serving as a change champion and supply chain orchestrator. For effective BIM diffusion along the supply chain, there should be appropriate technologies, processes and collaborative behaviors, within and between organizations, along the supply chain. More importantly, building a supply chain level BIM capability is a transformative process which needs a systematic approach and concerted efforts involving all key stakeholders. In this report, we propose a five-stage approach that outlines a structured road map of how to develop a BIM-enabled supply chain.

Finally, we observe that, although BIM benefits are widely recognised, project level gains are difficult to measure. Most benefits are 'soft', or intangible, whereas 'hard', tangible and quantifiable, impact is yet to be seen. This concurs with our wider literature / industry research that quantifying BIM benefits and relating it to the bottom line of a business is a challenging task.

# Acknowledgement

We would like to extend our sincere thanks to all participants who have supported our research via various activities such as attending focus groups and interviews, responding to our survey as well as having frequent informal dialogues with us. In particular, we are grateful for the continuous support we received from Ms. Lucia Fullalove (Highways England) and Mr. David Owens (Costain) throughout the whole project. Our gratitude also extends to Mr. Tim Embley (Costain) and Mr. Matt Blackwell (Costain) for their help, in particular on the BIM Supplier survey. Finally, we thank Mr. Andrew Fielding (Costain), Mr. Phillip Harris (Cardiff University) and Dr. Andrew Davies (Cardiff University) for their administrative support.

## Contents

Executive summary .....	2
Acknowledgement .....	3
1. Introduction .....	5
2. Project aim and research questions .....	6
3. Understanding BIM adoption .....	7
3.1 A multiple stakeholder perspective.....	7
3.2 BIM perception and challenges: Perspective from Main Contractor and Supplier.....	8
4. Survey on execution capability, vision for the future and critical success factors (Appendix 2).....	15
4.1 Current BIM understanding and capability .....	15
4.2 BIM future vision.....	18
4.3 Critical success factors to BIM adoption, and BIM related benefits .....	20
5. Infrastructure projects as a system .....	23
Understanding the traditional approach and current progress .....	23
6. A vision for a BIM-enabled system .....	25
7. Route-map to implementation .....	29
8. Discussion and Reflection .....	31
9. Recommended reading.....	32
Appendix 1: Summary of interviews.....	33
Appendix 2: Survey results (in a separate pdf file 27 pages).....	34

## 1. Introduction

In the construction industry, many projects have their unique characteristics and customer requirements, such as new processes, new engineering work and different companies working together in new ways. Such an environment presents significant challenges to organizations working in the sector, who must cope with considerable levels of uncertainty and innovation when designing and developing such projects. Finding suitable information technology (IT) systems to support their endeavors is also a challenge. Advances in digital engineering have led to the emergence of a plethora of technological innovations such as in procurement of construction projects, virtual design and progress tracking. Central to this trend is the development and adoption of 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, or 4D, parametric object based information systems. 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 providing information for decision-making throughout a project life cycle. Therefore, BIM breaks the silo-effect among various participating organizations in a construction supply chain and connects fragmented processes in a more integrated manner. Because 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.

Digital engineering is often used interchangeably with BIM. However, it embraces a much broader array of technologies. At the heart of it is effective information management. Therefore, having a well-articulated information management strategy within an organisation is essential, as it outlines the digital needs of your organisation and enables you to keep in pace with, or ahead of, industrial norm. We also observe efforts that connects BIM with other existing and emerging digital technologies. For instance, BIM can be integrated with Enterprise Resource Planning (ERP) systems for material planning and scheduling. Integrating with geospatial technologies such as Radio Frequency Identification (RFID), Geographic Information Systems (GIS) and Global Positioning Systems (GPS) for construction progress tracking is another area of its increasing application. We also witness the innovative use of BIM with imaging technologies such as augmented reality for site management.

Recognizing the importance of BIM as a 'game changer' and a 'key agent for economic growth' to the UK's construction sector, the UK government has recently announced that the use of BIM on publicly-funded projects will be mandatory after 2016. This reflects the government's ambition to take on "a global leadership role in BIM exploitation" to maintain and develop its international construction competitiveness. Further, the mandate demands all centrally procured projects to achieve a certain level of compliance by 2016. Per the 4-level (level 0 to level 3) BIM maturity model developed by the UK BIM task group, the

minimum requirement is Level 2, requiring building information to be available digitally in a specified standard format, but can be stored in separate BIM tools and these tools are integrated via middleware or proprietary interfaces.

Yet, there are significant challenges for the construction industry to achieve the mandatory requirement and the capability to fully exploit BIM. Two recent UK surveys<sup>2</sup> find that progress towards achieving BIM targets has been slow. This is particularly the case for suppliers, where only one in ten believes that the construction industry is ready to deliver on the Level 2 target; with a quarter feeling they lack the skills and knowledge they need to deploy BIM effectively. Large engineering contractors, which are often leading the way in this area, depend on both their own capabilities and on those of their suppliers, which may be of varying sizes and include suppliers as well as material and equipment providers. While implementing BIM may be less of an issue for the larger engineering contractors, which usually have sufficient in-house resources and BIM expertise, this may not be the case for suppliers, in particular for small-medium sized enterprise (SMEs). In fact, the annual NBS National BIM survey report, presenting the findings, across the UK construction industry, regarding BIM attitudes and adoption since 2011, has revealed that in all its previous years' (2011-2016) surveys, this problem persists - *"In previous years, 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"*.

## **2. Project aim and research questions**

The aim is to establish a road map to accelerate and support BIM adoption. This will be achieved through answering three research questions.

- Are contractors and their suppliers ready and capable to achieve the UK mandated BIM target?
- What knowledge exchange mechanisms are, or should be, in place at the supply chain level to improve suppliers' performance in successful BIM adoption?
- How are benefits and risks of BIM adoption allocated along the supply chain?

### **Research approach and main activities**

Our research contains four main activities:

- Desk based research examining BIM and related developments in the UK and internationally.
- A focus group exploring, from multiple stakeholders, barriers and enablers to BIM adoption. This included 15 participants in total, including five academics from different institutions, two Tier 2/3 suppliers, three representatives from two Tier 1 main contractors, one designer and representative of BIM4SME, and representation from the client (i.e. Highways England, hereafter abbreviated as HE).

---

<sup>2</sup> This refers to NBS survey 2016 and BIM Heat map survey 2014. Please see recommended readings section for further details.

- Interviews with main contractor and suppliers as well as client (30 interviewees, see Appendix 1 for further details)
- A survey of Tier 2 and 3 suppliers to further understand their capabilities and concerns about BIM adoption as well as their strategic intent for BIM in the future (19 respondents out of 79 targeted, see Appendix 2 for further details).

To further complement our empirical research, we also attended industrial and academic BIM conferences and workshops, as well as interrogated a wide range of industrial reports such as NBS BIM survey data and Government BIM task group publications. Furthermore, presentations were also made to the HE BIM community to debating and engage with to determine desirable and feasible changes. This included regular presentation at HE Lean R&D meetings as part of our iterative process of inquiry. Comments and advice obtained were then fed back to our project for reflection and further actions as required. The above activities provided rich information about the current landscape of BIM adoption in the UK, industrial and organisational capabilities for BIM exploitation, as well as factors that inhibit or support its adoption.

We report our detailed findings in the following sections. Section 3 gives the findings of our focus group and interviews. Section 4 gives a descriptive synthesis from our survey. Due to the small sample size, we do not provide any tabulated or graphical data but instead we relate the survey findings to existing know-how regarding BIM or other forms of IT adoption. We then conclude the report by bringing together all the various findings into a holistic ‘route map’ for enabling successful BIM adoption and provide answers to our three research questions.

### **3. Understanding BIM adoption**

#### **3.1 A multiple stakeholder perspective**

In our focus group, we asked our group of participants to write down on ‘post it’ notes their perceptions of the top three benefits and top three challenges of BIM. These were then mapped against a wall chart ranging from very positive at the top, to neutral in the middle, to negative at the bottom. This did not include a quantitative scale, but did offer a structure for participants to position their notes. This provoked further debate as more participants mapped their perceptions onto the wall chart. The outcome of this activity is shown in Figure 1.

The themes that emerge from the perceived benefits are:

- Improvements in health and safety
- Better lifecycle management
- Reduction of risk and uncertainty
- Greater efficiency

The themes that emerge from the perceived challenges are:

- Protectionism and resistance to change
- Contractual, commercial and procurement issues
- Guidance and inconsistency of requirements for T2&3 suppliers

- Expertise gaps

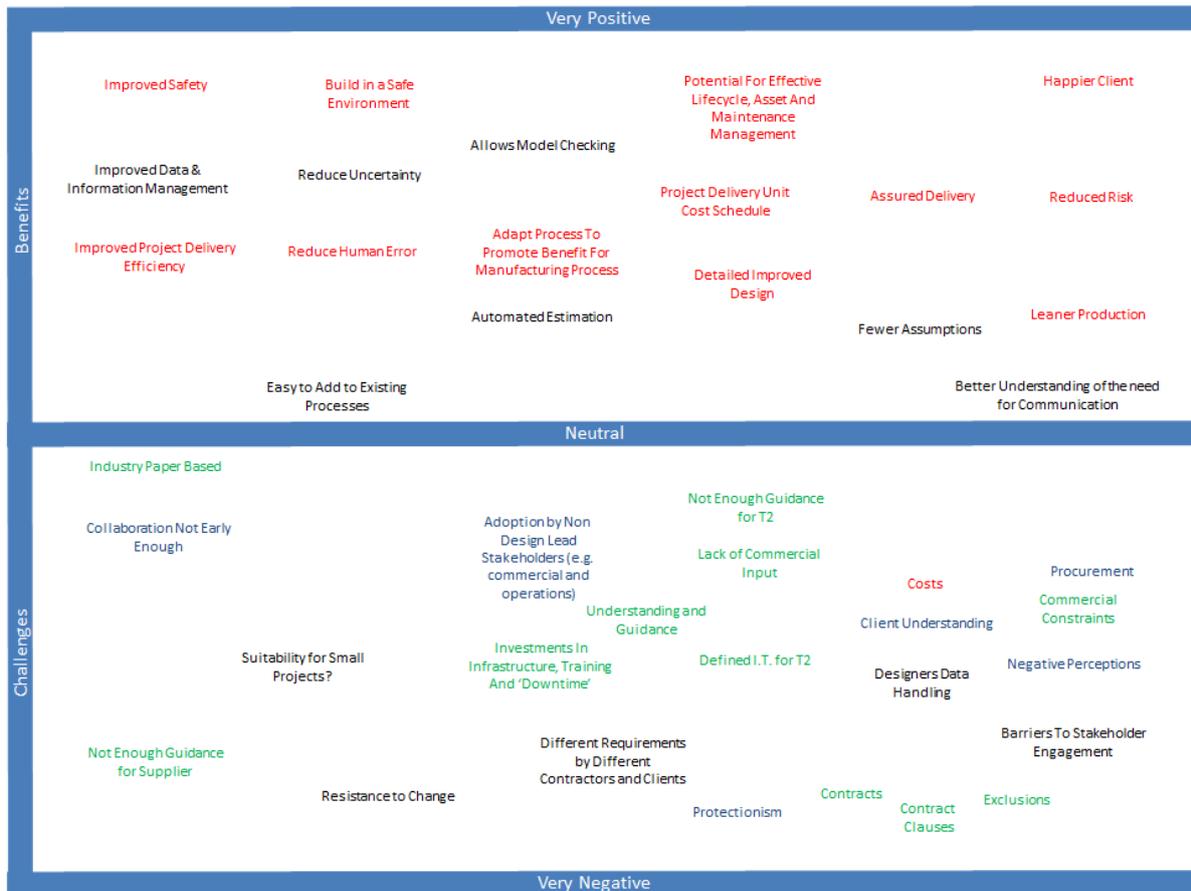


Figure 1: Force-field diagram of challenges and benefits to BIM adoption.

The focus group was important for two reasons. Firstly, it gave a holistic view across the supply chain as to the challenges and benefits faced by the supply chain. Secondly, it informed the interview and questionnaire survey phases of the project by highlighting the significant issues that needed further interrogation and questioning.

### 3.2 BIM perception and challenges: Perspective from Main Contractor and Supplier

The practitioner and academic literature claims significant benefits from BIM adoption in the construction supply chain (see Section 1). Do the claimed benefits from BIM adoption practically resonate? How do actors in the supply chain interact to realise the benefits? Who takes the lead and who shares the benefit? In this section, we address these by mapping the perceptions of main contractors with that of Tier 2/3 suppliers. We conduct 30 interviews with 14 companies, including 18 interviews with Tier 2/3 suppliers, 6 with main contractors, 2 design consultants, 1 technology service provider, and 3 from HE. The data collected helped to identify the main contractors' and suppliers' perceptions of BIM, understand the factors affecting acceleration of BIM adoption in the supply chain, and ascertain (a) symmetrical benefits and risks sharing in the supply chain from BIM adoption. Understanding of the current state enabled the research team to envision a more integrated future state map based on a federated BIM model to accelerate its adoption in the construction supply chain.

### 3.2.1 Main Contractors' perspective

Interviews with main contractors revealed that the key motivation to implementing BIM was to comply with the mandate but more importantly generate commercial benefits. The respondents perceive BIM implementation may help to identify the fragmented information management process (a lot of scanning, handwriting which is costly and time consuming) in the supply chain, the improvement of which will lead to less Request for Information (RFI), rework cost, improved information and process flow, on-time delivery of project, and better asset management. Clients seem to gain most from the BIM adoption followed by the main contractor, though it is still difficult to quantify the bottom line impact from its adoption for different stakeholders.

Majority of the interviewees believed that main contractor should take the lead in enhancing BIM understanding, knowledge, and capabilities across the supply chain, not designers (they don't understand SC) or the clients (haven't got enough knowledge on BIM). Clients are not able to explicitly state their BIM requirements, clearly communicate their expectations, or set expectations and guidelines for the supply chain actors to follow. Neither client nor the suppliers have the required knowledge and capabilities about BIM, resulting in its slow adoption in the construction supply chain.

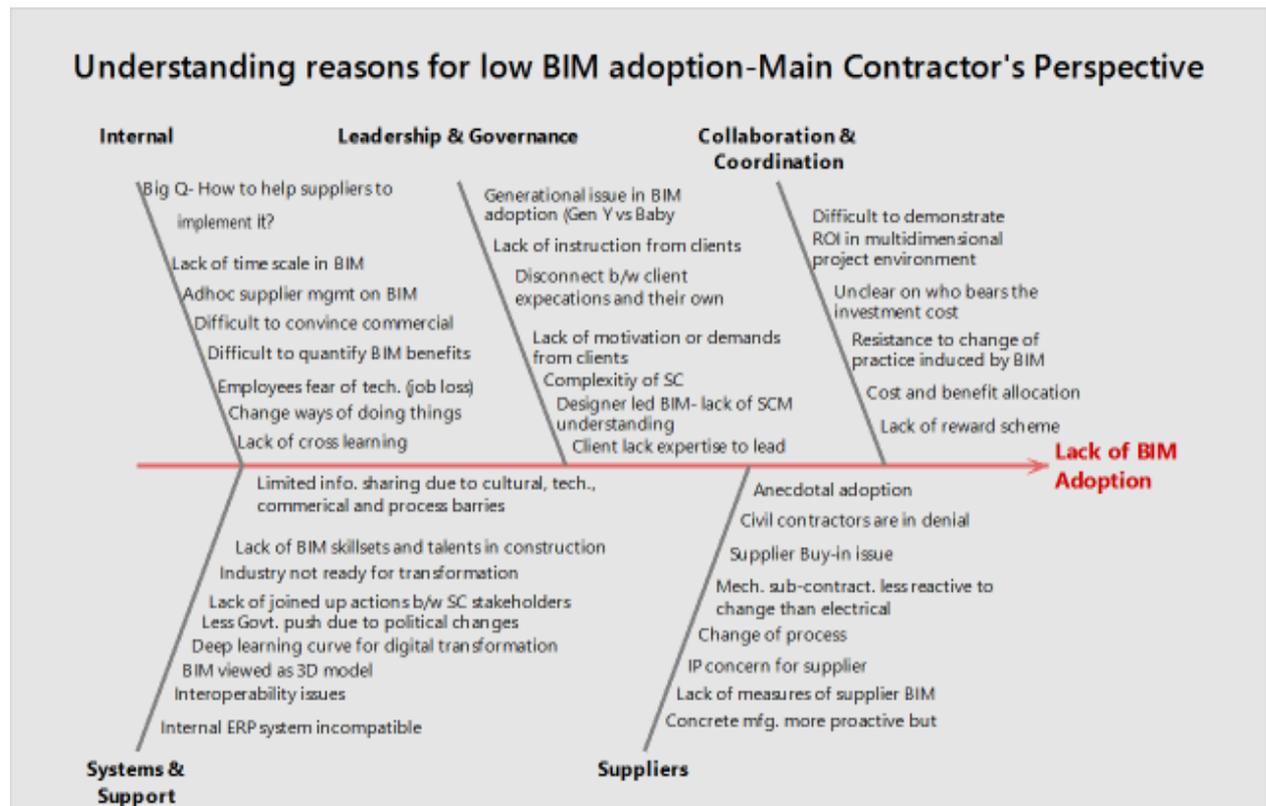


Figure 2: Barriers to BIM adoption from the main contractor perspective

Though the software vendors, such as AutoCAD and Bentley, play a key role in BIM adoption, the interoperability issues between software does not help Tier2/3 suppliers to decide which software to adopt as each contractor may be using different software systems. Hence, designers or software vendors should not lead the BIM initiative. Here, collaboration and co-ordination between main contractors and software vendors is critical to accelerate

BIM adoption in the supply network. The outputs from different BIM models should be pulled together as a federated model that could be understood and used by all stakeholders in the supply chain.

There are other systems issues in the construction supply chain that requires restructuring and improvement to enhance co-operation and co-ordination between supply chain actors - limited availability of BIM skill-sets and talents; inter-operability issues between BIM software; limited information sharing in the supply chain due to cultural, technical, commercial and process barriers; and lack of compatibility between BIM and other planning tools such as collaborative planning or enterprise resource planning (ERP) system.

The main contractor perceives that a 'carrot and stick' approach will not help to get buy-in from Tier 2/3 suppliers to accelerate BIM adoption. Main contractors should take the lead and provide clear roadmaps and guidelines to suppliers on how to start, adoption where to start, provide information on the right training modules to develop capabilities of suppliers, and focus on incremental rather than radical change. Suppliers should not look upon main contractors to cover the cost of BIM implementation. An option could be to include the implementation cost within their quotation but that may put suppliers in a less competitive position. Summary of key issues, from main contractors' perspective, that affect BIM adoption in the construction supply chain is presented in Figure 2.

**Box 1: Observed good practices from main contractors**

- Have a (BIM) change champion within the organisation to drive the adoption.
- Appoint a BIM manager for every (large) project who coordinates within the main contractor and with suppliers at operational level.
- Establish an online learning tool on BIM that is completely free for suppliers, as well as employees and clients to use.
- Celebrate BIM success and enable cross-learning between projects

### **3.2.2 Suppliers' Perspective**

#### **BIM definition & expectations**

BIM definitions varied across the sample with most of the small suppliers perceiving BIM as 3D modelling and a technological solution. Experienced design and engineering companies implementing BIM perceived it as a better information and asset management system – *'getting the right information to the right people at the right time'*; *'one platform that gives client information about the asset'*; *'one source collection of information and to create 3D images for maintenance purposes'*. Most of the suppliers started investigating or investing in BIM due to the requirement from government, and hence clients, to be BIM Level 2 compliant by April 2016. This resulted in main contractors asking their suppliers to develop BIM capabilities to work on current and new projects.

The *SME suppliers* are externally motivated and driven by their contractors to implement BIM. In most cases, the contractors and clients include a clause of BIM capability when bidding for a new contract or ask the suppliers to develop their BIM knowledge without handholding and giving clear guidelines on how and where to start. To have senior management buy-in in SMEs to invest in developing BIM knowledge and capabilities, they need to be convinced of the tangible benefits from BIM from the short to the long-term.

According to most of the suppliers interviewed, HE and main contractors expect suppliers to have BIM knowledge and also implement it but they don't provide enough guidance on where to look for information or help, how to implement, which module to implement, which document to look into and consider, and tangible benefits from BIM.

In the *case of large suppliers*, especially those involved in design and engineering work, the drive to implement BIM is primarily commercial. They have resources to hire skilled and talented designers with BIM knowledge or invest in-house to develop the capabilities of the existing designers and engineers. All suppliers, whether SMEs or large companies, agree that BIM knowledge and capabilities will provide them a competitive advantage, especially when operating in the BIM mandated environment, and they may then be seen as 'preferred suppliers' when bidding for the future contracts.

Summary of key challenges, from suppliers' perspective, that affect BIM adoption in the construction supply chain is presented in Figure 3.

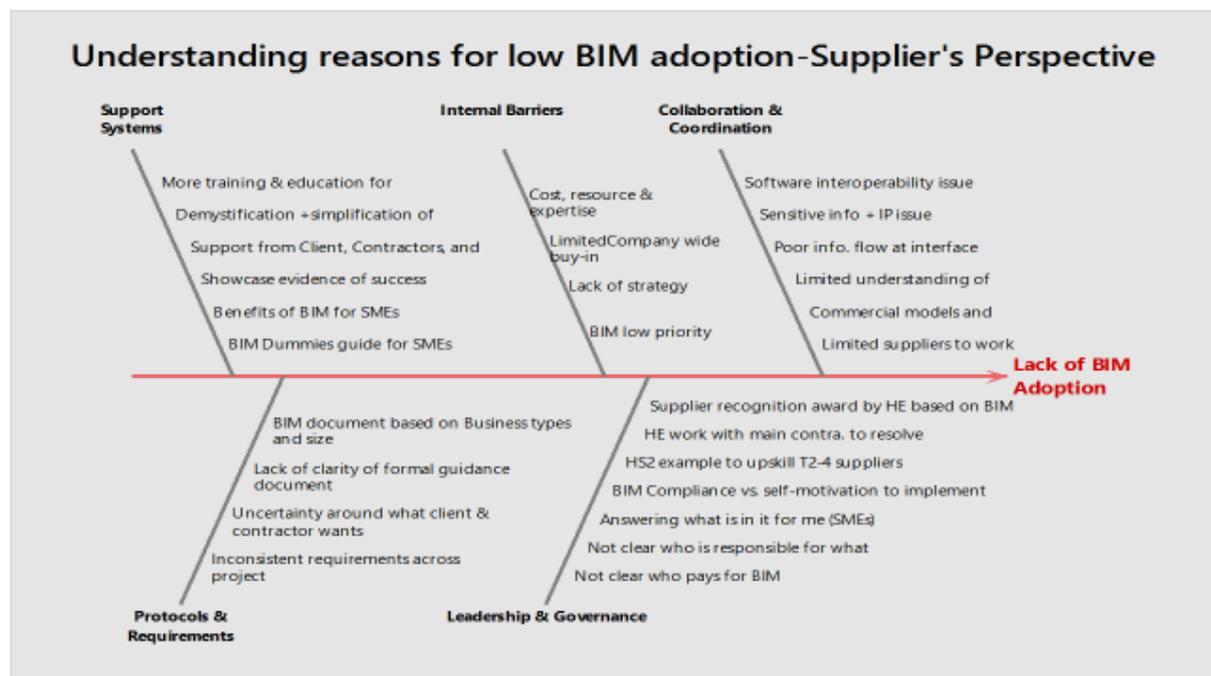


Figure 3: Barriers to BIM adoption – Tier 2/3 suppliers' perspective

### Challenges to BIM implementation

- Category of Supplier:** Appendix 1 shows the type of supplier interviewed during our study. Companies that operate across the range of activity, including design, manufacture and installation, are likely best placed to lead on BIM, but then face the challenge of integrating with organisations that do not operate across the full spectrum. For companies that focus primarily on site installation and management there is a direct interface with many other contractors and hence there is a need to be BIM conversant so that informed discussions may be had. However, the lack of direct design expertise can be a problem for such organisations. For those that focus primarily on production and supply, such as aggregates, there is less of a tradition of using technical design software. Those that design and manufacture are key in building the federated model, but a challenge here is convincing such companies

that their intellectual property is not comprised and that benefits can accrue to them. It is comparatively easier for large suppliers to invest time and money in learning BIM packages, and also easier for design and engineering companies to understand the technical jargon and language of BIM compared to suppliers involved in other types of work.

- *Interoperability and compatibility between software:* The main issue with BIM and the supply chain are the interfaces between software packages such as Revit , TEKLA 3D, Auto CAD, Microstation, and the ability to migrate from one software package to another effectively; until these software provider, talk to each other, to agree on interoperability, models cannot be transferred without problems.
- *Interoperability- usage of output generated:* The outputs, such as, 3D models, generated from one package is not automatically compatible with others; the imported data behind modelled parts is usually limited or of very little use, and because of the need to manipulate the import, the integrity of the model and its accuracy are open to question; although all software packages offer alternative export file formats, the integrity of the information exported is of variable quality.
- *Interoperability- long-term effect:* a great deal of work has been invested by the international community to develop neutral file formats that work effectively, but there is still a long way to go; the effectiveness of BIM will continue to be severely compromised until this issue is adequately resolved.
- *Ownership, liability and IP:* Liability and IP is not fully worked out. Who owns the IP? No one wants to take risk and responsibility of completely own a centrally located model; so suppliers then have to build their own model; Tier 2/3 suppliers cannot supply free of charge; it can take weeks for a full model to be developed; SME suppliers cannot really afford this luxury; clients and designers are best placed to assume responsibility for a central model.
- *Sharing of best practices:* Limited sharing of best practice examples of BIM usage and benefits by HE and main contractors; contractors have knowledge but they are not effectively passing that information to Tier 2 / 3 suppliers.
- *Training needs and delivery:* Not sure what type of BIM training to attend, especially what software to learn as each main contractor have different requirements; not aware of who are the best providers of such training in the industry - most of the training is focussed on technicalities of BIM and taught in a 'highly technical language' language; it's difficult for SME suppliers to envisage BIM benefits by attending the training; there is a lack of a professional body with established credentials to provide BIM certification. United Kingdom Accreditation Service (UKAS) is currently considering extending its accreditation activity into BIM but is yet able to provide such accreditation, particularly for BIM level 2.
- *Collaboration within and between supply chain parties:* sharing of models with other parties is difficult; how to pull together a federated model requires substantial time and coordination efforts.
- *Intra- company support and joined up initiative:* functional silos exist that results in lack of joint up thinking within the company in terms of BIM adoption, a need of a

BIM strategy, and a lack of vertical communication on BIM from director level to project teams.

#### Accelerating BIM in the supply chain - voice of the Tier 2 / 3 suppliers

- *Leadership in developing federated BIM model:* Clients, main contractors and designers are best placed to assume the responsibility for a central federated BIM model.
- *Leadership in BIM knowledge sharing and development across the supply chain:* Clients and main contractors should take the lead to share best practices on how to build BIM capability; share real-life case examples of BIM implementation; more case examples of how it worked; case examples on how BIM can help to address efficiency issues; what are the financial benefits to suppliers; examples of where to look for BIM information.
- *Leadership in sign-posting the suppliers:* Identifying recognised and accredited BIM training providers for suppliers - HE and main contractors are best placed to start this process; an example of this is the establishment of an online page for BIM training – [www.bimupskilling.com](http://www.bimupskilling.com) by High Speed Two (HS2) Ltd - this online training platform has been developed to upskill Tier 2/3 on BIM knowledge and its application; [www.bimupskilling.com](http://www.bimupskilling.com) by High Speed Two (HS2) Ltd - this online training platform has been developed to upskill Tier 2/3 on BIM knowledge and its application.
- *BIM knowledge transfer in non-technical language:* Suppliers expect HE and main contractors to host more workshop on BIM and provide simplified explanation of BIM and its benefits; they also need support and guidance on where to start. The quote below from one of the suppliers summarises their expectation.

*“We need a dummies guide for BIM in construction in a non GEEKY language for suppliers to implement BIM modules”.*

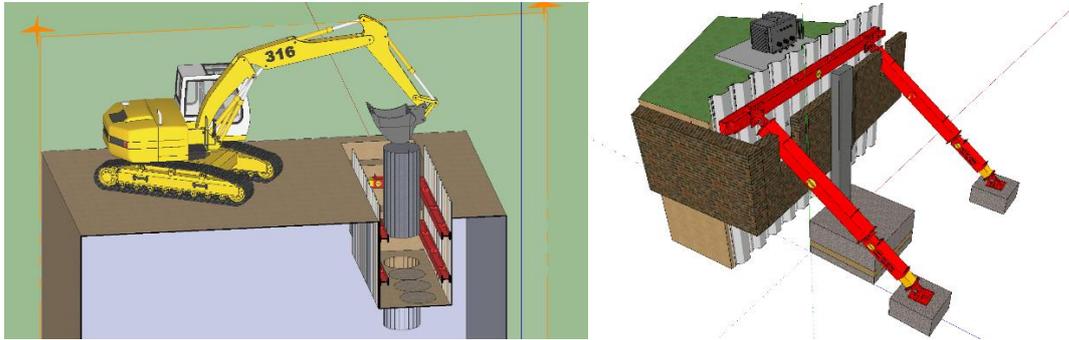
- *Modular approach to BIM adoption:* BIM should not be sold as technology driven system to small companies but broken into small and simplified step-by-step modular approach customised to the needs of suppliers, e.g. design & engineering vs. other suppliers.

#### Box 2: Requested Good Practice Guidelines from main contractors and clients

- Signposting on where and how to start
- Sharing best practice examples and benefits realised from BIM implementation at Tier 2/3 levels
- Taking lead in enabling BIM knowledge transfer in a ‘non geeky’ language
- Develop federated BIM model to resolve interoperability issues

Box 2 explains one company's journey in developing their BIM capabilities.

#### Box 2 – MGF's Digital Engineering Journey



- MGF are a UK based Tier 2 supplier / supplier of excavation safety solutions, operating in the temporary works space. It completes over 4500 engineering and design projects per year, employing over 30 design engineers & supplies approximately a third of the UK market.
- Its BIM journey began by contributing to the full BIM model developed as part of the M25 widening. Since then, the company has contributed to a wide range of major projects, as well as developed its own approach to digital engineering.
- The initial drive for BIM was based on a need to produce manufacturing drawings, technical files and develop health and safety and safer systems of work. However, MGF soon realised that there were broader benefits related to risk management, including clash detection, capacity management, better management of certificates and permits (e.g. certificates to load and remove), improved visibility leading to better sequencing and decision support, better quality control and efficiency of business, understanding of your own components and methods, and of others, as well as 'speaking the right language to customers'.
- The journey started with early investment in Autodesk, developing 3D images for technical files and an internal product library. This led to investments in using 3D images for animations and sequencing, resulting in 2 full time animators, and a more formalised approach to the safe systems of work. As the capabilities of the company grew, this was upgraded to a full Revit offering.
- A further capability is 'Scalable BIM'. Recognising that fast decision making and agility is key, all 30 CAD engineers can use SketchUp and using the software a working 3D sketch can be developed within 30 minutes - 1 hour. This dramatically improves collaborative dialogue between different parties, as problems can be visualized in prototype form. Hence, it helps to support decisions about the type of solutions needed, potential risks, and the implications for different stakeholders.
- More recent developments have focused on broader digital engineering capability. Three software developers were recruited with a remit to automate the design management process and create better internal systems. This includes design workflow systems to manage resources and revisions, product configurator systems to help choose solutions and generate risk registers, as well as data mining programmes. Looking forward, the aim is to be a digitally intelligent business, making use of big data to link in to existing datasets.

**What lessons can other Tier 2 and 3 Suppliers learn from the MGF case?**

1. *Develop a proactive trial and error mindset, incorporating incremental build-up of internal capability and accumulation of evidence to convince internal decision makers.*

Much of the early development work at MGF was done 'on the side', outside normal job descriptions using existing resources. The people doing so were passionate about making technology work for the business that a lot of the learning was done in their own time. In-house capability was developed gradually, via trial and error, including hiring people with an inclination to learn and develop digital aspects of the organization along the way. A further feature was the gradual accumulation of case studies, anecdotes, and data to support the use of BIM, so that key internal decision makers could recognise the benefits.

2. *Leverage in house capability, and your people*

A striking feature of the MGF case is the use of internal resources. Hence, it is useful to keep in mind that outsourcing is not necessarily the answer. Digital solutions need to suit your organization, so try to get inspiration from your own people and the way that they work.

3. *Consider BIM within a broader digital engineering agenda*

Recognise that BIM is part of a bigger digital engineering agenda. Hence, there is a need to think bigger than just a 3d model, reaching to see where smart digital solutions can work across your organisation.

4. *Developing strategic relationships with universities and best practice forums*

For the last 5 years, MGF have been working with universities, supporting PhDs, student projects, hosting placement students, as well as giving guest lectures and participating in research projects. It also contributes to best practice studies, forums and organisations.

#### **4. Survey on execution capability, vision for the future and critical success factors (Appendix 2)**

Although a relative small set of samples were returned from Tier 2 / 3 suppliers, in total 19 responses received out of 79 targeted, most of our respondents are senior representatives of their organisations. Their responses give us a good degree of confidence in the data collected and when seen as in addition to our interviews and focus group.

##### **4.1 Current BIM understanding and capability**

Thanks to the regulatory force by the government and the expectations of trading partners, suppliers would have no choice but to adopt and implement BIM, as the use of BIM is becoming a 'market qualifier' i.e. a criterion that a firm must exhibit to be a viable competitor in the marketplace. Although the UK government is optimistic that mandating the use of BIM will help to improve the overall competitiveness of the UK's construction sector in a global market, such optimism may not yield the desired results without due consideration of the current capability of execution in the industry.

Furthermore, it is likely that suppliers' capabilities in implementing BIM will vary, given the different types 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 lies in the strategic capabilities they have or have tried to develop. These capabilities can serve as a catalyst in transforming IT-related resources into higher value for a firm. 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 the use of BIM. A 'one-size-fits-all' approach to influence BIM adoption is unlikely to work.

With the BIM mandate having come into effect March 2016, via our online survey, we observe a greater diffusion of BIM into the construction supply chain. However, the level of diffusion varies largely among suppliers: some have used BIM in a wide range of their projects, while others have only just embarked on their journey. Of the companies surveyed, about half of them have used BIM for less than four years, while about 20% are more experienced, using BIM for over 7 years (Figure 4).

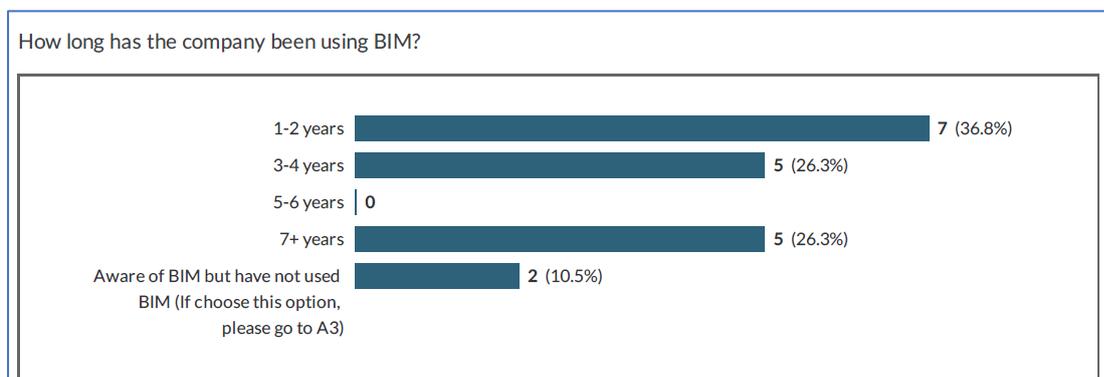


Figure 4: Years of experience in using BIM

Motivations for using BIM split into two types. Two thirds of companies are driven by potential commercial benefits while the rest are pushed by coercive forces from government and their clients. Therefore, it is a combination of both push and pull pressures that fuels the deployment of BIM along the supply chain. Technical tools relating to BIM use largely concentrates on 2D and 3D CAD, with a few pioneers moving to 4D (time) and 5D (cost). Coupled with this, BIM has been integrated with other information systems such as data management systems and geographical information systems, albeit less popular.

Operational use of BIM within the organisation

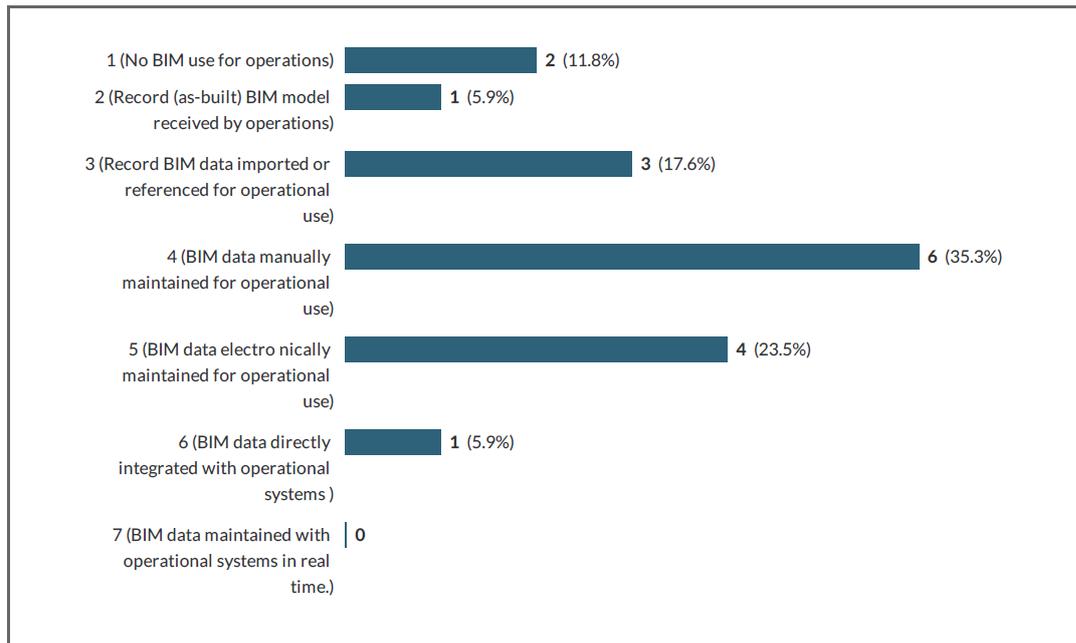


Figure 5a BIM use within the organisation

Other than producing a 3D model, over half of suppliers also deploy BIM, either maintained manually or electronically, for operational use (Figure 5a). Most suppliers, over 80%, also share BIM related information with their supply chain partners. However, data interoperability seems to be a big issue as 18 out of 19 respondents said BIM information shared with partner companies need to be converted before integrating into their existing database (Figure 5b). This will be a big technical hurdle if there is a push for BIM level 3, which envisages a wholly integrated project information model, hosted and fully developed in a common data environment, by all members of the project team in real time. It is at this maturity level that clients, such as Highways England, would gain strategic benefits on asset lifecycle management via the use of BIM as an Asset Information Model (AIM). HE, as client, can derive significant improvements in cost, value and carbon performance through the use of open sharable asset information". A good AIM is crucial for the correct operation and cost control of an asset.

Extent to which BIM information exchanged with partner company needs to be converted/translated by your company.....

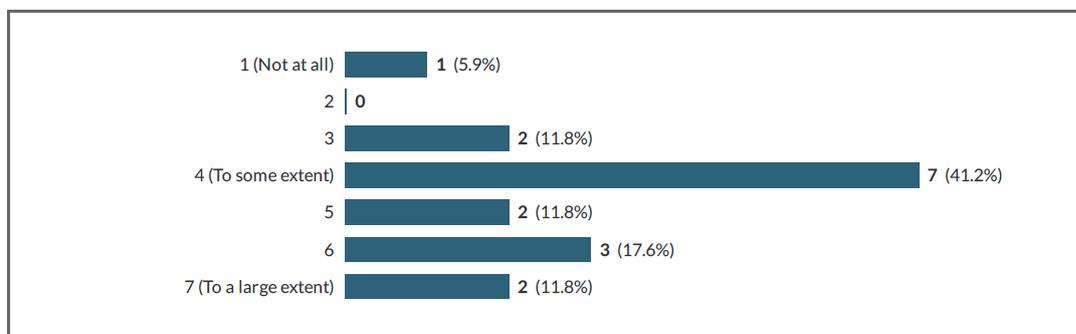


Figure 6b The extent of BIM interoperability

For those who have not used BIM, the main reasons are that they

- a) are yet to see the business value of using BIM
- b) have not been asked to do so by their customers.

Other barriers discussed in our interview sections such as technical compatibility and complexity exert negative influence in the adoption of BIM as well. Nonetheless, suppliers' sureness in using BIM is quite positive with over 88% being confident. However, we have to bear in mind that our responses on this are biased towards larger suppliers, given that only four out of 19 suppliers are SMEs in our survey. The lack of SME response may reflect the fact that many are struggling to make sense of BIM and do not see ways of using BIM in their practices – an issue also picked up by our interviews.

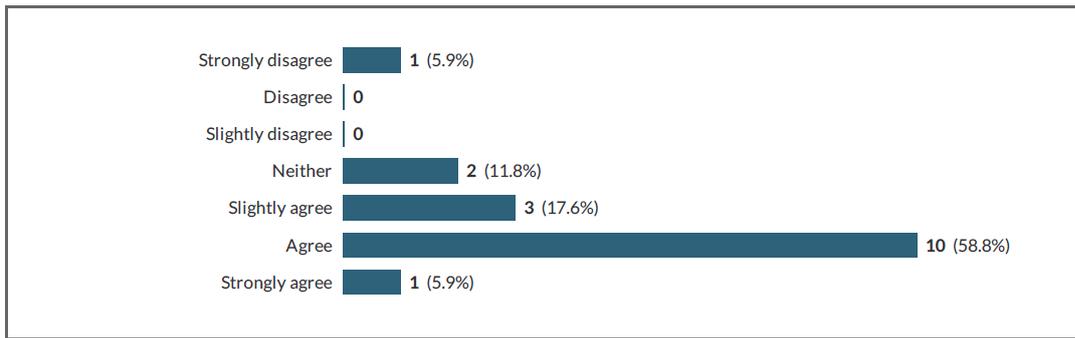
To understand further the supplier capability of using BIM, we asked six specific questions examining whether there is sufficient management and financial commitment, in-house expertise, IT infrastructure and a clear understanding of their customers' BIM requirement. Most responded positively, indicating structures and resources are in place for the uptake and exploitation of BIM into supply chain processes.

#### **4.2 BIM future vision**

We believe that for BIM to be effectively taken up by construction supply chains, we need to examine not only organisations' current capabilities, but also their vision for the future. A future looking strategy is important because there is potentially a high risk that BIM implementation will take place only at a superficial level if suppliers are purely responding to coercive pressures imposed by their customers and government. This is evidenced in other sectors such as healthcare and chemistry. For instance, previous study has investigated IOS mandatory implementations across different tiers of the healthcare supply chain in Australia and it found that strong coercive pressure, if exerted on an organization, tends to generate a cosmetic response at the administrative level. Assessing supplier's 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 a long-term vision for reaping the potential benefits BIM might offer, it is unlikely such technological take-up at the 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. From management strategist perspective, 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. Having a BIM strategy and vision defines the type of value the companies intend to extract from BIM and guides the scope of its BIM investment and deployment process choices. In addition, strategic vision influences and guides execution

We have a well-articulated BIM strategy.



We have clear goals and objectives for future development of BIM.

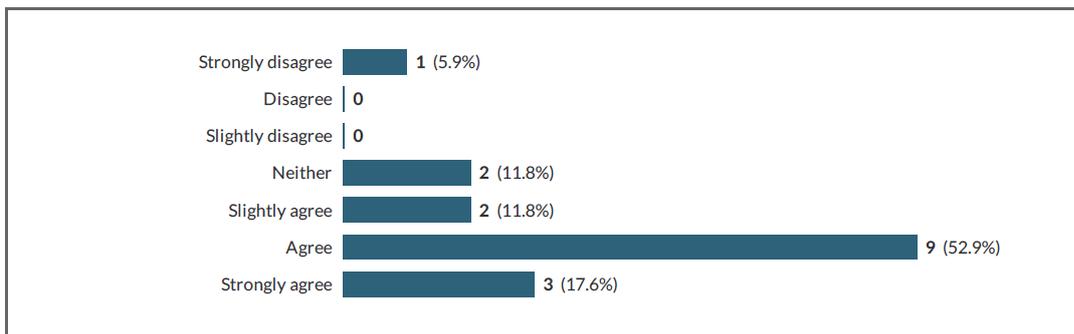


Figure 7: BIM strategy, goals and objectives for future development

With the aforementioned rationale, we designed a specific section asking six further questions on their future vision for BIM adoption centring considering strategy, future objectives, investment, change programme and culture. The majority of respondents confirmed that they have a well-articulated BIM strategy in place, and have clear goals and objectives for future development of BIM (See Figure 7 for example). The survey also shows that most companies are proactive in capturing and understanding the latest BIM developments. To operationalise their strategies, organisations may need to set up a change programme to drive further BIM diffusion or have a process champion to align activities with firm's strategic intent. However, survey results suggest that this practice has not been embedded fully in supply chains.

In addition to have institutional architectures and framework in place, behaviour changes at individual level is required if we are to really infuse BIM into day-to-day practice. Building a BIM-oriented culture helps to make sure changes are sustainable and do not only occur at surface level. Behavioural change will then reinforce the culture of using BIM for both exploration and exploitation within firm and along the supply chain. Academic literature suggests that positive cultural transmission is the predominate force in behavioural change . Again, survey results show mixed responses on this. Main contractor and suppliers need to work together to find a viable process model that will transform the current construction practices and incentivise desirable changes. We discuss more what needs to be done in Sections 5 and 6.

### 4.3 Critical success factors to BIM adoption, and BIM related benefits

Having understood the current capability and future vision of suppliers, we now turn to examine critical success factors (CSFs) to BIM adoption, and areas where organisations have seen benefits in using BIM. CSFs are for any business, the limited number of areas in which results, if they are satisfactory, will insure successful competitive performance for the organisation. In our context, they are the few key areas where ‘things must go right’ for a successful BIM diffusion along the supply chain and the supply chain to benefit and flourish.

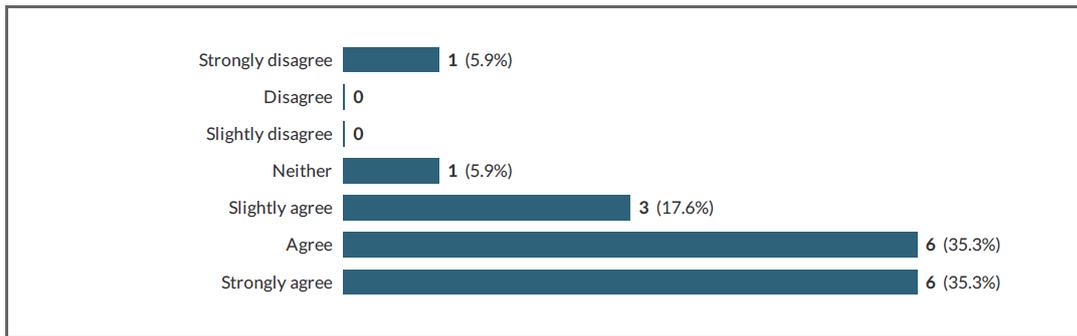
Questions in this section of our survey concentrates in the following four areas, which were derived via our field studies with suppliers as well as from a wide range of academic literature;

- 1) Organisational support
- 2) Procurement and Contractual arrangement
- 3) Collaboration and Process integration
- 4) Infrastructure and interoperability

Responses are quite consistent to those CSFs falling into the aforementioned 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> category – where we have the majority to either ‘agree’ or ‘strongly agree’. For instance, having a standard contract protocol such as CIS BIM protocol, earlier involvement of suppliers by main contractor, and BIM informed collaborative planning between the parties. A large consensus also exists for infrastructure and interoperability factors: IT infrastructure, BIM protocol and standards are critical to cross-organisational BIM deployment.

Interestingly under the first category of organisational support, there are quite a diverse set of responses. In particular, CSF relating to supplier development have not received enthusiastic support, i.e. respondents are not very keen in the idea of having a supplier association or supplier support centre to facilitate BIM deployment, although a popular practice in automotive sector. Equally almost half of our respondents did not consider supplier recognition awards for their BIM efforts as critical to a success BIM adoption. On the other hand, most respondents would welcome continuous communication of needs and vision from both client and main contractor (See below Figure 8). Clear guidance and leadership from main contractors is seen by the majority to be critical. This clearly points out that main contract needs to be the process champion and supply chain orchestrator for BIM deployment along the supply chain.

Continuous communication of needs and expectation from main contractor



Clear guidance and leadership from main contractor

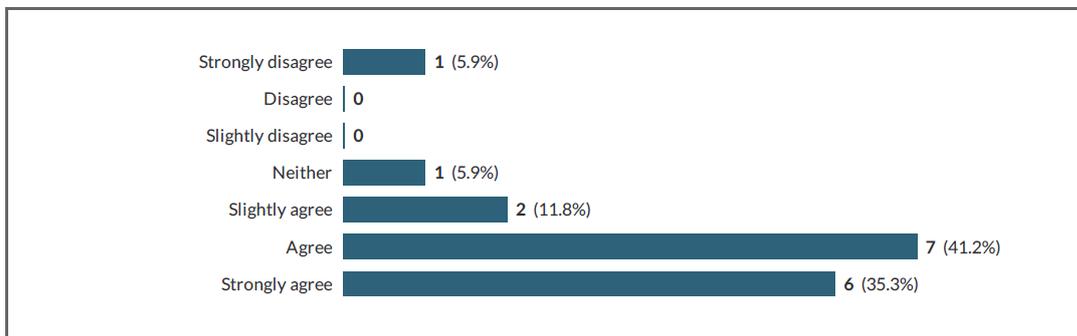
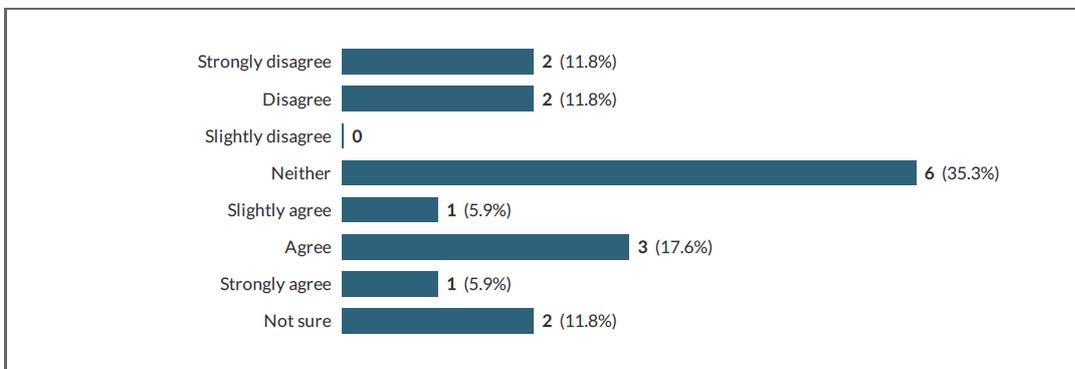


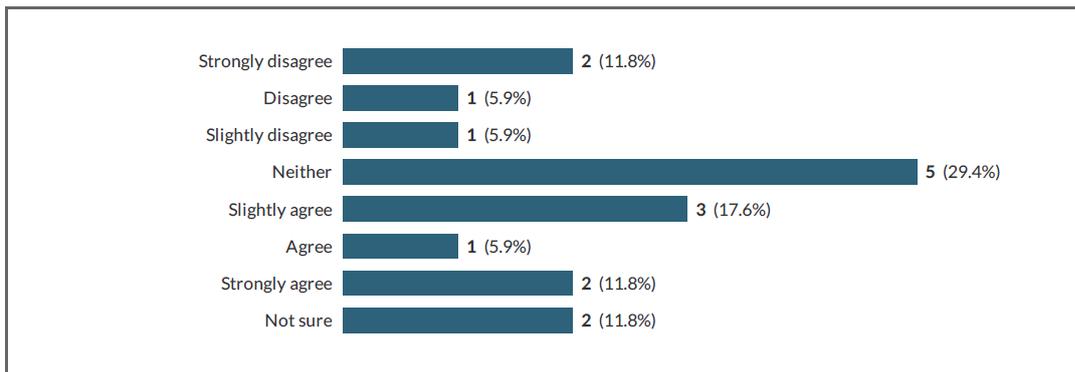
Figure 8: Two example critical success factors on BIM adoption along the supply chain

Despite the fact that overall there is a good consensus from suppliers as to what are critical to BIM adoption, and most are actively using BIM, our survey results reveal that they are yet to see tangible benefits at a project level. For instance, over 60% of respondents either disagree or are not sure about the statements that ‘productivity improved because of the reduction of number on RFI, change orders and idle time’ (Figure 9). Participants also have not seen safety practice improved because of the use of BIM, nor on their profitability. There are more positive perceptions on the quality of work and the time taken to complete work.

The productivity is improved because the number of Request for Information (RFI) has reduced.



The productivity is improved because rework and idle time has been reduced.



Our safety practice has improved (for instance records of trips/falls and near misses reduced).

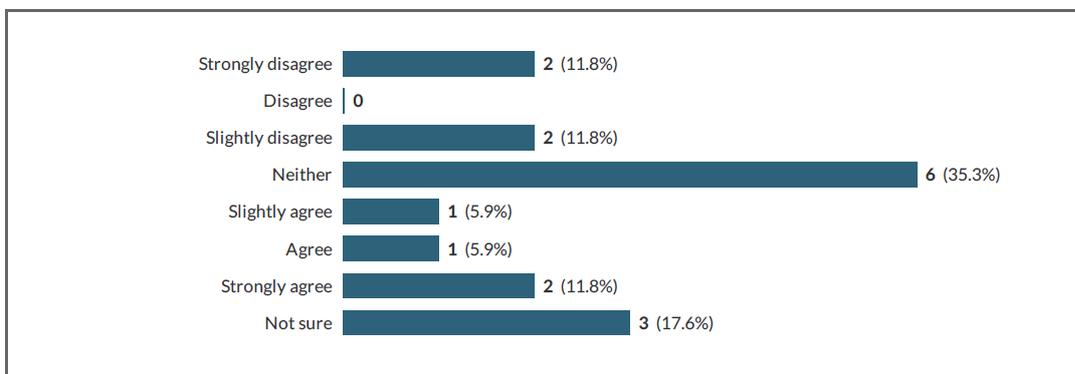
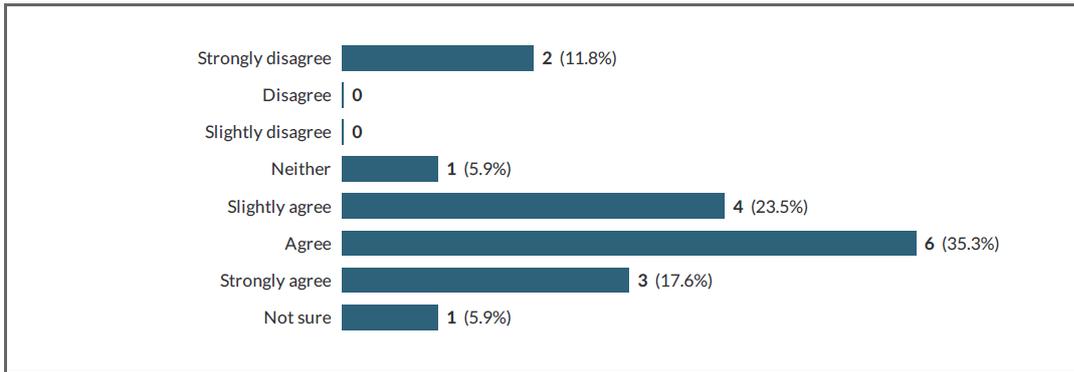


Figure 9: BIM related project level benefits (selected example response)

Comparing with project level benefits, benefits at an organisational level are more obvious to most respondents. Most are confident that, as a result of using BIM, they have improved their customer satisfaction, seized more business opportunities and respond more flexibly to the environmental changes and unanticipated events. Suppliers are also positive that they become more innovative in their products offering and processes (Figure 10).

We have improved customer satisfaction.



We have more product and process innovations.

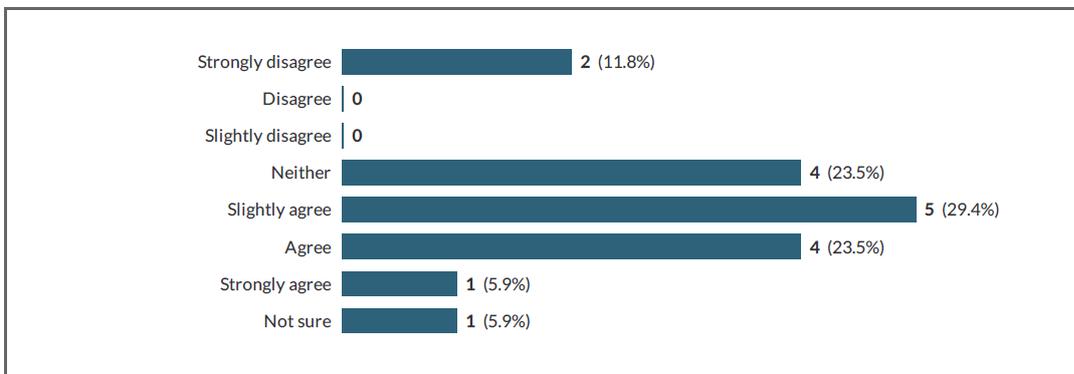


Figure 10: BIM related organisational benefits (selected example response)

In a nutshell, most benefits are 'soft', or intangible, whereas 'hard', tangible and quantifiable, impact is yet to be seen. This concurs with our wider literature/industry research that quantifying BIM benefits and relating it to the bottom line of a business is a challenging task.

## 5. Infrastructure projects as a system

### Understanding the traditional approach and current progress

Figure 11 shows a representation of the way that different actors interact to develop a major project. It shows the main actors in the total supply chain: the client, the Tier 1/main contractor, Tier 2 and 3 suppliers, and the designer. For completeness, it also shows the technology service provider and central government. These different actors must work together to complete a project, which is depicted at the centre of the diagram. Each actor has a 'mindset', shown as a thought bubble, and has a range of interactions with other actors and processes, as illustrated by the various arrows.

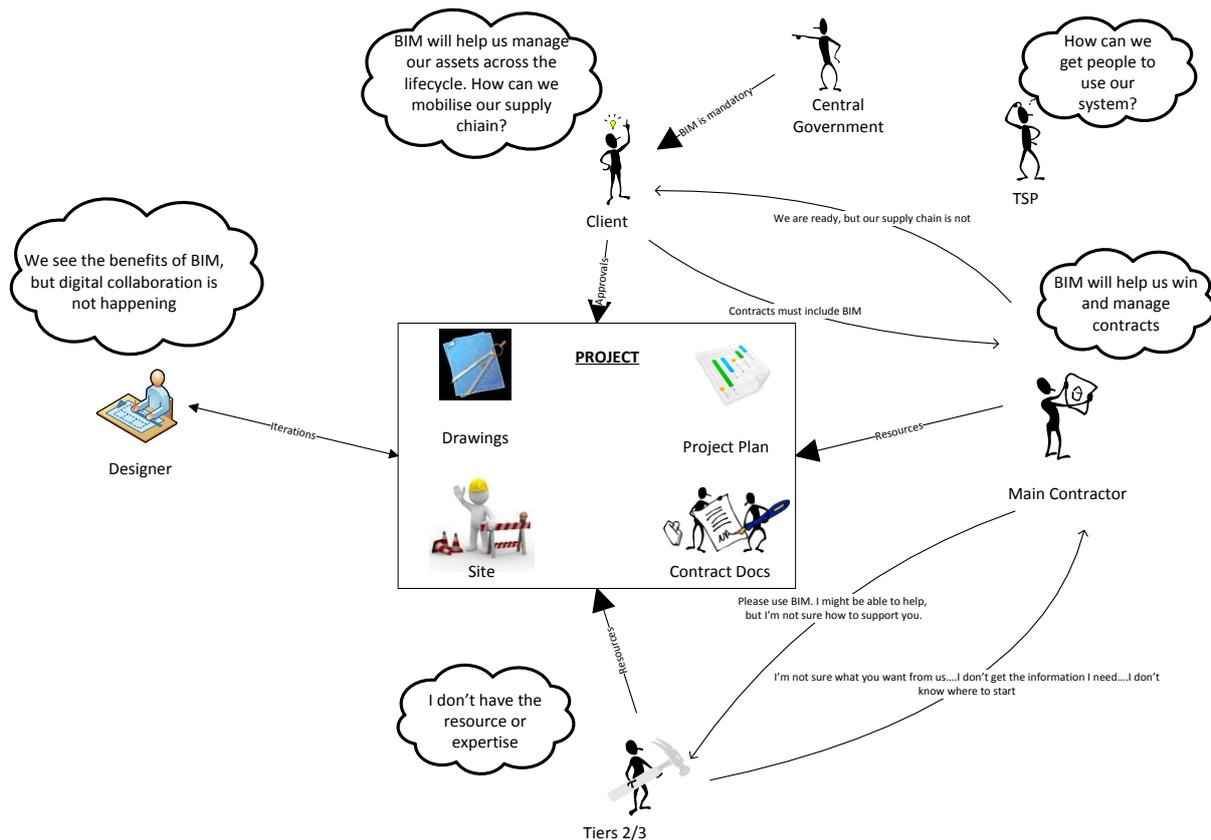


Figure 11: A rich picture of BIM adoption in supply chain (as-is)

The project revolves around a set of drawings, a project plan, relevant contractual documentation and specifications, and the site. In a very 'traditional' situation, actors operate at arms-length, and many processes are carried out using paper or non-collaborative digital techniques. There are also likely to be many broken links, where different actors do not interact, and myopic mindsets. In practice, the current situation is likely somewhere between a very traditional approach and the BIM enabled future highlighted later in the report. Islands of good practice and progressive thinking are evident, but serious systems problems can be identified.

As can be seen from the rich picture diagram in Figure 11, designers, tier 1 contractors and the client, are largely convinced of the benefits of BIM, but have different issues and motivations about implementation. Many Tier 2 / 3 suppliers did not share this positive view of BIM, and had concerns about resourcing, clarity of requirements and their own expertise in relation to BIM. Those who have yet to adopt any BIM approaches did not know where to start.

Based on the empirical evidence collected throughout the research project, the issues with respect to BIM adoption are summarised below.

For the client:

- Integrating different departments within the organisation to form a coherent strategy for BIM.

- Understanding the information requirements from all the different actors across the asset lifecycle. Very often information sources are fragmented, and rely on complex chains of processing.

For the T1 Contractor:

- Developing and hiring experienced BIM talents
- Knowledge and cross-learning from different projects
- Establishing patterns of behaviour across sites

For the T2/3 Supplier:

- Handholding expected from Tier 1, main contractor, and clients on where to start and how to start
- Cost, resource & expertise
- Lack of strategy
- Making internal business case

For the whole system:

- Poor information flow and Information sensitivity
- Lack of incentivization schemes & joined-up action
- Interoperability issues
- Clarity over ownership and responsibilities, who bears cost/rewards, and who leads.
- Broken links between different actors
- Governance and leadership
- Behavioural and cultural change

In addition to the above, we also identified issues at the interface between the main actors. The Client - Tier 1 contractor interface appears to be dominated by co-ordination efforts, such as getting the right information, at the right time, at the right place, and including the right people. The Tier 1 contractor – Tier 2&3 supplier interface appears to be characterised by:

- Commercial models that do not recognise time invested in BIM
- Inconsistency of requirements for T2 and 3 suppliers across Tier 1s and projects.
- Command and control approaches, rather than positive support schemes.

## **6. A vision for a BIM-enabled system**

The intention of this section is to set out a vision for a BIM enabled system. In some places this is illustrated by islands of excellence from current practice. Figure 12 envisages a future looking system, BIM enabled, and underpinned by collaboration. The system design principles and change levers used to developing the future state rich picture are shown in Box 3.

### *Box 3 – system design principles and change levers*

Principles to support good system design (Adapted from Gosling et al. 2015):

- **Design for X principle** - design is fit for purpose and enables 'right first time'.
- **Control system principle** – appropriate oversight of whole system with mechanisms to capture feedback and support system level decisions.
- **Time compression principle** - every activity should be undertaken in the minimum reasonable time needed to achieve task goals
- **Information transparency principle** – real time, secure but undistorted access to information at all levels.
- **Echelon elimination principle** - There should be only the minimum number of levels and complexity appropriate to the goals of the supply chain.
- **Synchronization principle** - All events should be synchronised, so that activities are visible at discrete points in time, and there is continuous simultaneous decision making throughout the chain.
- **Learning principle** – Learning is promoted, captured and mobilised throughout the chain. Lessons learnt are not forgotten.

Using Systems Change 'levers':

- Attitudinal – the mindsets and attitudes of different actors
- Process – how work is undertaken, or methods used.
- Technology – the systems and technologies applied.

#### *1) Federated BIM Model becomes central to project workflows, and is incorporated into collaborative planning processes*

A major area that departs from the traditional system is the way that BIM interacts with site operations, and becomes central to project workflows. At the centre of Figure 12 it is possible to see a federated BIM Model with appropriate access portals, so that different stakeholders can access the data in a way that suits their requirements. To ensure that BIM links explicitly with site processes, it is proposed that there is a two-way interaction between the federated BIM model and collaborative planning meetings, and any changes are fed back into the model to keep it up to date.

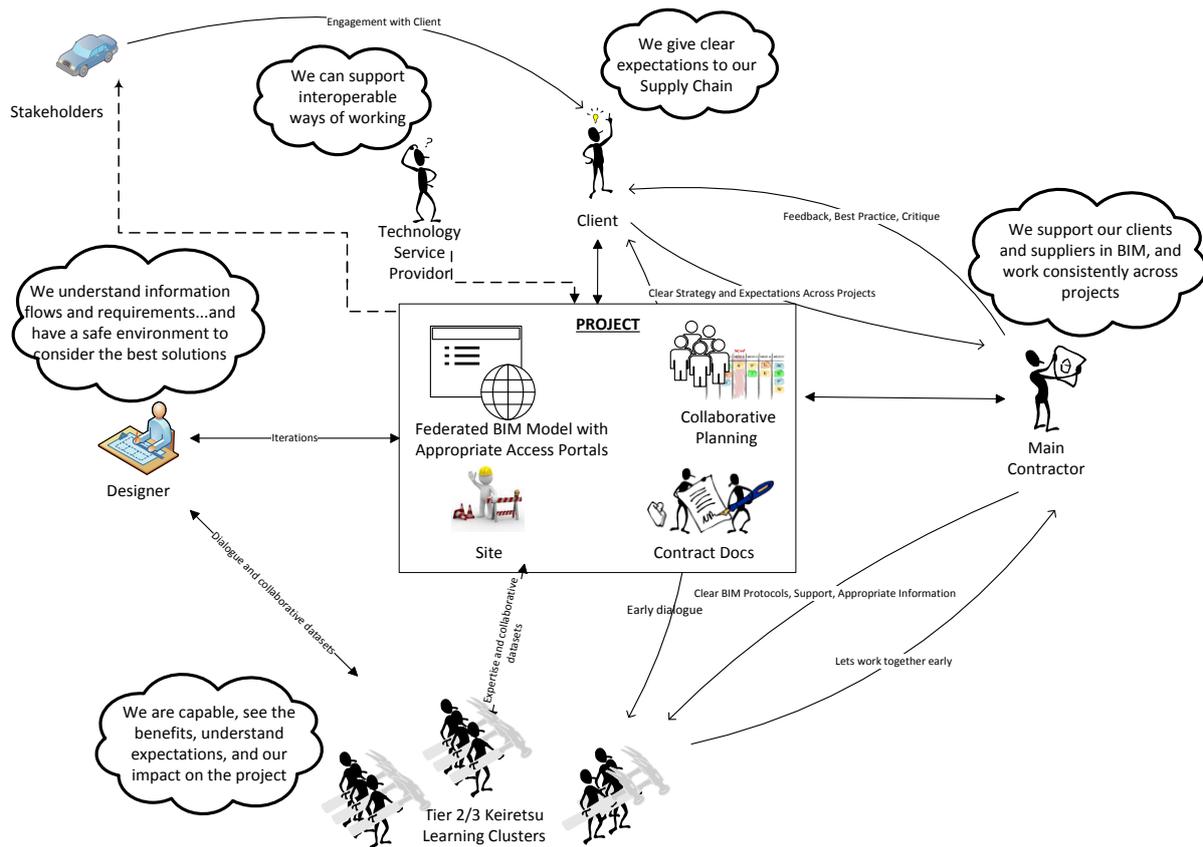


Figure 12: : A rich picture of BIM adoption in supply chain (to-be)

## 2) Learning clusters and active supplier development programmes are developed

Figure 11 shows a different approach to the organisation and support of tier 2 and 3 suppliers. There is a need to move beyond technological focus to process and people centred approaches to accelerate BIM adoption in the construction supply chain. This may help to share and learn from ‘islands of good BIM practices’, at Tier 1 and 2 levels (main contractor and few large suppliers) with other stakeholders in the Tier 2/3 levels of the construction supply chain. This approach may help to shift the focus from component knowledge (knowledge of the parts rather than the whole) to architectural knowledge (the shared understanding of the interconnection of all components, it provides the big picture including the conflicts emerging within it), which aligns with the definition of BIM.

As explained in box 2, this rests on a combination of keiretsu, supplier association structures and active supplier development. The proposed three steps, influenced from Toyota’s knowledge sharing network (Dyer and Nobeoka, 2000), may help construction supply chain members to develop a ‘routine- based’ learning by having regular interactions among members to permit creation, transfer, or recombination of specialized BIM related knowledge (or knowledge linked to any other initiatives such as collaborative planning).

The first two are proposed in order to create a more collaborative and ‘joined up’ tier 2 and 3 community, which allows their voice and lessons learnt to be captured more effectively. Active supplier development replaces a command and control approach. In the latter,

suppliers are simply mandated to change, without the support structures and systems to make it realizable.

**Box 4- Lean Supply Chain Development**

**Vertical Keiretsu** – close and strong relationship between original equipment manufacturer (OEM) and its suppliers, moving beyond arm’s length relationship that is based on trust and goodwill to work together for mutual benefits. Here, number of organisations link together usually by partial ownership in each other resulting in close relationships. This is the traditional Japanese approach to working closely with suppliers. In the construction supply network, this can take a form of loosely connected organizations that are strategic to main contractors and strive to work together to find ways to lower the costs and share the savings from BIM implementation.

**Supplier Associations** – This is an inter-firm network forum for creating a shared social community which is based on network norms and facilitate sharing of explicit knowledge among network members. This will also provide a platform to share the ‘voice of the suppliers’ with main contractors and clients in the construction supply chain. The activities of the association should be managed by Tier 2/3 sub- contractors.

**Supplier Development Team** – Main contractors should have a supplier development team whose primary responsibility should be to help suppliers at Tier 2 & 3 levels in implementing solutions such as BIM, Collaborative Planning tool, Lean Manufacturing principles, and problem solving.

*3) Broken links between actors are fixed, and collaborative datasets based on early dialogue are established*

In the traditional supply chain links between designer and Tier 2 & 3 supplier, as well as the client and Tier 2 & 3 supplier are weak or non-existent. Hence, in the future state system, we see these actors with direct collaborative links. If an accurate federated model is to be developed, tier 2 and 3 suppliers will need to work directly with client, tier 1 contractors and designers to develop collaborative datasets. The different actors will also need to work using early involvement approaches, since expertise is needed early in order to feed into collaborative BIM models. Hence, supporting Early Contractor Involvement (ECI) initiatives. The future will likely also open up avenues for BIM models to be used to interface with external stakeholders. We have included this in the future state diagram to show how BIM models may be used to educate and inform external stakeholders, such as local communities or planning authorities.

*4) A BIM governance framework is established, giving clear strategy, protocols, expectations, incentivization systems and support structures*

The future system state relies on the establishment of a sophisticated governance framework, which encourages consistent good practice across projects. This will include integrating changes to contracts, incentivization and support systems under a clear BIM strategy, which should be used to inform procurement approaches. The strategy should

allow all actors to ‘speak the same language’, and convey a clear position bringing together protocols and expectations.

## **7. Route-map to implementation**

As noted in many studies of change management, it is not advisable to attempt all aspects of systems change in one go, nor is it advisable to drag out change across many years of very minor changes. What is needed is an optimal array of bite-sized chunks. Hence, in this last section, we propose a number of stages to move from the ‘traditional’ system depicted in Figure 11 towards the future state proposed in Figure 12. A five-stage route map is proposed:

1. Agree BIM focus and strategy at Client – Tier 1 level

This first stage is the critical enabler for the future state model. The client and Tier 1 main contractors need to agree on a strategy to ‘speak the same language’, which includes issues related to inter-operability of systems, incentivization schemes, support and incorporation of standards into governance models, agreement on measures that will drive BIM adoption, as well as agreeing procurement and contractual processes that will positively embrace BIM. Finally, this stage will require agreement on the costs and benefits of working together to enact the following stages.

2. Strengthen the Tier 1 – Tier 2/3 link, and change the mind-set

As the survey results have indicated, Tier 2/3 suppliers are reluctant to adopt the Keiretsu Learning Cluster approach that has proved successful in other industry sectors in developing and enhancing supply chain practises. Hence, the first step should be for Clients, such as HE, and Tier 1 contractors, to invest and actively develop their Tier 2/3 supply base. This moves beyond command and control (i.e. simply mandating that BIM is used), and involves pro-active support of supply chain. This may occur on a one-to-one basis at first through supplier development teams, to show the needs for and benefits of BIM adoption, but then to broad clusters of suppliers, as indicated in Stage 3. Here the role of supplier association is critical in forming cluster with Tier 2/3 suppliers, who can take the lead and help each other to jointly develop their BIM capabilities under the guidance of main contractors and clients.

3. Establish the learning clusters

Stage 1 will allow for the ‘trickle down’ of Client / Tier 1 protocol and expectations, whereas Stage 2 will begin the top down development of BIM capabilities across the supply chain. The next step is for supplier associations to form a more bottom-up cluster model. In this way Tier 2/3s will adopt and adapt BIM for their own business needs, have internal heroes (Keiretsu champions) who see the value of BIM as a broader digital engineering agenda. Once clusters have been developed and progress has been made on overcoming attitudinal barriers, Tier 2/3 suppliers are ideally then in a position to share learning experiences among themselves as well as with T1s.

4. Develop collaborative datasets between tier 2/3, Tier 1 and designers

Stage 4 addresses some of the 'broken link' identified in the systems diagrams. In this stage, Tier 2/3 suppliers, or clusters thereof, engage with designers (as well as clients and Tier 1) to establish collaborative datasets. This brings detailed product and technical knowledge from suppliers into design models and risk registers at a very early stage.

5. Engaging BIM with the Site and Supplier Clusters

Finally, there is a need for BIM to play a more active role in site operations. To do this, a centralised database, including a federated BIM model is proposed, which enables appropriate access portals for different parties. Once this federated model is in place, site teams will be able to access BIM and actively use the information to inform ongoing site work. There is a particular need to incorporate BIM into collaborative planning sessions. At present this can be done via virtual 'fly through' exercises, so BIM can help to support collaborative planning sessions, and, as technology evolves, it should be possible to update BIM models with up to date information generated at collaborative planning session. A final step could be to include relevant Tier 2/3 Keiretsu clusters in such sessions.

Table 1 shows a summary of the implementation phases, and their link to supply chain principles and the change levers described earlier in the report. It is possible to see that our recommendations flow from the client – Tier 1 interface, down to the Tier 1 - Tier 2/3 interface and then towards the re-organisation of the structure of the Tier 2/3 supply base to incorporate learning clusters. It then moves to the Tier 2/3 designer interface in the pursuit of collaborative datasets, before finally addressing the engagement of BIM with site operations, where a key link with collaborative planning is proposed. The following can be observed:

- Stages begin by focusing more on attitudinal and process change levers, before moving towards technological solutions.
- Stages begin with more of a focus on control and information transparency, moving to learning and design for X, and then finally addressing multiple principles in the final stages.

Table 1: Interactions between implementation phases and supply chain principles and change levers.

Implementation Phase	Supply Chain Principle							Change Levers		
	Design for X principle	Control system principle	Time compression principle	Information transparency principle	Echelon elimination principle	Synchronization principle	Learning Principle	Attitudinal	Technology	Process
1. Client – Tier 1 Interface		✓		✓				✓		✓
2. Tier 1- Tier 2/3 Interface				✓			✓	✓		
3. Learning Clusters	✓				✓		✓	✓		✓
4. Collaborative Datasets	✓		✓	✓					✓	
5. Site Engagement			✓		✓	✓			✓	✓

## 8. Discussion and Reflection

This report has presented a holistic view of the challenges, enablers and changes required to fully exploit the advances in digital engineering, and it is within this broader digital engineering landscape that BIM is best understood and positioned. At the most fundamental level, in terms of efficacy, there is a need to make sure that the deployment of BIM will improve information exchange processes within and between organisations. Data integrity is fundamental to any effective decision-making and business operation but often is neglected in the digital engineering agenda. However, compromise on data integrity could have a detrimental effect on business and supply chain performance. Having robust and flexible technological infrastructure is important to allow for the creation and capture of essential data. Connectivity and linkage is another key issue that has to be addressed in order to enable data flows across a variety of IT platforms and reach to a wide range of supply chain partners when needed. We need to be mindful that only the ‘right data at the right time at the right place’ is captured to avoid information overload and fatigue, and unnecessary consumption of resources and time.

At the next level, digital engineering efforts should concentrate on

- a) dealing with the quality and speed of information sharing within and between organisations, and
- b) helping to streamline and optimise current construction supply chain processes.

Namely, do our efforts lead to efficiency gains?

Finally, BIM could also be utilised alone or, better still, combined with other digital technologies to offer innovative products and services that otherwise would not be available in the marketplace. In this case, BIM is firmly embedded in organisations’ digital capabilities and becomes an ‘order winner’ for suppliers. We envisage a dynamic digital engineering capability that allows organisations to integrate, build and reconfigure internal and external information, process and relational linkages within the supply chain to respond quickly to the changing environment. This dynamic capability also enables the suppliers to

switch between projects at ease with minimal cost penalty whilst retaining rich knowledge gained in previous projects.

A final point to reflect on is the utility and potential for BIM across the different types of companies across the supply chain. The challenges for clients, main contractors, designers and different types of tier 2 and 3 suppliers are different, as explained throughout this report. For suppliers, those that already have a level of design expertise will find our future state vision easier to fit into. Those that do not will require substantial support.

## 9. Recommended reading

For an understanding of the UK government's latest action on BIM and general industry perceptions of the implications of BIM, one can refer to

- Building Information Modelling (BIM) Task Group  
<http://www.bimtaskgroup.org/http://www.bimtaskgroup.org/http://www.bimtaskgroup.org/http://www.bimtaskgroup.org/>
- National NBS (National Building Specification) BIM Annual Survey: The latest survey report is available from <https://www.thenbs.com/knowledge/nbs-national-bim-report-2017>.
- Institution of civil engineers, [www.ice.org.uk](http://www.ice.org.uk): BIM Heat Map report 2014, <https://www.ice.org.uk/disciplines-and-resources/best-practice/bim-heat-map-report-2014> (more present reports are also available).

For an understanding how to build effective inter-organisational information integration yet remain responsive to supply chain needs, one can refer to

- Han, J., Wang, Y. and Naim, M. 2017. Reconceptualization of information technology flexibility for supply chain management: an empirical study. *International Journal of Production Economics* 187, pp. 196-215. <https://doi.org/10.1016/j.ijpe.2017.02.018> (open access paper)
- Eadie, R., Browne, M., Odeyinka, H., Mckeown, C. & Mcniff, S. 2013. BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, 36, 145-151.

For an understanding of how a closed supply chain collaborative network works in practice (technological, relational and process configurations), one can refer to

- Wang, Y. et al. 2011. A case study exploring drivers and implications of collaborative electronic logistics marketplaces. *Industrial Marketing Management* 40(4), pp. 612-623. <https://doi.org/10.1016/j.indmarman.2010.12.015>
- Bröchner, J. & Badenfelt, U. 2011. Changes and change management in construction and IT projects. *Automation in Construction*, 20, 767-775. <https://doi.org/10.1016/j.autcon.2011.01.001>

For an understanding of how to develop suppliers into relational categories for effective project management, one can refer to

- Gosling, J., Naim, M., Towill, D., Abouarghoub, W., & Moone, B. (2015). Supplier development initiatives and their impact on the consistency of project performance. *Construction Management and Economics*, 33(5-6), pp. 390-403. <http://dx.doi.org/10.1080/01446193.2015.1028956>
- Sako, M. 2004. Supplier development at Honda, Nissan and Toyota: comparative case studies of organizational capability enhancement. *Industrial and Corporate Change*, 13, 281-308. <https://doi.org/10.1093/icc/dth012>
- Wagner, S. M. 2011. Supplier development and the relationship life-cycle. *International Journal of Production Economics*, 129, 277-283. <https://doi.org/10.1016/j.ijpe.2010.10.020>

For an understanding of how to develop SMEs and develop suppliers associations, one can refer to

- Arend, R.J., 2006. SME–supplier alliance activity in manufacturing: Contingent benefits and perceptions. *Strategic Management Journal*, 27(8), pp.741-763.
- Terziovski, M., 2010. Innovation practice and its performance implications in small and medium enterprises (SMEs) in the manufacturing sector: a resource-based view. *Strategic Management Journal*, 31(8), pp.892-902.

### Appendix 1: Summary of interviews

Company (number of interviews)	Supply Chain Position	Primary Area of Focus	Position of interviewee(s)
Company 1 (1)	Tier 2/3 Supplier	Installation and site management	Business Development
Company 2 (1)	Tier 2/3 Supplier	Installation and site management	Technical Design Manager
Company 3 (2)	Tier 2/3 Supplier	Production/Supply of Materials	Major Projects Director (DC), Compliance & Business Improvement Manager (IT)
Company 4 (2)	Tier 2/3 Supplier	Design and Manufacture	Design Services Manager (MD), Chief Civil Engineer (YDR)
Company 5 (2)	Tier 2/3 Supplier	Design and Manufacture	Head of Business Development, Design Engineer
Company 6 (1)	Tier 2/3 Supplier	Installation and site management	Director
Company 7 (6)	Main Contractor	Main Contractor	Senior planning manager, BIM manager, supply chain

			director, technology director, design manager
<b>Company 8 (1)</b>	Tier 2/3 Supplier	Design and Manufacture and Installation	Technical Director
<b>Company 9 (4)</b>	Tier 2/3 Supplier	Design and Manufacture and Installation	Design Engineers
<b>Company 10 (3)</b>	Tier 2/3 Supplier	Design and Manufacture and Installation	Engineering Director, Software Engineers
<b>Company 11 (1)</b>	Tier 2/3 Supplier	Design and Installation	CAD Team Leader
<b>Company 12 (1)</b>	Consultant	Lean	Director
<b>Company 13 (1)</b>	Tier 2/3 Supplier	Design and Installation	Managing Director
<b>Company 14 (1)</b>	Consultant	Lean and Collaborative Planning	Head of Lean/Collaborative Planning
<b>Company 15 (1)</b>	Technology Service Provider	BIM	BIM advisor and consultant
<b>Highways England (4)</b>	Client		BIM manager

**Appendix 2: Survey results (in a separate pdf file 27 pages)**