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Implementing Lean in construction

Lean construction and BIM

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Feedback

CIRIA and the project steering group welcome your feedback on the documents in the Lean series.

However, before reading this guide, and without reference to the contents list, please write down five areas or specific questions that you are hoping the guide will help you with.

We invite you to list these points, and the extent to which they have been covered, in the Lean questionnaire, which can be found at: **www.ciria.org/service/lean**

Implementing Lean in construction: Lean construction and BIM

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Why read this guide?

In this guide, academic and professional knowledge regarding the joint application of Lean and BIM has been compiled for the first time. The information is based on up-to-date experiences and knowledge regarding the topic, gained by pioneering organisations in different countries.

The guide contains a clear description on the links between Lean and BIM, and how these can be marshalled to provide a range of benefits in an incremental manner. It provides specific advice for different parties of a construction project and for different project stages, as well as references to the wider literature. The guide provides essential reading to anyone interested in practical and effective improvement of construction.

Background to topic

Building Information Modelling (BIM) and Lean construction have existed as two different initiatives to improve construction, with distinct communities and interests. In the last 10 years or so, both have started to diffuse into advanced practice, with accelerating speed. However, recently the insight has gained strength, first among pioneering practitioners and then among academics, that these two initiatives have a considerable mutual synergy and that it is highly advantageous to implement them jointly. In view of this, there are increasing needs to make BIM champions and users aware of Lean principles, methods and tools, as well as Lean champions and implementers aware of the functionalities of BIM. This guide is intended to provide a means to fulfil these needs.

CIRIA Lean guides

This guide is one of a series of publications and, together with an overview document, can be found at: **www.ciria.org/service/lean**

C725 Lean and BIM (Dave, B, Koskela, L, Kiviniemi, A, Owen, R, Tzortzopoulos, P)

C726 Lean and sustainability (Corfe, C)

C727 Lean benefits realisation management (Smith, S)

C728 Lean client's guide (Chick, G)

C729 Selecting a Lean consultant (Fraser, N)

C730 Lean tools – an introduction (O'Connor, R and Swain, B)

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Professor Lauri Koskela is one of the pioneers of Lean construction. He coined the term, together with Dr Glenn Ballard, in 1993. He is a founding and continuously active member of the International Group for Lean Construction, and a board member of the Lean Construction Institute UK. Before being nominated Professor at the University of Salford in January 2004, he worked at VTT Technical Research Centre of Finland. He has published widely on construction management, Lean construction and project management, and he is one of the most cited authors in these fields. His current research interests cover Lean production, as adapted to various contexts, such as construction or healthcare, Building Information Modelling (BIM), production management, design management, theory of production and theory of design, project management, and causes and cures for the irrelevance problem of management research.

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Bob has recently moved to Queensland University of Technology as Associate Professor, Research Development – Institute for Future Environments, where he continues to lead the CIB priority global research theme on improving construction and use through integrated design & delivery solutions.

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Introduction

The current focus on cost and value is, understandably, accelerating the rate that the construction industry and its clients are considering a Lean approach. Likewise, in addition to the efficiency gains, the UK Government BIM strategy (BIS-BIM Industry Working Group, 2011) with its requirement that all suitable government construction projects use Building Information Modelling (BIM) by 2016 is focusing the minds of those in the industry. BIM has become a ubiquitous term across the industry and, like Lean, is widely documented.

The breadth and diversity of the construction sector means that organisations' experience and capability in BIM will vary significantly. Within Government, some departments, such as the Ministry of Justice, are already pioneering early application in advance of the 2016 deadline. Also, the private sector is rapidly embracing BIM along with new approaches to collaboration and decision making. The same variation in experience is true of Lean. While many practitioners will be familiar with the concept and have experience of applying Lean in many situations, some in the industry will be less familiar or even totally unfamiliar with the concept.

This guide is about the links between Lean construction and BIM. Given that both topics are developing rapidly in terms of knowledge and application, the guide assumes the reader already has some familiarity with these.

This chapter will answer the question 'Lean and BIM are well-established, so what are they all about and why should the industry know more about them?'

Background information is covered in this guide for the first time reader. Individual explanations of Lean construction and BIM are provided first. It is then explained how they are related to each other and what benefits are expected by exploiting them synerginistically. The chapter also highlights the organisations around the world that are using Lean and BIM for strategic advantages, and the main characteristics of a Lean and BIM project.

While earlier sections of this guide introduce BIM and Lean concepts to the reader, its focus is on advanced applications (particularly of BIM), which are likely to become the norm. Where possible, the document will refer to the Government maturity levels as introduced in Box 1.2.

Box 1.1 What is Lean?

Conventional approaches to construction, in-line with conventional approaches to management, assume that a project (or system) can be broken down into a series of stages. By taking decisions that optimise each of these stages, the overall project (or system) is then optimised.

Lean challenges this approach, recognising that each of the stages is likely to contain 'waste' and can be 'improved'. Another tenet of Lean is that the project stages are interdependent. So, breaking down of projects into separate stages and decisions – to be made optimally – introduces both value loss and waste as the interconnections of stages and decisions will not be fully taken into account. Lean is about optimising the project (or system) as a whole rather than justfocusing on individual stages.

Lean originates from manufacturing. It is applicable to construction, despite the obvious differences. However, applying Lean in construction involves tackling an additional challenge. Often, this is called 'making do'. Starting construction before designs are finalised is a common example of this practice, leading to decreased efficiency and effectiveness.

The application of Lean approaches and tools can help to achieve a joined-up approach, a focus on the whole project for reducing waste and increasing value. Collaboration across stages and across the supply chain, and the application of new planning and production control approaches towards eliminating making do, are just two examples that will help achieve such an approach.

Lean and BIM have major synergy effects, which are increasingly being explored and implemented by leading practitioners. For detailed understanding of the synergy and nature of interaction between Lean and BIM, it is recommended that the reader refers to Sacks *et al* (2010). The UK Government has recognised this linkage and recently stated their intent to now develop Lean construction processes to build on the BIM Task Group's earlier work (HM Government, 2012).

1.1 HOW LEAN AND BIM ARE RELATED

Lean construction has two main goals to serve during the construction process:

1 Minimise physical and process waste.
2 Improve the value generation to the client.

As depicted in Figure 1.2, there are four major mechanisms for how Lean and BIM interact. A basic recognition of these mechanisms is of interest as they convey the message that for capturing all benefits from BIM, systematic Lean processes are needed, besides careful management of the information model itself.

In the following, these mechanisms are discussed and exemplified in detail.

1 **BIM contributes directly to Lean goals:** an example of such a contribution is provided by clash detection. This is a function of BIM where models from separate disciplines (architectural, structural and MEP) are aligned against each other and are checked for any physical or clearance clashes. Once clashes are found designers can correct the problems and iterate the models until they are clash free. By carrying out this activity virtually, a significant amount of time and money that would otherwise be wasted through rework or delay is saved. This would be nearly impossible to achieve with traditional 2D CAD technologies, where even if drawings are overlaid on each other, they do not always make it easier for the user to identify where the clash would be in a 3D space. Also, there is no method to automate clash checking.

   Another example relates to visualisation of co-ordinated/synchronised models. Models from separate disciplines are synchronised and visualised from the early conceptual design stage. This allows clients and, in particular, end users to provide their input, and designers to better understand the requirements from the client. This ensures a much better requirement and design intent flow down through the various stages of the project. This function contributes directly to waste minimisation and value generation principles of Lean construction. However, it must be understood that for this to happen, early involvement of stakeholders in the project.

> On the One Island East project (a large $300m commercial office building with seventy floors) in Hong Kong, Gehry technologies helped identify 2000 separate clashes in design before construction. It was anticipated that about 15 to 20 per cent of total project cost was saved by Lean and BIM implementation on this project (Eastman *et al*, 2011).

Box 1.2 What is BIM?

Eastman *et al* (2011) defines BIM as “a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation.” The result of BIM activity is a ‘Building Information Model’. BIM software tools are characterised by the ability to compile virtual models of buildings using machine-readable parametric objects that exhibit behaviour commensurate with the need to design, analyse, and test a building design (Sacks *et al*, 2004). As such, 3D computer-aided drafting (CAD) models that are not expressed as objects that exhibit form, function and behaviour (Tolman, 1999) cannot be considered BIM.

However, BIM also provides “the basis for new construction capabilities and changes in the roles and relationships among a project team. BIM also facilitates a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration.” (Eastman *et al,* 2011). In this sense, BIM is expected to provide the foundation for some of the results that Lean construction is expected to deliver.

The UK Government has set up a special BIM Task Group to help develop a roadmap for implementation of BIM in the UK. To help with a gradual adoption they have specified levels of BIM that will have to be adopted by construction projects, with a mandate that all projects achieve Level 2 BIM by 2016. Figure 1.1 explains the BIM levels and what they entail. The maturity levels depicted in Figure 1 are described as follows (from the Government Construction Client Group, 2011):

> **Level 0:** unmanaged CAD, information is exchanged as text or 2D drawings on paper (or as electronic documents).
>
> **Level 1:** managed CAD in 2D or 3D format using BS1192: 2007 with a collaboration tool providing a common data environment, possibly some standard data structures and formats. Commercial data managed by standalone finance and cost management packages without integration.
>
> **Level 2:** co-ordinated 3D BIM environment. Separate discipline models consisting of objects with attached data. Commercial data managed by an ERP (enterprise resource planning) system. Level 2 may use 4D scheduling data and 5D cost elements. This is the current typical, advanced use of BIM and also the level that UK Governments’ Construction Strategy requires as the minimum by 2016.
>
> **Level 3:** fully open process and data integration enabled by open standards and managed by a collaborative model server. Can be regarded as iBIM (integrated BIM) and potentially employ concurrent engineering processes. Difficult to achieve with the current technologies.

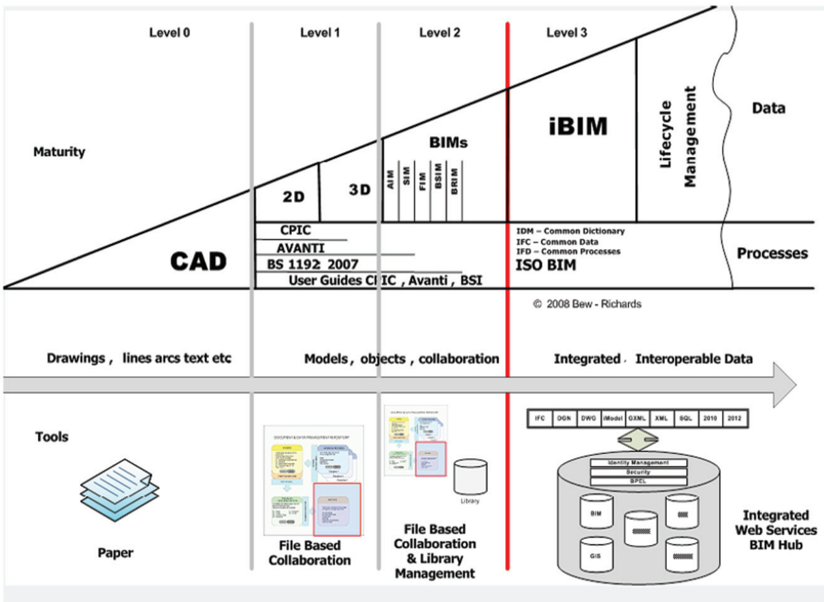


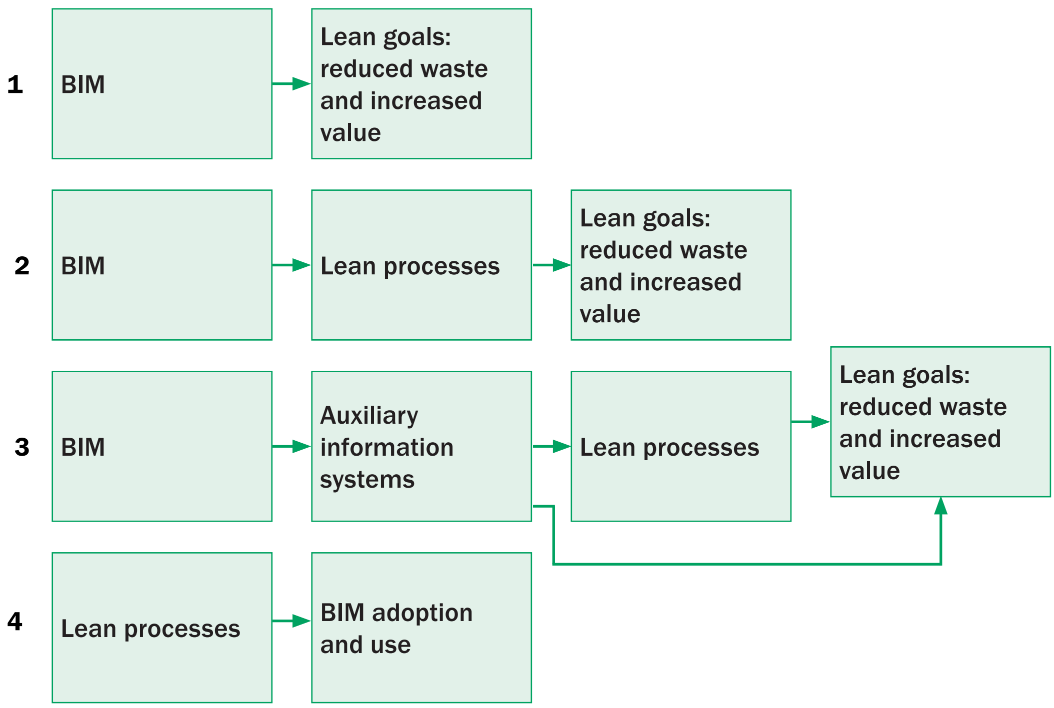
Figure 1.1 UK Government BIM roadmap

The UK construction industry is making significant progress in terms of BIM adoption, which has accelerated considerably following the UK Government’s announcement of its Construction Strategy However, the general maturity level in the UK (and international) construction industry varies significantly. Major variations in maturity exist between clients, designers, contractors, and subcontractors. Also, different maturity levels between large and small organisations (and sometimes even within organisations) in the supply chain can also be observed. So, it is quite difficult to generalise BIM competence level for a country with such a large construction industry as UK. This guide considers that the reader is familiar with at least Level 1 BIM practices as recommended in the UK Government roadmap and is striving to improve and reach higher levels of sophistication.

2 **BIM enables Lean processes and contributes indirectly to Lean goals:** this can be exemplified by the use of the BIM model during production. Collaborative planning is one of the major contributions functions of Lean construction and is popular among the Lean tools on construction projects in the UK. It is becoming increasingly difficult for stakeholders to visualise the task at hand and also the sequence of the process, particularly on a complex project where there are complicated services being installed. One of the main features of collaborative planning is to gain a deeper understanding of the planned activities in advance. Also, one of the related activities is 'first run studies' where users try different work methods and sequences to identify how a construction task can be best performed and optimised. By using BIM tools such as 4D planning, where a 3D model is linked to the project plan and simulated to demonstrate the activities for a selected period, the team visually gains a much deeper, mutual understanding as compared to the use of 2D drawings during planning meetings. If used appropriately, 4D scheduling can also serve the function of a virtual 'first run study'.

3 **Auxiliary information systems, enabled by BIM, contribute directly and indirectly to Lean goals:** analysis models for cost management or carbon footprint are examples of this. Such models carry out useful, value-adding calculations that were too cumbersome to do using drawings. However, for deriving full benefit from such calculations, it may be necessary to change the design process so that the possibility of design improvements through rapid iteration can be realised in design practice.

4 **Lean processes facilitate the introduction of BIM:** the environment of Lean construction, with emphasis on predictability and discipline but also on collaboration and experimentation, will ease the introduction and implementation of BIM based technologies and enhance their effectiveness. This is especially relevant during the initial strategic adoption of a new technology being applied within the project life cycle.



Note

1 BIM contributes directly to Lean goals.
2 BIM enables Lean processes, which contributes indirectly to Lean goals.
3 Auxiliary information systems, enabled by BIM, contribute directly and indirectly to Lean goals.
4 Lean processes facilitate the adoption and use of BIM.

Figure 1.2 Conceptual connections between BIM and Lean

There are many other examples that can be provided where Lean functions are supported by BIM activities and vice versa. A detailed study was carried out by Sacks *et al* (2010), which found 56 unique interactions between BIM functions and Lean construction processes (see Section 4.1). Also, the study found empirical evidence from past and ongoing construction projects to support these interactions. Some important aspects that emerged during this study strongly support the notion that Lean construction and BIM are not only synergistic but that the synergy spans the entire life cycle of the project and not just design activities. During the study it was found that three Lean principles had the most interactions with BIM functions (ie they are best supported by BIM).

1 Reduction of waste by getting the quality right first time (through a better designed product, reducing the product variability, ie reduction of the need for changes during the later stages of design).
2 Improved flow and reduced production uncertainty.
3 Reduction in overall construction time.

As these are the core functions of Lean construction, it can be deduced that if exploited properly, these two initiatives have the right ingredients for a successful project delivery. However, it should be noted that the discovery of the breadth and depth of interactions between Lean and BIM are relatively recent, and it is probable that new types of interaction will be found.

While it has been observed that there are significant synergies between these two concepts, it is also important to identify how it transpires into the characteristics or functions of a construction project. Table 1.1 summarises some of these characteristics in various stages of the project. It should be noted here that not all the features mentioned have to be present in an integrated Lean and BIM project but these may be taken as a guideline. These concepts are further described in detail in Chapter 2. As it is an emerging field, new ideas are being developed and individual organisations may find/develop their own unique way of implementing these features.

Table 1.1 Some characteristics of a Lean and BIM project

Design and detail	Construction	Operations and facilities management
Collaborative development of design and detailing	Increasing the resolution of planning by linking fine grained plans to BIM (going beyond 4D). Construction improvement through iterative optimisation	Linking the BIM model with facilities management system
Co-location of design team	Collaborative sharing of models during planning meetings	Using the model for facilities management and operations and maintenance functions
Involvement of downstream stakeholders during design	Sharing models across the whole supply chain for detailed planning, model based estimating, safety planning and carrying out digital first-run studies (and 'what if' scenarios)	Keeping the as-maintained model updated to ensure reliability
Using collaborative planning in design	Updating the models throughout the project to ensure an accurate as-built handover model	Use of COBie UK 2012 'drops' throughout the project to ensure that FM staff are prepared before operation
Detailing the models for construction use	Tagging assets during fit out, track progress of fit out visually and capture relevant asset information and link it to the model	Linkage of tagged assets with maintenance and warrantee data for use by maintenance staff via 'smart' devices

Other things to consider while planning a Lean and BIM implementation project, especially when starting fresh in an organisation are:

- focusing on long-term benefits
- visualising the project purpose and expected results
- using appropriate requirements management
- employing design simulations and verification

- continually assessing project benefits
- clearly defining governance structures
- evaluating outcomes and impacts of projects (benefits over the life cycle)
- analysing environmental and life cycle impacts.

While learning about the characteristics of a Lean/BIM project, it is also important to learn what factors actually hinder the implementation of Lean/BIM. Projects with such characteristics may not be said to be implementing Lean/BIM. Some of these factors (apart from those that do not use Lean constructio and BIM) are:

- non-involvement of key stakeholders in relevant stages of project
- having discipline models that are not synchronised or federated (see Section 2.2.1)
- using BIM for one discipline only (ie architectural, structural or MEP)
- using BIM for design and clash detection only and not during production planning and control
- using Lean construction for just one project phase (eg design or construction)
- not sharing the models across the supply chain.

1.2 WHY IMPLEMENT INTEGRATED LEAN AND BIM?

As discussed in Section 1.1, conceptually there are significant synergies between Lean and BIM. However, it is well known that the construction industry is more receptive to proven practical solutions, rather than to concepts. Even with its short timespan in implementation, significant benefits have emerged from past Lean/BIM projects. Consider the following results from the Sutter Health Castro Valley project (reported by the owner) where integrated Lean and BIM have been implemented:

- 0 per cent cost overrun (following design finalisation)
- anticipated completion date six weeks early
- rework down an average of 15 per cent (compared to benchmark from similar experience with California)
- almost no compromises to owner's space programme.

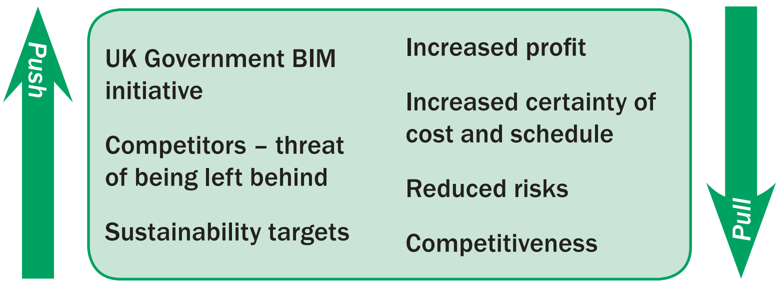


Figure 1.3 Key drivers for Lean and BIM implementation

The main drivers for implementing Lean/BIM can be classified under two main categories, push and pull (see Figure 1.3):

Figure 1.4 (page 7) shows a high level workflow for the Ministry of Justice (UK) department's Lean and BIM implementation strategy. MoJ are currently undertaking pilot projects, where BIM is being implemented to improve the project performance and also support their Lean strategy. These pilot projects will help refine their Lean and BIM workflow for future projects, and also help them achieve the Level 2 BIM as set out by UK Government BIM roadmap.

Figure 1.5 describes potential advantages of implementing integrated Lean and BIM on a construction project during various stages of the project.

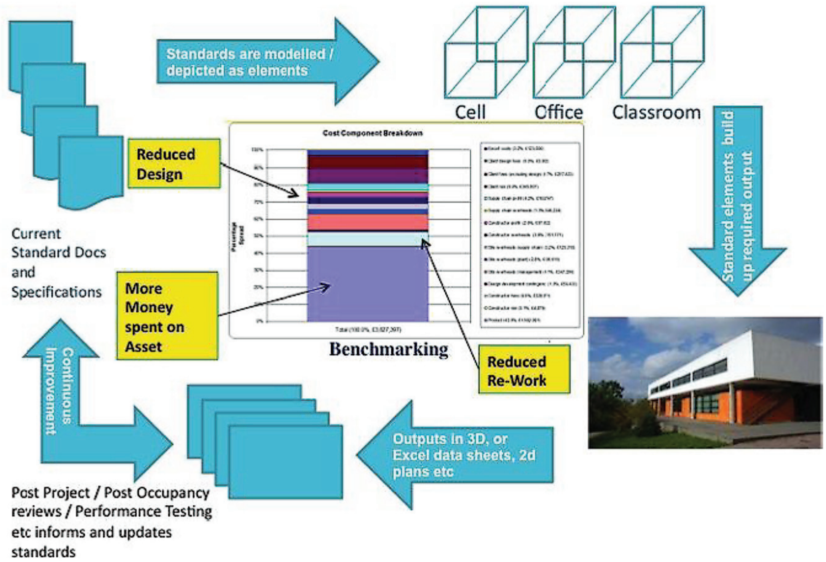


Figure 1.4 *Lean and BIM workflow for Ministry of Justice (courtesy MoJ, UK)*

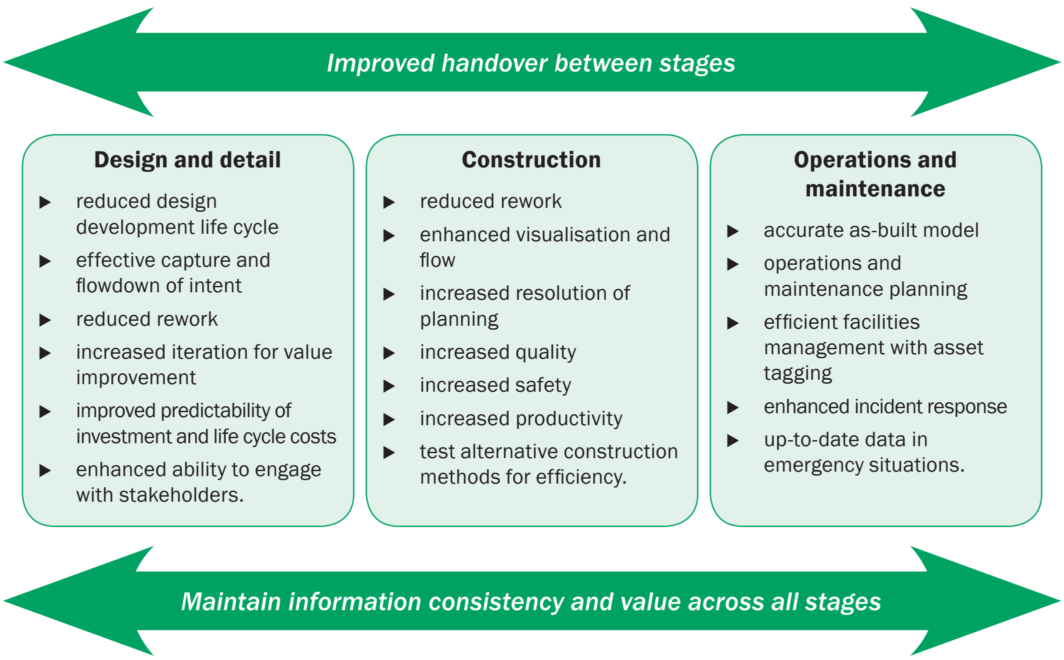


Figure 1.5 *Benefits of using Lean and BIM*

The UK Office of General Contractor (OGC) (2007) estimates that savings of up to 30 per cent in the cost of construction can be achieved where integrated teams promote continuous improvement over a series of construction projects and that single projects employing integrated supply teams can achieve savings of 2 to 10 per cent in the cost of construction. Use of new technologies in conjunction with collaborative processes results in increased productivity and decreased change orders, requests for information (RFIs), design clashes found on site, waste, and project delays. It is worthwhile to note that with any new adoption, be it technological or a process change, the first three projects are often either breakeven or at a cost. However, an acceptable ROI (Return on Investment) should be realised in the long run depending on the effectiveness of implementation. Achieving the benefits naturally requires some investments in technology procurement and learning and process development, but typically increased productivity is achieved in companies after the first or second project and the long-term ROI can be significant.

1.3 WHO IS IMPLEMENTING LEAN AND BIM?

There are several companies around the world who are implementing Lean construction and BIM in a synergistic way. The most prominent example is the collaboration of Sutter Health and DPR construction who pioneered the use of integrated Lean and BIM. They started exploring the potential for Lean/BIM implementation from their Camino Medical Centre project in 2003. However, their Castro Valley project became much more well-known due to the sophistication of the processes and tools deployed and the results achieved. Swire Properties' One Island East project in Hong Kong is also worth noting for its innovative use of virtual first run studies (through discrete event simulation) and use of BIM during the early design, tendering and construction stages (Eastman *et al*, 2011).

In the UK, the Heathrow Terminal 5 project, Network Rail's Borough Viaduct project and the Highways Agency's Bidston Moss (Costain) and M4/M5 Automation (Balfour Beatty) projects have used Lean construction and BIM simultaneously with positive results. Other notable companies implementing Lean and BIM together include Balfour Beatty (UK and global), Costain (UK), Laing O'Rourke (UK), Morgan & Sindall (UK), Mortenson (USA), Skanska (Finland and UK), Sundt (USA), Tocci (USA), and BAM Nuttall (UK).

2

What does a Lean and BIM project look like?

Now that the synergistic nature of Lean and BIM and increased benefits that can be derived from integrated implementation have been established, it is important to look at some specific tools and processes that support Lean and BIM implementation. The tools are discussed within the context of a construction project life cycle and strengthened by providing examples from past projects.

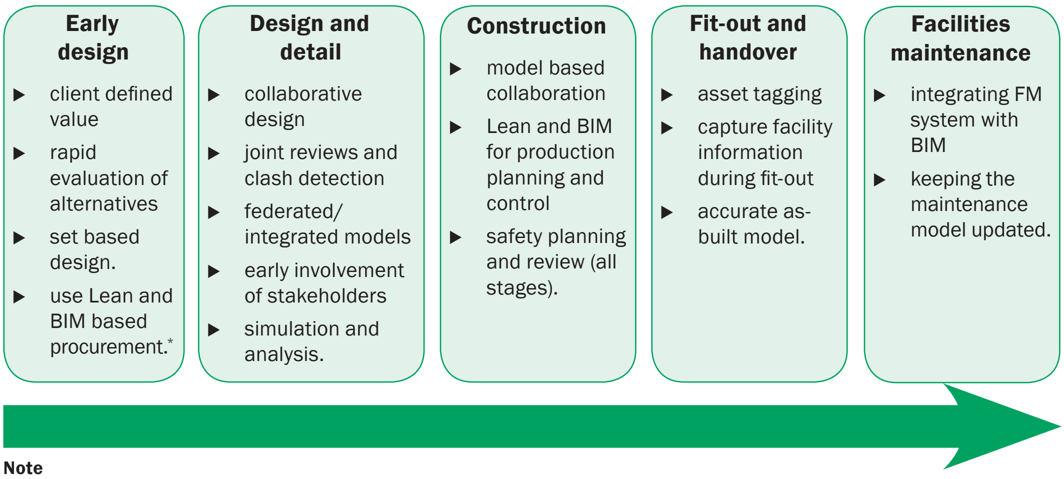
Several case studies have been included in this guide. However, the aforementioned Castro Valley Medical Centre, California features throughout. The reason being is that not only is it one of the most advanced examples of Lean and BIM but one that pioneered the integrated implementation of Lean and BIM. The improved collaboration between the client Sutter Health, main contractor DPR and their main supply chain partners through integrated project delivery (IPD) is also exemplary.

This chapter explores the core Lean and BIM tools and assumes some knowledge of the subject area. There are several guides (for example, Eastman *et al,* 2011, and Kymmel, 2009) that cover the individual areas of Lean and BIM and can be referred to by the reader to gain better understanding first if needed.

This chapter will answer the question 'what are the main tools and techniques that are being applied in a Lean and BIM project?'

2.1 THE LEAN AND BIM WORKFLOW

The Lean and BIM workflow spans the entire life cycle of the project and an example is provided in Figure 2.1. This section describes the main tools and techniques being applied on an integrated Lean and BIM project. It is supported by case studies where possible. As this is an emerging area, this is not meant as an exhaustive list but an indication of the common Lean and BIM processes currently used by the industry.



Note

* The UK Government are currently stressing Lean in this area.

Figure 2.1 Lean and BIM workflow – functions

2.2 EARLY DESIGN

> The function served by Lean and BIM processes and tools is that of defining, retaining and communicating value from the client's perspective.

Traditional design methods do not support sophisticated and accurate visualisation or rapid iteration and evaluation of ideas that will help clients decide the option(s) to select. The Lean and BIM processes and tools not only provide a much more accurate and sophisticated 3D visualisation capability, but also help evaluate the options from a range of criteria set by the client. Through parametric design and collaborative processes, the value loss is minimised when the conceptual design is passed along to later stages.

2.2.1 Client defined value

> In a pilot project undertaken by the Ministry of Justice. (UK) in construction of a correctional facility, the use BIM during conceptual design resulted in a reduced work scope, saving cost, but more importantly provided the client with a facility that was more efficient during operation. This also resulted in reduction of late changes in design and construction specifications, reducing waste from the overall process.

The value gained during the early design stage through efficient capture of requirement and intent can be quite significant, which is one of the core tenets of Lean. Buildings (and structures) are built to serve a purpose, and the industry needs to focus on that purpose, as illustrated in Figure 2.2. If construction cost is 1, the total costs of design are typically less than 0.1, operation and maintenance costs in 20 years' time are 3 to 5 and clients' operational costs, mainly salaries and related costs, are 40 to 200. From this viewpoint even marginally improved business productivity would outweigh any traditional design costs, ie creating value should be more important than minimising design costs. This is assuming that the value is measured using consistent and reliable methods.

So a shift of focus from the delivery of products to the generation of value and benefits to clients is needed. The main concern is no longer the capital asset, system or facility, but increasingly the challenge of linking clients' business strategy to projects, maximising revenue generation and managing the delivery of benefits in relation to different stakeholder groups (Winter *et al*, 2006).

The traditional approach in the industry to 'value' has been on defining a set of requirements through the project brief, and then designing and delivering a building through quite a linear process. There is not much emphasis on evaluating and refining the design early against requirements through an iterative process. However, it is a fact that project requirements evolve over time as ideas are tested and alternatives evaluated, but this notion is not sufficiently considered or supported by traditional processes or tools. 'Value' is more typically associated with value engineering, which is more aligned to construction cost reduction

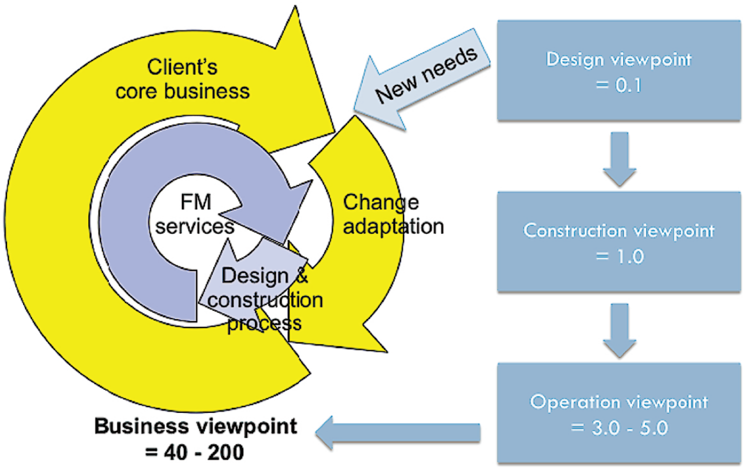


Figure 2.2 Project life cycle and value

In this context, generating value implies understanding client's purposes and helping them to fulfil those purposes with minimum resources (ie costs, time). This is where integrated Lean and BIM concept helps significantly as it enables the industry to better focus on life cycle values.

The Ministry of Justice in the UK have started to develop their BIM standard component library, which supports standardisation and continuous improvement, ultimately helping create the Lean environment the organisation is striving for.

2.2.2 Rapid evaluation of alternatives

The feasibility study stage is the point where the project scope is determined, and the client decides to invest in designing and building a facility. At this stage ideas gain shape, and initial plans are developed, leading to their approval and execution. Also, this is when clients know why they need a building, while contractors know what needs to be built and how to achieve a specified purpose. So, it is important to integrate these different views to create a shared understanding of why a building is needed, what is needed and how it can be achieved, to ensure projects deliver expected benefits. Such understanding shoud be dissminated throughout the project team to ensure reduced waste and to encourage alternative and improved options for construction.

BIM enables rapid visual creation, communication and assessment of project alternatives (Sacks *et al*, 2010), as the outcome of the modelling process is a virtual repository of building information with its object parameters and properties. From this it is possible to extract information for various purposes that enable better decision support during a feasibility study. For example, links between building information to energy, structural, M&E (mechanical and electrical) analyses and cost estimations, conformance to requirements and sustainability goals can be created. Such links help to significantly reduce information re-creation, re-handling and re-work during design stages. Also, it helps the client to better define requirements and improves value creation and flow throughout the project, which is at the heart of Lean construction. The use of models in the bidding process can reduce risks by providing more and more accurate information of quantities, and offers opportunities to evaluate alternative production methods with relatively small effort if the contractors are familiar with BIM. So it can improve the quality of bids and lower price by reducing variation caused by uncertainties.

2.2.3 BIM based procurement

BIM based quantity take off and estimating are now increasingly used during early stages to provide an accurate Bill of Quantity and reduce the time taken to produce this information. As a rule of thumb, cost per successful bid for a contractor averages from six per cent to 10 per cent of project cost as bidding is a very intensive activity requiring careful consideration of design and interpretation of specifications. With BIM, the client can provide accurate information in a partly or fully automated way that has the potential to reduce the risk for all project stakeholders. This reduces the overall time associated with procurement. Several BIM tools now offer the facility to automate the quantity take off, and some tools offer the possibility to link cost data to produce an automated estimate. However, it is advised to check this information thoroughly and ensure that the correct business rules are applied and that the quantity take off has been accurate.

During the later stages of the project, it is also possible to integrate the procurement system with BIM model to visually track the procurement of component and materials arriving on site. In several BIM software programmes, it is possible to track components as they are fabricated, shipped and received on site (and also when they are installed) to improve production planning and management.

2.2.4 Target value design

Target value design (TVD) and set based design (SBD) are advanced methods, which can be combined with BIM and Lean and used throughout the design process, as explained in Sections 3.3 and 3.5.

2.3 DESIGN AND DETAIL

At the design and detail stage, there are two functions that are served by Lean and BIM implementation. These are value retention and creation, and waste minimisation in current and later stages.

As discussed earlier, BIM provides a sophisticated toolset that helps capture value (also retaining value from the earlier stages) and also helps further value development. The Lean processes, along with the BIM toolset, help minimise waste throughout the design stage by improved design reviews and clash detection and by early involvement of project stakeholders. The collaborative design processes help minimise delays and compress the overall time taken. Given the current considerations and UK Government priorities regarding the measurement of carbon, it should be noted that there are examples of integrating carbon calculations while designing the building (and possibly also through operations).

2.3.1 Collaborative design

The distributed information model paradigm, an evolving technology trend in the industry, means that a range of BIM tools exist for each player to create their own models, which have to be periodically combined for collaborative working or analysis. This is the current practice in industry, and has benefits as it allows for experimentation and flexibility in business models, for technology and business practices to emerge organically. Also, it places greater market demand for interoperability (Smith and Tardiff, 2009).

This highlights the need for specific data creation and exchange protocols, aiming to ensure information is appropriately managed throughout the design process. Procedures for collaborative working are needed to support design domains where teams of designers/engineers are concurrently working on the same project. In this context the following issues should be addressed:

- how to ensure that everyone has up-to-date information
- how to make sure that several people are not editing the same objects at the same time
- how to notify about ongoing work and changes
- need for flexible distribution of the work based on location, task, object type and attribute type.

Also, other issues have to be addressed when co-ordinating multi-discipline design (usually across organisations) including:

- is there a need to see what the other designers are currently doing?
- what information is needed by other designers for critical decision making, and when is it needed?
- there are many temporary changes in trying to find solutions, so when is it adequate to exchange information?
- is there a need to 'freeze' design solutions so that other disciplines can start design?

An extensive value stream (process) mapping exercise can help understand these issues including identifying critical design handover points, the level of detail required from each discipline at handovers, and general scheduling of the design process (see Figure 2.3). In Lean and BIM design, effective information management is a prerequisite for information modelling and process improvement.

Figure 2.3 Using process mapping to design the design process at the Sutter Health Eden Medical Center Project (courtesy Sutter Health)

2.3.2 Consideration of Intellectual Property Rights (IPR)

While BIM based collaborative design brings new opportunities to the process, it should be mentioned that managing Intellectual Property Rights (IPR) should be taken into account while drawing the contract for design services. This is understandably one of the trickiest issues as traditionally the architects are apprehensive about handing over IPR to any other party. However, from the building life cycle perspective, there is significant value in using the model through construction, handover and later the operational phases of the project. The following issues should be taken into consideration regarding IPR:

- what data/information from the model is required and at what stages and ensuring that all parties understand this correctly before signing the contract
- the IPR clauses should identify the contributions from each stakeholder (architects, consultants, contractors) and ensure that they each provide access to each other and use of their individual contribution during the project (and also during the operational phase of the facility)
- the National Building Specification (NBIMS, 2007) suggest a good practice regarding joint ownership of model as "one way to achieve this is to define in the amendment what would constitute joint authorship, and recognise the right of the original author to accept or reject any addition and be saved from any liability for errors where an addition is made without its consent"
- the NBS also suggest that the confidentiality of the shared information during the BIM process can be covered by a simple confidentiality and non-disclosure clause in the contract agreement.

2.3.3 Joint design reviews

Joint reviews go hand-in-hand with collaborative design. Project teams are using iterative modelling co-ordination meetings to address clashes, errors and omissions that have been identified in the design. On the Maple Grove Hospital project, Minnesota, USA, the team said that "the software's 3D modelling environment helped our engineers visualise the design and fit all the piping, ductwork, and equipment into tight spaces" (Autodesk, 2008b). Not only is it important for gaining correct building information, but also to improve common understanding and knowledge through project team virtually building a project (Kymmell, 2009). Such meetings can use BIM-based applications that compare old and new versions of models by means of colour coding to track the changes. In the Sutter Medical Castro Valley project, this helped to prevent a major issue emerging by early identification of a design error, when the depths of some of the existing beams had been changed, causing collisions (Tiwari *et al*, 2009).

2.3.4 Clash detection

Clash detection is considered to be one of the "low hanging fruits" in the adoption of integrated BIM, as it is one easily achievable benefit. There are two types of clashes, a hard clash where objects occupy the same space, and a soft/clearance clash where objects are so close that there is insufficient space for access. There are several specialised software products for this, eg Navisworks and Solibri Model Checker, Tekla BIMSight, which allow automatic geometry-based clash detection to be combined with semantic and rule-based clash analysis for identifying clashes.

2.3.5 Federated/co-ordinated model

Information validation is an important part of a BIM-enabled design process. Such validation includes both the knowledge that the information is from a trusted source, and also the need for confirming the integrity of information, eg is an industry foundation model (IFC) complete for a specific purpose? There are data validation tools available, which enable the sharing of responsibility for data integrity for both information authors and recipients (Smith and Tardiff, 2009). This supports greater transparency throughout the process, one of the aims of Lean processes.

Krygiel *et al* (2008) provides an example of the co-ordinated use of models (Figure 2.4). Here the workflow is divided into four collaborative steps (adapted):

1 Architects and consultants work on co-ordinated models.

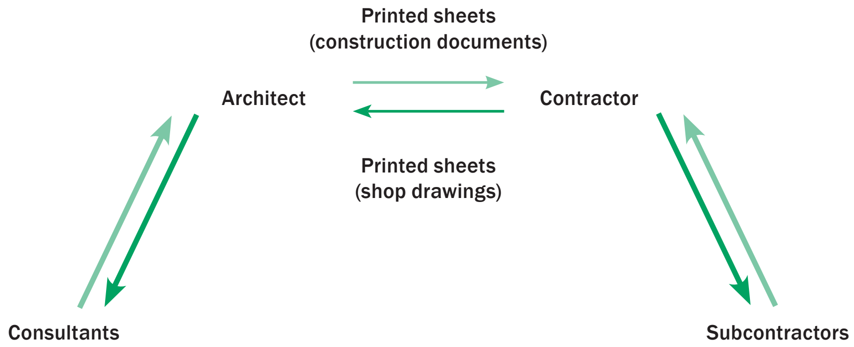
2 Stage of refinement, where the models are passed to the contractor and building team.

3 Models are adjusted to reflect the changes that happened in the field.

4 Updated as-built model is shared with owner and facility's maintenance operators.

This workflow example demonstrates that a BIM model is not a static piece of information source, but it is constantly being updated throughout the life cycle. It should be noted that this can only be taken as a guideline and each project should develop their own information exchange and design development protocol, based on the environment, systems, capabilities and type of project.

The traditional method of design review



An integrated approach to design review

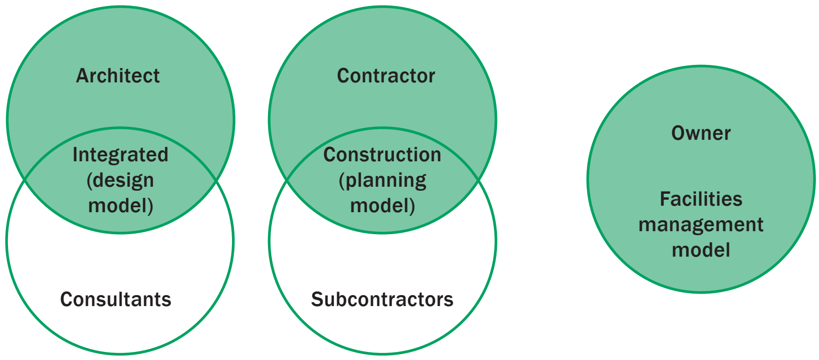


Figure 2.4 The traditional and co-ordinated approach to design review (from Krygiel et al, 2008)

Early involvement of stakeholders

The need to involve major project stakeholders from the initial stages of a project has been discussed for many years. As an example of benefits from early involvement, contractors can contribute to design development by providing construction specific information (also including information about temporary structures and site conditions) early in the design process. This improves decision making and results in fewer design errors and less re-work. Also, the design models will be more usable for contractors in their processes, eg estimating, detailing for fabrication, site planning, production planning (4D–3D models linked with construction schedule) and resources planning (5D–4D with budget). The BIM process gives the project team the opportunity to virtually plan and build construction projects before major commitments to money and time are made, ie enhanced constructability analysis. This is depicted in the Kaiser Permanente Oakland Medical Centre replacement project, where the 3D modelling process was carried out in parallel with a traditional project delivery. Constructability reviews, through design modelling, highlighted more than 200 issues at each stage that were not found by the simultaneously carried out traditional constructability process (Kala *et al*, 2010). This resulted in reduction of errors in the execution stage.

Simulation and analysis

There are a range of parameters that a building or a structure has to be validated against. These include (but are not limited to):

- structural integrity
- thermal performance
- acoustics
- ventilation and circulation
- lighting (including solar studies)
- energy (requirements and consumption).

Evaluating the design using traditional CAD technologies and related tools can be a time consuming and tedious process. BIM provides an opportunity where the design model can be simulated against the performance criteria listed from an early stage. This ensures that the design is fit for purpose, improving value to the client as well as reducing waste due to non-performance and rework (in case failures in performance warrants rework).

A range of automated tools are now available that help perform such simulation, for example, Autodesk Ecotect Analysis, Graphisoft Ecodesigner, Bentley Tas Simulator, Bentley Hevacomp and IES VE-Pro. It should be noted that the analysis produced by these tools depend greatly on the quality of input provided, and that analysis from models with poor level of detail (or inaccuracies in design) will not be accurate.

Supply chain involvement

One of the challenges to construction projects is the variable and temporary nature of the supply chain. When introducing new approaches, such as Lean and BIM, it would be ideal to involve the supply chain through training and provide them access to the latest BIM model. The Construction Strategy includes the statement that: "Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016." The standard for asset information will be Construction Operations Building information exchange (COBie) and it will be employed on the projects to enable clients to check that the facility meets their requirements. Also, it will improve information handover.

> *"In order to improve the measurement and management of public assets, it is recommended that public clients request that specific information be delivered by the supply chain. The specified information set, called COBie, delivers consistent and structured asset information useful to the owner-operator for post-occupancy decision making."*
>
> (BIS-BIM Industry Working Group, 2011)

As stated by the BIM Task Group "COBie allows the team to document their knowledge about a facility in both its spatial and physical aspects." To achieve COBie compliance it is important to engage the supply chain so that they can provide information on equipment supplied through documentation of a COBie spreadsheet.

Automated generation of drawings and specifications and design for prefabrication

Studies have shown that incomplete project documentation is one of the main reasons for problems and re-work on site (Kala *et al*, 2010). Traditional drawings and specifications will be a necessary part of the design and construction process at least in the near future, and also in the BIM-based processes, because they have the status of the legal contract documents. However, BIM-based applications provide efficient means for the extraction of accurate and consistent drawings of any set of BIM objects or specified view of the project (Eastman *et al*, 2011). This should significantly reduce the time needed and errors associated with generating construction drawings. The same occurred in Phoenix Children's Hospital, HKS's (architect) use of BIM enabled them to work in a fully integrated fashion with contractors and their clients, allowing more time for designing rather than construction document production (McKenzie, 2009). Beyond the traditional drawings, Dunham (subcontractor on the Maple Grove Hospital project) used the software to automatically create 3D isometric drawings and colour coded images of highly congested areas. These were then incorporated into construction documents to more clearly communicate the engineering design to the system installation contractors and the owner (Autodesk, 2008b).

The Castro Valley project team also demonstrated that the focus should be on the end goal rather than just producing permit drawings (drawings for approval). As shown in Figure 2.5 in the Sutter Medical Castro Valley project, the approach taken by the team was to produce a multidisciplinary, fully co-ordinated BIM model, to help automate the workflow of design–detail–co-ordinate–fabricate–install. This approach reduces non-value adding activities (by automating them) and helps keep the focus on value adding activities.

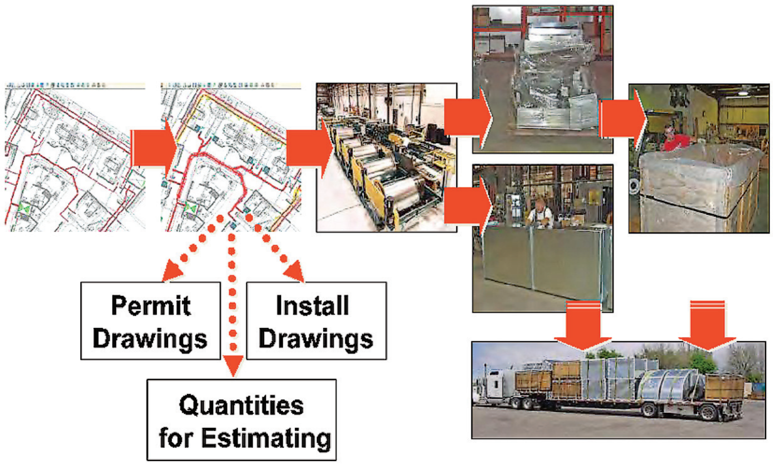


Figure 2.5
Implementing workflows that focus on value generation activities: design–detail–co-ordinate–fabricate–install (courtesy Ghafari Associates and Super Air Handling)

2.4 CONSTRUCTION

> The primary function of Lean and BIM during the construction stage is to minimise waste and shield production from uncertainty. This helps to compress overall time taken and improve quality (and value) for the client.

There are a wide range of Lean and BIM tools and processes such as clash detection, co-location of supply chain, collaborative production planning with 4D and 5D, and model based prefabrication that help achieve the goals of waste minimisation and value retention (and generation). The main focus should be to ensure that rather than creating conflicts and duplicate processes, Lean and BIM tools support each other throughout the construction process.

Use of BIM during the construction stage is fast evolving. An accurate BIM allows for a smoother and better-planned construction process that saves time and money and reduces the potential for errors and conflicts (Eastman *et al*, 2011). The recommended practice is to involve contractors at the design stage, which permits them to provide valuable input early in the project. Tasks such as scheduling, value engineering, construction budgeting, construction document co-ordination, record-keeping and consultations can be performed with the help of BIM used in the pre-construction phase. However, construction companies can also benefit using BIM, even if they were not involved in the design phase, by developing a model in-house with the collaboration of subcontractors and fabricators, or through having a consultant to help create the model. Some of the BIM applications that support the construction process include (Eastman *et al*, 2011):

- clash detection
- quantity take-off and cost estimating
- constructability analysis and planning (through visualisation and 4D)
- integration with cost and schedule control and other management functions
- offsite fabrication
- verification, guidance and tracking of construction activities.

Many contractors are now pushing the boundaries by going beyond the general uses such as clash detection, visualisation and 4D planning. Using BIM to support functions such as model based quantity take off and costing, helps in making the pre-construction activities more efficient. During construction, using laser scanning for accurate as-built model and to compare actual product with design (crucially in refurbishment projects) and using tracking systems to locate material and components, significantly helps during the production management and handover processes.

2.4.1 Model based collaboration

The big room

One of the biggest drawbacks of the traditional construction process is the communication breakdown, especially due to the heavily enforced work breakdown structures that have led to deep subcontracting levels within the industry. Also, due to the geographically distributed teams of designers and other specialist subcontractors who are collaborating using traditional CAD technology, the number of Requests for Information (RFIs) generated during a project is significant. The big room setup, as seen in both the Sutter Health Castro Valley Project and London Underground Victoria Station Upgrade Project (see Figures 2.6 and 2.7 respectively). Also, by using BIM and state-of-the art communication facilities it is possible to bring geographically dispersed members into review meetings.

Figure 2.6 The Big Room during the Construction Phase of the Sutter Health Eden Medical Center project (courtesy Sutter Health, USA)

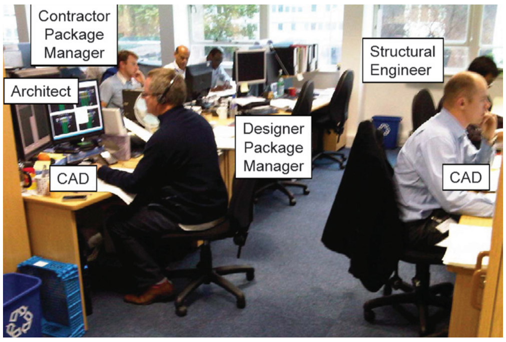


Figure 2.7 The big room at the Victoria Station Upgrade Project (courtesy Taylor Woodrow, BAM Nuttall JV)

2.4.2 Production planning and control with Lean and BIM

Using BIM during site setup and pre-construction

The general contractor's main responsibility is to plan and control the production stage of the project, co-ordinate its execution, and manage the conformance of outcomes. Harnessing BIM capabilities does significantly help contractors carry out detailed planning before the construction phase. However, this does not reduce the importance of planning and control activities during construction, which is one of the major uses of integrated Lean and BIM practices during the construction phase.

The objects in a building model have attributes, and one of the attributes is location. The location of each component is established according to the co-ordinate system. A model in the co-ordinate system offers another dimension to co-ordinate and control work. Information about co-ordinates (xyz) can be extracted from the model and may be used for survey and scanning systems for various purposes (Eastman *et al*, 2011, Tudor, 2010 and McKenzie, 2009). Figure 2.8 demonstrates the use of BIM combined with laser scanning for accurate site setup. Some of the investigated Lean and BIM projects reveal that survey and scanning systems and methods can be used for three main purposes:

- surveying and scanning existing structures and systems. Results can be used to perform BIM modelling (Sacks, 2010)
- extracting information about co-ordinates from the model enables their use in survey and scanning systems for layout and installation works (Tudor, 2010 and McKenzie, 2009)
- quality control by surveying and scanning new structures and systems. The results can be used to compare reality with the planned BIM model (Tudor, 2010).

Collaborative planning and BIM

One of the most important features of any Lean construction project, collaborative planning, is equally important for a Lean/BIM implementation. All successful Lean/BIM projects use collaborative planning throughout the project, including design. When used during design, Last Planner™ helps the development of design in an integrated way, improving the accuracy and reducing waste (both during design and construction). During construction, it provides a vehicle/tool to increase the resolution of production planning and control that improves the predictability of work and reduces waste, when integrated with BIM.

It is possible to exploit mobile technologies such as smartphones and tablet computers during construction to extend production related information to field workers. Some BIM software vendors have now started to develop mobile solutions for Apple™/Android™/Windows™ platforms, which make it possible to visualise the model during construction. Also the use of integrated global positioning system (GPS) devices help identify the location of the construction operator, enabling them the use of augmented reality applications such as the one developed by a BAM Nuttal project team (see box) as shown in Figure 2.8 (although GPS has not been used at the Victoria Station Underground (VSU) project). The VSU project instead used Jet Grout rigs fitted with equipment that enabled data from the model to be used to orientate the machines without the need to re-enter data manually. It is possible to use RFID (radio frequency identification devices) along with GPS tracking to locate incoming supply of material (and other resource such as equipment), locate deliveries on site, and use applications to enable information management in the field.

Both the Castro Valley, California and the Skanska Headquarter, Finland projects used Last Planner™ (or collaborative planning) very effectively during the production management stage of the project to identify process clashes, gain better spatial information about tasks, and to better understand the sequence and tasks in hand. On both projects, a BIM manager/operator was available to navigate and interrogate the model during the planning sessions (look-ahead and weekly). This allowed the project team to visualise the tasks being planned in more detail and better understand the constraints, ultimately improving the 'flow' throughout the project delivery.

The BAM Nuttall, UK project team on the Victoria Station Upgrade project, London, in collaboration with BIM provider Bentley, are hoping to trial a new technology that will take the BIM to the construction team on site. Once fully developed, this will allow elements of the model to be downloaded to a mobile device such as a tablet PC or smartphone. Then, holding the device up to the correct section of site, the model will be overlaid over the image from the device's camera. Combining the virtual model and physical reality will effectively show the previously surveyed services beneath the ground without having to re-expose them. This technique could be used to show where the finished building will stand, and how it interacts with existing structures around it.

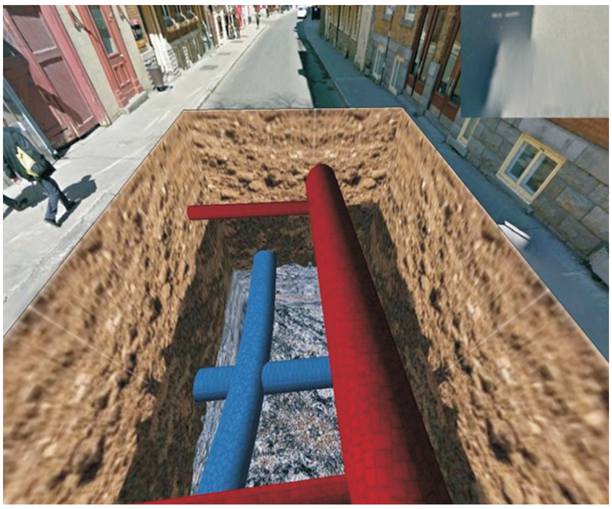


Figure 2.8

Using augmented reality applications to visualise underground services (courtesy Bentley Systems)

2.5 FIT-OUT AND HANDOVER

> Fit-out and handover, and in general the finishing stage of a construction project involve a large number of parallel and sequential activities. The challenges during this stage are to minimise scheduling and space conflicts between workers, ensure minimal waiting time and that the quality is maintained so that there is minimal rework at the end. Through tools such as sophisticated visual tracking and fine grained visual scheduling with Lean and BIM tools it is possible to achieve a smooth and trouble free handover process.

During construction, it is important to monitor the progress of construction works to compare planned activities with work completed to allow the stakeholders to focus on tasks that have fallen behind schedule (Harty *et al*, 2010). This is often complicated in traditional project delivery processes, as communication is based on 2D drawings.

Monitoring can also be used to track material delivery, handovers from design to construction and from construction to client, resources flow etc as different types of information can be attached to objects and visualised in the model (Eastman *et al*, 2011).

> In the Saint Bartholomew's and Royal London Hospital project, hand-held devices (mobile phones, PDAs, barcode readers, tablets) were used to record the information about the actual start and completion of work on site. This information was fed back to the BIM application, and was used to produce a comparative animated model (4D model) showing actual activity on the site over time (Harty *et al*, 2010). These two models were then run in parallel to check actual against planned activity, allowing better communication between project parties.

An emerging trend is the use of Radio Frequency Identification (RFID) technology to link the physical building components with digital information (Eastman *et al*, 2011). It is useful for on-site inspection of work and documentation, real time project progress management, and quality assurance, all of which are important aspects of implementing Lean in construction (Pedersen, 2010). Conceptually, a similar approach is to use barcodes, which can be less expensive, as was done in the Maryland General Hospital project. Barcodes were used for tracking progress of the closeout phase, project handover documentation, and facilities management, where each piece of medical equipment was tagged with a unique barcode as shown in Figure 4.2 in an accessible location, enabling seamless information exchange from field to database and from database directly to field hand-held devices. Figure 2.9 shows the use of laser scanning technologies combined with photogrammetry to provide the client an up-to-date model of the facility.

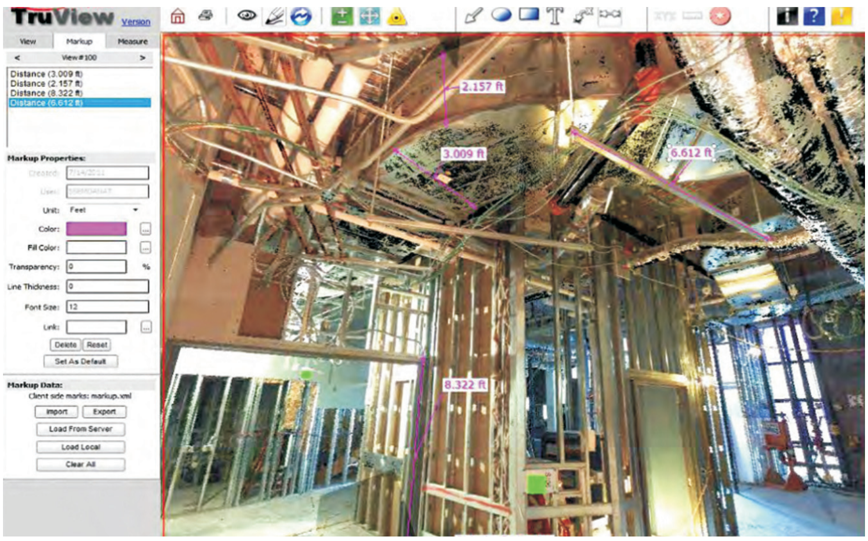


Figure 2.9 ***Giving the client an up-to-date model at the Sutter Health Eden Medical Center project (courtesy Sutter Health, Ghafari Associates)***

> Minimising the loss of original value (set out by the client) and minimising waste in operational and maintenance processes are two key functions served by Lean and BIM during this stage. Through an up-to-date BIM model integrated with the FM system and extended through mobile technologies, it is now possible by the FM teams to access the information and knowledge captured during the design and construction to maximise efficiency.

2.6 FACILITIES MANAGEMENT AND OPERATIONS

In the Maryland Hospital Project, the main objective in implementing BIM for closeout and FM was to create a central database containing closeout documentation and up-to-date asset information including its location. Information related to maintenance and repair calls could be easily accessed and maintained in the field, and assets could be easily located due to better visualisation. This helped to better visualise the FM processes, and improve the response times for maintenance calls (Eastman *et al*, 2011). Maintenance and management of facilities was rendered more efficient, by reducing operating costs and ensuring better operations.

During a construction project, information is generated during each project phase and often re-entered or produced during hand-off between different phases and organisations. Normally at the end of a project, all the as-built information is sorted and archived in boxes, which are then handed over to the client. However, as the information is mostly recorded on paper, this resource is hardly ever used or synchronised with a client's facilities management system. With BIM there is an opportunity to link FM-related information with the building model. This can help better visualise the FM process and improve the response times in case of maintenance calls. Some of the problems that the facility managers have to deal with are:

- life cycle of the equipment not being optimised
- warranty and other product related information not being readily available
- up-to-date inventory of equipment and its location not being readily available.

The resulting processes are quite informal and dependent on knowledge gathered by experienced staff members about the facilities operations over the years. As a result, the asset owners spend considerable resources on FM but do not get the results that are needed.

Here, the BIM process workflow enables recording and delivery of as-built information, which can be linked with facilities management systems and processes. The model has to be developed in sufficient level of detail to ensure that it supports capturing of as-built information (Kymmell, 2009).

3

Enablers, methods and tools

This chapter describes the Lean methods and tools that are used in connection with BIM. Although some of the tools and processes are covered in the previous chapter, a detailed explanation is provided here about key enablers, tools and methods that are important for a Lean/BIM implementation. Tools such as 'the big room' that are described in sufficient detail in the previous chapter are not repeated here.

3.1 RELATIONAL CONTRACTING

Traditional procurement routes and forms, such as design-bid-build (DBB), can be the biggest hindrance to a proper Lean/BIM implementation (or even individual Lean or BIM implementation). Maximising value and minimising waste is difficult when the contractual structure inhibits co-ordination, stifles co-operation and innovation, and rewards individual contractors for both reserving good ideas for themselves, and optimising their performance at the expense of others (Howell, 2005). A partnering approach, as supported by the new form of contracts such as Alliancing, ConsensusDocs, IPD/IFOA (Integrated Project Delivery/Integrated Form of Agreements), has the ability to support integration and collaboration that is inherently required for Lean/BIM implementation. While the new engineering contract does support collaboration it is not as advanced as IPD, which is why CIC/RIBA are exploring the development of a UK variant of IPD. Relational contracts enable an explicit recognition of the commercial 'relationship' between the parties (Colledge, 2005). Responsibilities and benefits are apportioned fairly and transparently, with mechanisms for delivery that focus on trust and relationship. Relational contracts also often provide team-based incentives or reward mechanisms, placing value on successful outcomes, rather than individual performance (Colledge, 2005). Co-location of teams, early contractor involvement, joint development of design and other such crucial requirements are better supported by relational contracting (and not by traditional contracting methods). The Castro Valley (and the Camino) medical centre projects featured both relational contracting and IPD approaches.

3.2 INTEGRATED PROJECT DELIVERY (IPD)

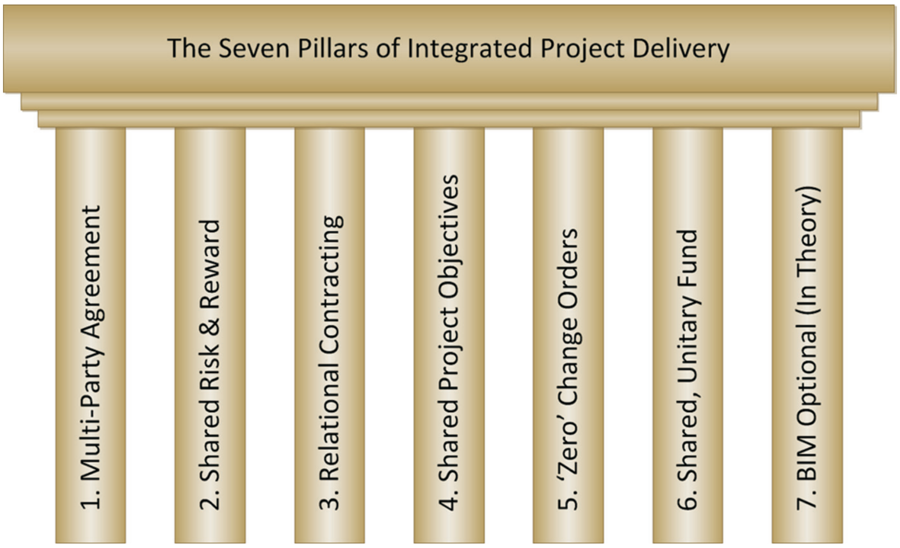


Figure 3.1 The Seven Pillars of IPD (after Spata, 2010)

The American Institute of Architects (AIA) defines integrated project delivery (IPD) as:

> *"a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimise efficiency through all phases of design, fabrication and construction".*

IPD provides an ideal platform and project environment for the integration of Lean construction principles and BIM. There are significant synergies and overlaps between IPD and integrated Lean and BIM, such as the focus on collaboration, waste minimisation and integration. Key features of Lean and BIM, such as early contractor involvement, integrated design and the whole life cycle approach are well supported by IPD. IPD leverages early contributions of knowledge and expertise through use of new technologies, allowing all team members to better realise their highest potentials while expanding the value they provide throughout the project life cycle. However, it is the collaborative structures inherent in an IPD legal agreement, which break down barriers and enable these benefits. Figure 3.1 shows the seven main pillars of the IPD project delivery. BIM is presented as an optional element (as it is considered as a technological tool), but it is considered to be a crucial element in all the projects.

3.3 TARGET VALUE DESIGN

Target value design (TVD) in the construction industry is the practice of constraining design and construction of a capital facility to a maximum cost (Ballard, 2008). On each project there is financial constraint set by the client (maximum available funds or minimum ROI requirements) that the project must meet to be considered successful. In TVD, there is evidence to suggest that a projects' initial scope is completed below market cost, often as much as 19 per cent below, and also that the expected cost falls as design develops. A validation study is essential for TVD, including an analysis of the allowable and expected costs, to thoroughly access business viability. The plan validation study is performed by main members of the team that will deliver the project, if funded. Designing to target costs involves a structured process, including:

1 Allocate the target cost to systems, subsystems and components.

2 Have cost modellers to provide cost guidelines to designers up front, before design begins.

3 Incorporate value engineering/value management tools and techniques into the design process.

4 Use computer models to automate costing to the extent feasible.

Most importantly, in TVD the budget becomes an influence on design and decision making, rather than an outcome of design.

3.4 VALUE STREAM MAPPING

Value stream mapping (VSM) is a tool for documenting all the steps in the workflow that add value to the final deliverable from the perspective of the customer. The team discuss, as they create the map, their understanding of the design, their own work, and how their work connects to the work of others on the team. The team negotiates what they need to produce and at what level of detail so that downstream work can proceed with more certainty. The plan is reviewed on a regular basis. As more information becomes available and as the design evolves, the plan also evolves: new tasks are added, existing tasks are made more specific, and tasks that no longer add value are eliminated. Figure 2.3 shows how the Castro Valley project used process mapping during the design stages to understand the design process in more detail, identify important handovers and ensure a smooth design process. Also, it can be applied to later stages of the construction project to ensure a collective understanding and to eliminate any ambiguities in the process.

3.5 SET-BASED DESIGN

The concept of set-based design involves a simple idea: designers should consider sets of alternatives from the start of the design process rather than developing one alternative in detail. The conventional model, named point-based design by Ward *et al* (1995), is characterised by its sequential process. Based on a single design option, the designers proceed step by step in an iterative way until the feasible solution is defined. The sequential nature of the point-based design usually impedes effective collaboration between project participants, as well as reducing value added for the project. For instance, stakeholders situated downstream in the process, such as fabricators, contractors or subcontractors, get involved only later on the process. So their expertise is neglected at the beginning of the design leading to sub-optimal results, besides the waste created from design amendments resulting from late involvement.

In contrast, set-based design is a process in which the designers, along with a cross-functional team, start it by considering several design alternatives. These are then narrowed down gradually to a feasible solution as they get the necessary information to make a decision. According to Ward *et al* (1995) Toyota's engineers and managers seek to delay decisions until the last responsible moment, so the approach is viewed as a funnelling process. Liker (2004) points out that the consideration of a broad range of options at the beginning of the design process aims to avoid missing better alternatives by sticking to a decision early on. As stated by Parrish *et al* (2007), this approach seeks to maintain the design space as open as possible for as long as possible.

Ballard (2008) summarises set-based design, arguing that:

> *"the basic idea is to apply all relevant criteria in producing, evaluating and choosing from design alternatives from the beginning of design, rather than introducing new criteria as new stakeholders come onto the team. This implies that all key stakeholders, upstream and down, such as architects, engineers, general contractors, speciality contractors, regulatory agencies, and perhaps even suppliers become members of the design team".*

Finally, it should be mentioned that this approach offers significant opportunities for collaboration of project participants across the supply chain (Parrish *et al*, 2007). Although facing some cultural barriers and organisational issues, the implementations of set-based design in building projects has presented good results, as well as promising opportunities for improvements (Ballard, 2008).

3.6 CHOOSING BY ADVANTAGES

According to Suhr (1999) choosing by advantage (CBA) is a decision making system in which the significance of the advantages must guide decisions. Parrish and Tommelein (2009) describe CBA as “a system that considers advantages of alternatives and makes comparisons based on these advantages.”

CBA comprises methods for making decisions, from very simple to extremely complex (Suhr, 1999). By using sound methods, practitioners can make better decisions that will guide their actions, and produce improved outcomes. The main CBA principles as presented by Suhr (1999) are shown in Table 3.1.

Table 3.1 Choosing by advantages (CBA) main principles

The pivotal cornerstone principle	To consistently make sound decisions, decision makers must learn and skilfully use sound methods of decision making
The fundamental rule of sound decision making	Decisions must be based on the importance of advantages
The principle of anchoring	Decisions must be anchored to the relevant facts
The methods principle	Different types of decisions call for different sound methods of decision making

The CBA system presents several phases, ranging from the stage-setting phase, an innovation stage, the decision making phase and the implementation phase. For detailed information on CBA use in construction, see Parris (2009) and Parrish and Tommelein (2007).

3.7 A3

A3 is a relatively new addition into the Lean toolbox. The name refers to the paper size of A3. The basic idea is to document a problem solving process in a standardised way on one sheet of A3 paper. The method can be used for presenting a proposal or reporting a project status. The A3 method connects extremely well to other features of Lean. The format of an A3 document corresponds to the PDCA cycle. It requires systematic, disciplined and fact based approach. The method promotes collaboration and communication among all who have a stake or contribution to make in problem solving. Given its effectiveness to help continuous improvement, the method has rapidly diffused in the West after its introduction into publications in 2008 (for example, Sobek and Smalley, 2008). Through BIM it is now possible to include intelligent model based views in an A3 document.

3.8 THE LEAN/BIM MATURITY MODEL

Figure 3.2 shows the BIM maturity model that was developed by NBIMS (US National BIM Standard, Version 1) and adapted by the University of Salford in a project with Manchester City Council. The main benefit compared to the other BIM maturity level models is that the more granular model helps organisations to identify the weak areas and improve their skills in the areas, which are critical for achieving the organisational and project goals. The BIM maturity model has been provided as any Lean and BIM project will involve a significant BIM implementation effort. The BIM maturity model will help organisations identify where they are in their individual BIM journey.

On a collaborative Lean and BIM project, it may be useful to carry out a collaborative review of each stakeholder’s BIM capability to develop an informed implementation strategy along with identification of training needs. However, this model is applicable for BIM implementation and does not sufficiently cover the process aspects, which are crucial in implementing Lean. So, a Lean and BIM model has been provided to help guide the organisations in developing their strategy and identifying progress.

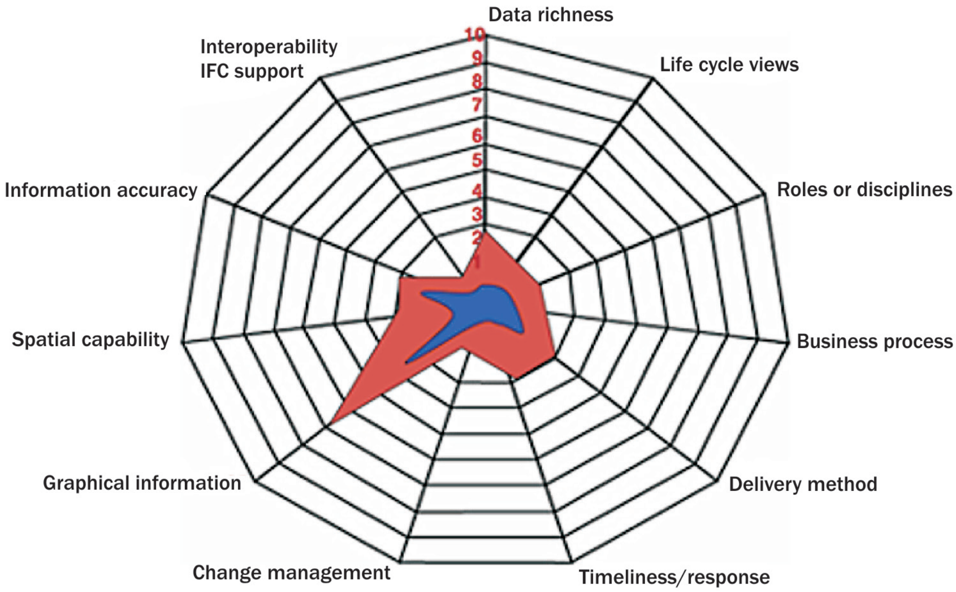


Figure 3.2 BIM maturity model

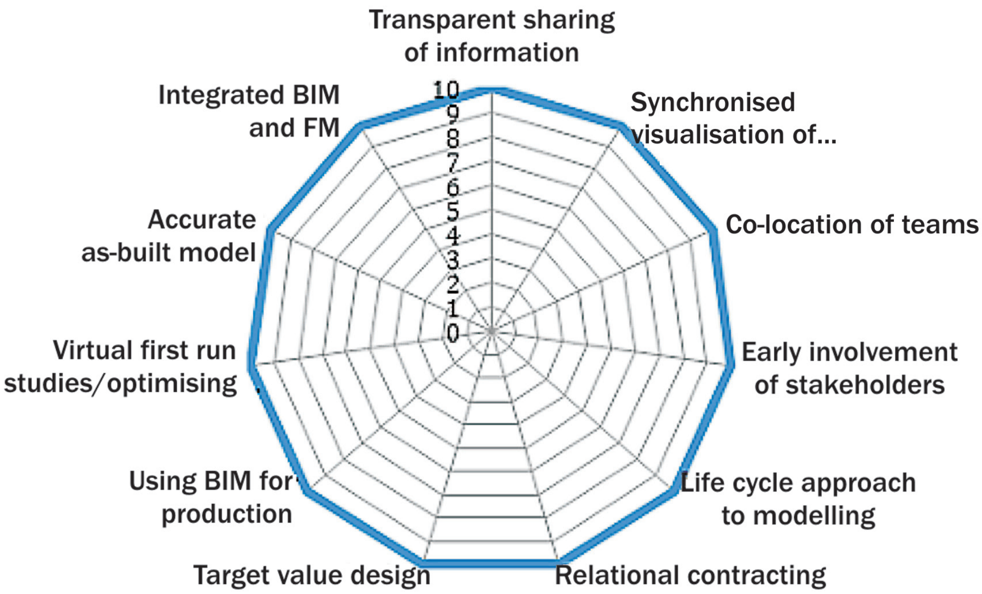


Figure 3.3 Integrated Lean and BIM maturity model

3.8.1 Explaining the Lean/BIM maturity model

The University of Salford has developed a maturity model for Lean and BIM (Figure 3.3). This model helps to assess the project's Lean and BIM implementation against the 10 identified main criteria and explained as follows. It is important to note that not all projects will have adopted these main elements right from the beginning, and their adoption can improve as organisations become more familiar with the concept. Also, the maturity model is provided as a guidance or framework, and more factors can be added to suit the nature of individual organisations, ie client, contractor or designers. The maturity model encapsulates some of the tools described in the previous section within the core processes represented in the model. The tools themselves are not represented as it is understood that organisations may use different or more than one tool (and also use different terminology), so the focus is rather on the core functions:

- **transparent sharing of information:** this is one of the key features of the maturity model and an absolute necessity during all stages of the project. It means that the model will be available to all relevant members of the supply chain and information will be shared between members freely. The goal is zero RFIs and improved accuracy of design and production

- **synchronised visualisation of models:** rather than working in the silos, this refers to a process where designers identify key handover stages and meet regularly to synchronise the models and resolve any issues arising. This will eliminate/minimise conflicts and rework, and improve the quality of design. During the construction phase, using synchronised models will ensure that all stakeholders have a common understanding of the project and help minimise errors
- **co-location of teams:** a method of significantly shortening the response times, reducing waiting and re-work as well as improving information sharing, especially related to the tacit knowledge
- **early involvement of stakeholders:** one of the main features of Lean and BIM projects, is to involve main contractors, specialist subcontractors and important user groups during design to efficiently capture the design intent, compare alternatives, predict the costs and to take into account constructability issues in design
- **life cycle approach to modelling:** ensuring the model is developed to the right level of detail and also has sufficient information to support building operations
- **relational contracting:** although Lean and BIM has been and can be applied without relational contracting (such as IFOA), it is strongly advised that client select this method of delivery rather than selection on basis of the lowest bid. It is well proven that Lean and BIM implementation prosper under this arrangement as all parties are working towards achieving a common goal of delivering the project as efficiently as possible and have appropriate incentives to do so
- **target value design:** using budget as a main parameter of design (target value design) is one of the key aspects of Lean design
- **using BIM for production management:** this is also one of the core features of the Lean and BIM implementation and is one of the core requirements. Using BIM beyond design and clash detection, especially to support collaborative planning is vital for the project success
- **virtual first run studies/optimising construction process using BIM:** by simulating the plan at a fine grained level will ensure that the plans are free of any process clashes and help optimise the sequence of programming. As demonstrated on the One Island East project (Eastman *et al*, 2011), optimising construction process using discrete event simulation can be highly beneficial in optimising the complex construction projects
- **delivering accurate as-built models:** as demonstrated by the Maryland General Hospital case study (Eastman *et al*, 2011), delivering an accurate as-built model means that the operational and maintenance teams can use the models to extract crucial information throughout the life of the asset leading to much better building performance
- **integrated BIM and FM:** integrating FM system with BIM will ensure that the FM team can respond in a much better way to maintenance and repair operations. As demonstrated by the Maryland General Hospital case study (Eastman *et al*, 2011) it is possible to integrate detailed information about assets within the BIM, which will help the FM team efficiently manage a building. Also, it would make operation more automated and/or intuitive.

4

What steps need to be taken to adopt Lean and BIM?

This chapter will answer the following questions:

1 An organisation is already pursuing Lean and BIM separately, so does this mean that they are already pursuing integrated Lean and BIM?

2 What steps will an organisation need to take if it wants to adopt integrated Lean and BIM?

3 Are software packages to implement Lean and BIM available to purchase 'off the shelf'?

4 Should a consultant be hired or should it be carried out internally?

5 Is it just about technology?

4.1 TAKING THE FIRST STEPS IN INTEGRATING LEAN AND BIM

Do not let it become overwhelming

If starting afresh on the Lean and BIM journey, it is possible that some of the tools and techniques are overwhelming and it may be better to start from a small pilot project, where selected/prioritised tools can be implemented from the ones outlined in Chapter 2. Almost all the BIM implementation plans suggested by leading authorities support the notion of starting from a small pilot. The key is to devise a benefits realisation plan (see Smith, 2013) at the start to outline what the aims of implementation are, and whether the project environment is conducive for that. Although there are a large number of technological and process tools (as outlined previously) there are three important enabling factors for a Lean and BIM implementation:

1 Supporting collaboration across the supply chain.

2 Ensuring information availability (24/7).

3 Taking a life cycle approach.

It is important to start with learning the main concepts about Lean and BIM – if necessary by appointing a consultant (see Fraser, 2013). There are currently many companies going through BIM adoption, and some who have adopted Lean construction. Although not all organisations would wish to share competitive knowledge, it is possible to learn from them through network events and industry groups. There are also Lean construction communities keen to spread understanding and help others to adopt Lean.

Chapter 3 outlined a range of tools and techniques to support a Lean and BIM project. Conceptually the interactions between Lean and BIM are many and they should be exploited to the maximum. Sacks *et al* (2010) identified 56 interactions, using a matrix that juxtaposes BIM functionalities with prescriptive Lean construction principles, and all but four interactions were positive. Construction executives, managers, designers and developers of IT systems for construction can benefit from the framework as an aid to recognising the potential synergies when planning their Lean and BIM adoption strategies. A small sample of the findings is shown in Table 4.1 and further reading can assist with understanding of where an organisation is currently in terms of integrating Lean and BIM.

Table 4.1 Sample of the interactions of Lean and BIM (from Sacks et al, 2010)

	Explanation	Evidence from practice and/or research
Achieving user needs	Due to better appreciation of design at an early stage, and also due to the early functional evaluation of design against performance requirements (such as energy, acoustics, wind, thermal etc) the quality of the end product is higher and more consistent with design intent. This reduces variability commonly introduced by late client-initiated changes during the construction stage.	Eastman *et al* 2008 Manning and Messner, 2008
Avoid incomplete information and clashes	Building modelling imposes a rigor on designers in that flaws or incompletely detailed parts are easily observed or caught in clash checking or other automated checking. This improves design quality, preventing designers from "making do" (Koskela, 2004) and reducing rework in the field as a result of incomplete design.	Dehlin and Olofsson, 2008 Eastman *et al*, 2008
Visualisation	Building systems are becoming increasingly complex. Even trained professionals have difficulty generating accurate mental models with drawings alone. BIM simplifies the task of understanding designs, which helps construction planners deal with complex products.	Eastman *et al*, 2008
Communication and stakeholder consultation	As all aspects of design are captured in a 3D model the client can easily understand, the requirements can be captured and communicated in a thorough way already during the concept development stage. This can also empower more project stakeholders to participate in design decision making.	Eastman *et al*, 2008 Manning and Messner, 2008

4.2 BALANCING PEOPLE, PROCESS AND TECHNOLOGIES

A Lean and BIM project is people- and process-oriented, where BIM as a technological platform acts as an enabling tool. So it is important to strike a balance between people, process and technological issues. It is well understood through previous experience that in any technology adoption project, the balance between people, process and technology is almost 40–40–20 as shown in Figure 4.1.

4.2.1 Process issues

As stated earlier, BIM and Lean construction are both deep process changes and although they are each quite different initiatives they can yield greater results when adopted in an integrated manner. A significant number of processes will be affected through a Lean and BIM implementation. So, it is better to implement such an initiative in a strategic way through a business change programme rather than taking a piecemeal or project-based approach. To do otherwise, although not impossible, is to substantially miss cross-project learning and so create significant hurdles to continuous improvement.

4.2.2 People issues

As this change affects the entire business, buy-in by the senior level team and sponsorship by a Board level 'champion' is very important. Also, it is crucial to understand the supply chain implications, as collaboration with the entire supply chain is one of the main success factors in a Lean and BIM implementation.

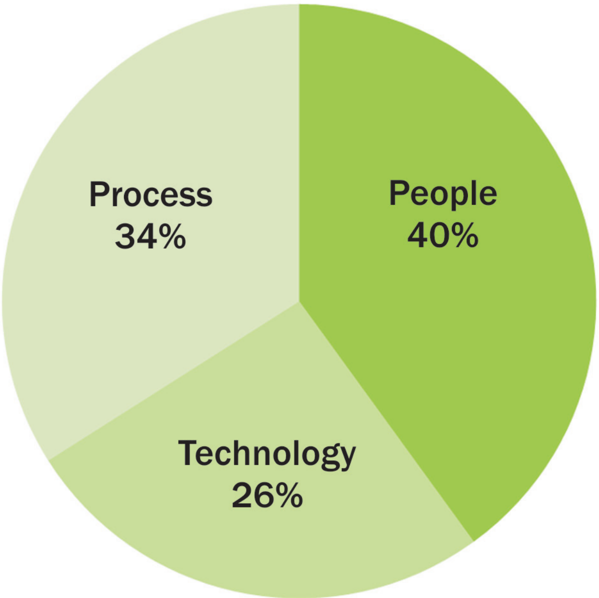


Figure 4.1

Importance of balancing three organisational pillars (from Shelbourn et al, 2007)

4.2.3 Technological issues

While technology has helped the adoption of BIM, it is the processes of implementation and their tailoring to the individual enterprise, which are important, and not the adoption of technology per se. BIM software can provide the toolset for implementing BIM, such software will not define the necessary processes to do so, let alone tailor them for any specific organisation.

4.3 LEAN AND BIM ADOPTION STRATEGIES

> Some examples of BIM implementation guidelines include Eastman *et al* (2010), Hardin (2009), and Smith and Tardiff (2009). Some examples of BIM maturity and capability models include B/555 BIM Roadmap (BSI, 2012), NBIMS BIM Maturity guideline (USA), CRC for Construction Innovation (Australia), and CIC research programme (Penn State, US).

Adoption strategies are context specific and depend on several factors including the type of organisation, supply chain structure, project type (building, infrastructure) etc. Any strategy must be based around the culture and business needs of the organisation/project/supply chain. From these, it is possible to prioritise processes, tools, methods and technologies that should be selected for adoption. Several BIM implementation guidelines exist along with capability maturity models that help organisations decide the best way forward to implement BIM and also to help identify where they are in the journey.

These BIM implementation plans share some common and important points:

1 Appointing a top level champion and a team.
2 Take the process and people view and select technologies to support them.
3 Start with a pilot project(s).
4 Develop an integrated process workflow with BIM and key organisational processes.
5 Taking a life cycle view.

At the organisation level, the key is to develop a core Lean and BIM strategy that will identify the business processes that will be affected and ensuring the relevant managers are on-board the new initiative. Also, it is important to identify training needs for the internal Lean and BIM team and also for the supply chain. The following describes the high-level implementation strategy:

- identify the main areas of focus for the organisation, for example collaborative planning and 4D planning

- create an adoption roadmap
- develop a standard that is an adaptable Lean and BIM project approach
- develop guidance for project implementations
- identify main success factors and aims for implementation of the roadmap in the organisation.

Section 4.3.1 provides guidelines for adopting Lean and BIM, however it should be noted that each organisation would take a different path according to their existing competencies, role, and supply chain.

4.3.1 Appointing a Lean and BIM champion

As with any substantial business change programme, it is important to appoint a senior level champion who is enthusiastic and knowledgeable in the subject area so that they can take it forward within the organisation. Ideally the champion should be a senior member of the organisation who is familiar with either Lean or BIM. The role of the champion should be to understand the business opportunity and its costs, risks and contribution, gaining support from their fellow Board members for any investment required, and ensuring that the strategy is deployed through the organisation. At the project level it is important to appoint internal operational champions – ideally project managers and site managers who will lead the project and co-ordinate with the supply chain.

While the senior champion would not need to be able to operate BIM on daily basis, they should at least be capable of understanding its risks and opportunities. The operational/project champions need to understand Lean and BIM in more detail.

Some main contractors in the USA such as Mortensen and DPR and in Europe, Skanska are now employing architects within their teams to interpret the design BIM into a construction BIM, and providing them with the responsibility to oversee the development of the project BIM implementation plan and supervise its use.

4.3.2 Training the team

The next stage is to provide training to the Lean and BIM champions and the project team to get them up to speed with the principal concepts and also to help identify what key tools should be used on the project.

The project team will also require training to an appropriate level. It will be important to establish what that level is, depending on how far along the adoption path the organisation is at any particular project implementation. There are risks in having team members at different levels of expertise (see the box in Section 4.3.5 on risk analysis).

While training the core team on Lean concepts is not apparently challenging, getting people to understand the underlying principles and motivating them may well require some mentoring, particularly through early projects.

Training for the use of BIM through project life cycle is more varied, depending on the role of the individual. Not everyone needs to understand how to drive a BIM model. However, all team members need to understand what is contained in the model, as it affects them, how to extract that information, and how to have it updated for an as-built/handover model. Also, of particular interest for UK Government funded projects is the use of COBie, and the handover of information (called data drops) needed from each stakeholder at relevant stages.

4.3.3 Setting up a pilot project

The earlier that Lean and BIM is mandated on a project, the more value to the project team can be provided. Top management (ideally the Board champion for Lean and BIM) should endorse such an approach and appoint a project champion, with operational champions provided by each project team organisation.

Pilot projects are a relatively low risk strategy for on-the-job learning, provided the aims are within the capabilities of the project team. Select the right project in terms that it will help develop overall skills, capabilities and advance process consolidation, rather than starting a business change programme from scratch on a project. To start with, send key champions/staff members to Continuous Professional Development (CPD) courses and train them on basic BIM and Lean principles. For Lean construction, initially concentrate learning on collaborative planning, Lean site setup and visual management. Refer to CIRIA C730 (O'Connor and Swain, 2013) for more details. For BIM, gain an understanding of basic BIM applications, such as clash detection, visualisation, 4D planning and quantity take-off. As this is a growing field, the industrial practice and academic understanding are still growing about how to implement Lean and BIM but the field will grow rapidly on the back of the UK Government initiative.

4.3.4 Selecting the technology platform

No single BIM software package can fulfil all of the needs of a project for design, simulation, construction, handover and operation. Some factors to consider in selecting the most appropriate technology are:

Costs

- of supporting each BIM function/operator, including:
- software seat licence (and portability, eg across time zones)
- cost and location of hardware (servers, workstations, laptops, displays etc)
- cost of training (including any need to retain consultants)
- cost of maintenance.

Risks

- compatibility across the supply chain
- development of data/information exchange agreements among stakeholders/supply chain
- software maturity and support
- availability of competent operators.

Opportunities

- compatibility with other software/functions
  - project management/planning and scheduling system
  - simulation
  - model checking
  - quantity take-off
  - life cycle support/FM and operations
  - model sharing (and project information management) platforms
  - mobile technologies.
- leveraging the use of mobile computing
- field-based task management.

Losses in data and information transmission can be avoided by allowing direct access to shared project information through project extranets or similar platforms.

4.3.5 Risk analysis

With any business change programme there will be risks, whether in the use of novel technologies, tools or processes, or in the change plan execution, including staff and partner buy-in. Initial learning can be planned but there is also the risk of downtime if the team has to be trained mid-project. Also, with Lean and BIM there are the risks of differential knowledge, whether one element of the project team knows more than the other or both sides misunderstand what they are capable of. This is illustrated in the first BIM lawsuit, as described in the box here.

Commercially, there is a perceived risk in sharing information through collaborative planning and design. This perception seems to reduce over time as true collaboration is practiced, whether or not a formal IPD contract is used. IPD specifically sets out to set-up a structure where information sharing is the norm and perceived to be in all the participants interests. In this case productivity is increased and risk reduced.

> During construction of a life-sciences building at a major USA university in 2011, the architect and their MEP engineer used BIM to efficiently design the MEP systems into the ceiling plenum. When the contractor was about 70 per cent through assembly, they ran out of space in the plenum. It came to light that the design team failed to inform the contractor that the extremely tight fit of components depended on a specific installation sequence. In the end, everyone sued – the contractor sued the owner, the owner sued the architect, and the insurance carrier sued the MEP engineer.

BIM should be used at an appropriate level of detail for the purpose of the particular model (eg architectural, MEP or façade), rather than everything being modelled, causing data and information deluge. Because separate or, at best, federated models are the norm, care should be taken to avoid data duplication and a model checker should be used to ensure coherence.

No single BIM software solution can perform every task and so compatibility between solutions and systems should be understood. Where clients require model support for many decades, information and data longevity might need to be considered in terms of who will support and transition information to future versions of software applications and even operating systems.

Data is often entered for a specific purpose and extracted for a different use, so accuracy of information while performing simulation or other tasks, such as model based quantity take off, needs to be understood.

4.4 ORGANISATIONS PRACTICING EITHER LEAN OR BIM

4.4.1 Organisations using Lean but not BIM

Few organisations in the UK are employing just Lean construction and not BIM, despite Lean construction having been deployed earlier. However, such an organisation would be familiar with concepts such as collaborative planning, value stream mapping and visual management. To adopt BIM, it is important to start learning basic BIM applications such as visualisation, 4D for production planning and control, model-based estimating etc. Some of the most popular tasks that BIM is used for are shown in Figure 4.2.

4.4.2 Organisations using BIM but not Lean

There is a rapidly growing number of companies adopting BIM and some are becoming proficient in using BIM for project process improvement and collaboration. As stated previously, when BIM is combined with Lean construction, benefits multiply. BIM-only companies would be familiar with concepts such as visualisation, clash detection, 4D planning, model-based quantity take off etc. To take the first steps in Lean construction is probably less technologically challenging but more challenging in terms of having to get a wider group of people to really understand what can be achieved and how. Early adoption can encompass collaborative planning,

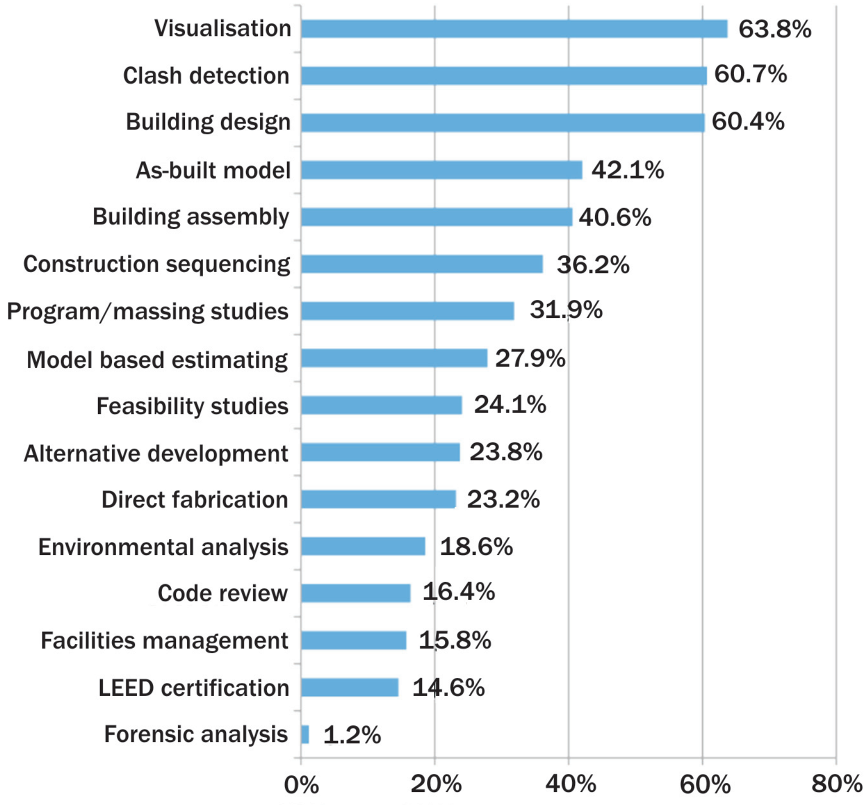


Figure 4.2 Most popular tasks for which BIM is used in the USA (from Becerik-Gerber and Rice, 2010)

Lean work structuring, visual management, first run studies and value stream mapping. Refer to CIRIA C730 (O'Connor and Swain, 2013) for more details.

For organisations already proficient in BIM, it is recommended to promote the Board BIM champion to become the Lean and BIM champion and then appoint a Lean manager/consultant to:

- train BIM operational champions in Lean construction methods
- start using BIM more collaboratively (if not doing so already)
- graduate over time to advance Lean and BIM tools such as model based prefabrication (automated fabrication a section of the model is sent directly to fabrication machines), just-in-time delivery and tracking through BIM, safety analysis, and accurate as-built modelling.

4.5 CONTINUOUS IMPROVEMENT

An often missed opportunity of project-based change in the construction industry is to ensure that there is a knowledge capture and reuse system in place so that hard won experience can be spread across the organisation and to main collaborators. This doesn't have to be complex and at is simplest could be several briefings from those with the experience to those who need to know.

Lean is heavily based on experimentation and improvement at the production level. Using BIM with Lean construction is an area that is yielding opportunities for innovation and differentiation. Not all applications have yet been developed, so being open to innovation is important. Leading organisations are now deploying collaborative knowledge management techniques that help capture knowledge from ongoing projects and enable continuous improvements (Dave and Koskela, 2009). Continually capturing knowledge and lessons learnt from the pilot projects (ie what does and does not work) and improving the organisations' process approach before rolling it out and testing it on the next project is crucial. The emphasis is to refine and re-implement the core idea to improve the efficiency of the process, and extending knowledge to the core supply chain partners.

5

Key considerations for clients, contractors and designers

This chapter will answer the following questions:

1. What are the main features that should have focus in a client organisation?
2. For a main contractor, the focus is on making sure that they respond to client requirements and keep the project on schedule and within budget. How do Lean and BIM help?
3. For a subcontractor, these are considered expensive technologies that may be unaffordable, so how can they ensure not to go over budget?

5.1 CLIENTS

Out of all organisation groups, clients are the biggest beneficiaries of Lean and BIM implementation. In the main case studies reported and observed by the authors, clients in most cases are also the organisations who are leading the change in this area.

The main consideration for the client when looking to select the right tools, processes, partners and contracting structure is to keep an eye on the 'big picture' and long-term benefit rather than short-term gains and keeping the costs down in the projects. As discussed in Chapter 2, the total construction cost of a project is a very small fraction of the overall life cycle maintenance costs, which in turn is a fraction when compared to the organisation's operating costs (ie staff salaries etc). So it is important to define and deliver value to the ultimate end users of the building during design and construction. In this context, using appropriate procurement methodologies, which support collaboration and enable all stakeholders to be involved in the project right from the start, is essential.

This is one of the main aims for selecting a best value service provider (ie designer, contractor) rather than going for a cheapest option, and selecting a relational contracting mechanism such as IPD that helps realise this value. In the UK, clients such as the Highways Agency, BAA, Manchester City Council and the NHS are leading the way in terms of collaboration with supply chain and Lean and BIM implementation. Owners can realise significant benefits on projects by using BIM processes and tools to streamline the delivery of higher quality and better performing buildings (Eastman *et al*, 2011):

- increased building performance
- reduced financial risk associated with the project
- shortened project schedule from approval to completion
- reliable and accurate cost estimates
- assured program compliance
- optimised facility management and maintenance.

Some of the key aspects for consideration for the clients while implementing BIM and Lean are:

- selecting the right project contracting structure (ie partnering or IPD type contract)
- selecting contractors based on their Lean and BIM capability rather than low price
- BIM enabled tendering process
- understanding model IPR requirements and establishing ownership of the model for life cycle use
- appointing a BIM champion
- early contractor and supply chain involvement
- identifying the main users of the facility and including them in main decisions for an effective use of the as-built model.

In an integrated BIM and Lean project, a combination of good process definition with well-defined deliverables creates a workflow that benefits the owner and drives best practices. In developing BIM requirements, care is needed so that the requirements are neither too broad, leading to outcomes that will not meet expectations (eg 'use of BIM software is required by the architect'), nor too narrow (eg Revit should be used by the design team to model and co-ordination carried out by Solibri) as the outcome could be increased liability by the owner and a narrow interest by design firms to propose their services.

The owners need to be provided with a combination of the designers', contractors', and building product manufacturers' BIM models, with diverse types of information about a building. An owners' BIM can serve not only as a virtual model but also as a database containing information about a buildings space, equipment, furnishings, installations, and critical warranties in graphical and non-graphical format (Reddy, 2011). The challenge is that this is not always the case, as the industry struggles with limitations in standards and software.

The BIM model could potentially serve as an electronic version of the owner's manual, with critical information about a building, where information is accessible and easily retrievable. For instance, during the maintenance of refurbishment program, the facilities manager can click on an equipment to find information on product, warranties, life cycle, maintenance period, replacement cost, who installed the product etc. The owners BIM database could also be linked to FM software (eg IBM's Maximo) for control and scheduling of any kind of maintenance on the equipment.

> Clients may not want to dictate the means and methods for contractors and designers to execute their scope, but should dictate the data that they will require to support the life cycle use of the facility at the handover and other important stages of the project.

In the case study of Maryland General Hospital as described in Eastman *et al* (2011), the contractor Barton Malow used a selection of BIM and field based mobile computing technologies to capture information about medical equipment and systems during the fit-out stage. The information was captured using barcodes and hand-held tablet computers, which had integrated barcode reader. The BIM that was synchronised with this information was then linked to the clients' FM system and handed over to the client along with hand-held computers once the project was completed. Figure 5.1 shows a barcode tagged to equipment that is then scanned in the field. Figure 5.2 shows the information about an asset captured and linked in the BIM model that can then be linked to the barcodes.

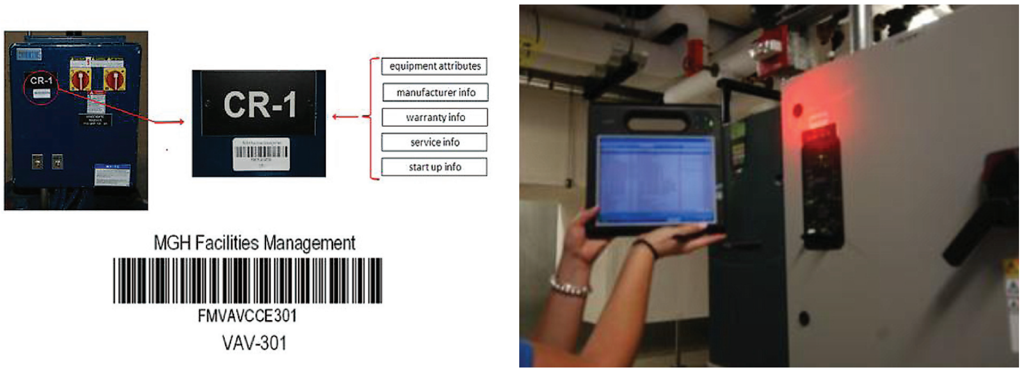


Figure 5.1 Use of barcodes to capture asset information at Maryland General Hospital

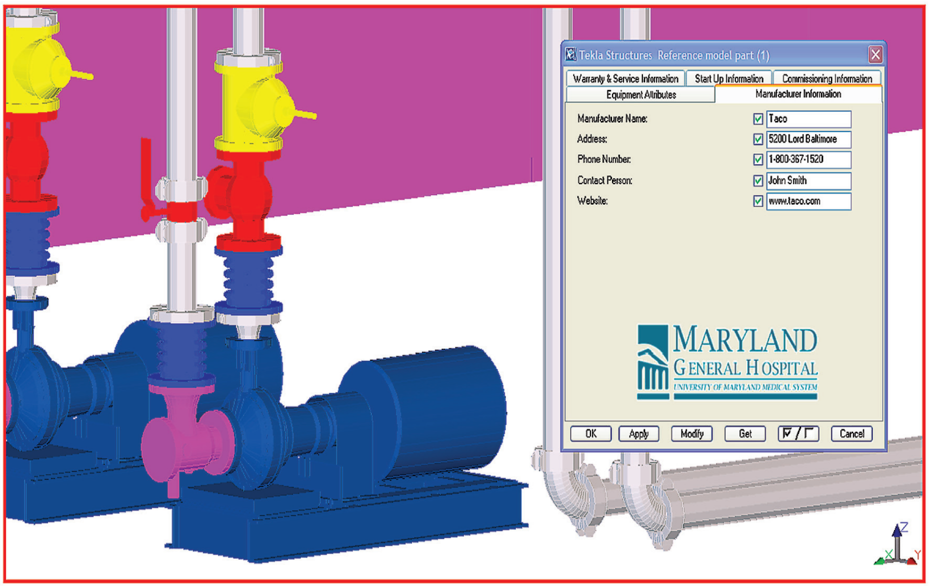


Figure 5.2 Integrated facilities management information in BIM

5.2 CONTRACTORS

Contractors are set to gain significantly from an integrated Lean and BIM implementation, especially through efficiency gains, even though BIM was traditionally believed to be a designer's tool. Use of BIM during production management and also during the closeout stages of the project considerably helps contractors to keep the project on-schedule and within budget.

As discussed in Section 4.1, the key for success in any project is early involvement of the supply chain including main and subcontractors. However it is understood that this may not be possible in all contractual situations. Many leading contractors such as Skanska, DPR (USA), Balfour Beatty and others have started to develop BIM models for their own use even if it is not mandated on the project.

Barton Malow, with help of specialist subcontractors, developed their own BIM models for use during construction and fit-out process on the Maryland General Hospital project, even when the use of BIM was not mandated by the client (Eastman *et al*, 2010). This helped them track the progress of work and visualise the workflow and status during fit-out of medical equipment. Many such examples are now emerging.

5.2.1 The need for a BIM manager/co-ordinator

Also, another very important aspect is to have a BIM manager. This can either be a dedicated position or someone who is trained in BIM technology from the project team, to help manage the models on the construction project. From a Lean and BIM perspective, it is recommended to have the BIM manager trained in Lean processes to make the whole process more efficient.

> Skanska now has a policy to appoint a BIM co-ordinator on all their major projects in Finland (a BIM co-ordinator was also appointed on their headquarter project). Skanska has identified main functions that the co-ordinator will serve:
>
> - co-ordinate with designers during the design process to ensure the correct use of Skanska libraries, templates and design guidance (on a project where design is in scope)
> - perform model auditing to ensure it is up to Skanska's requirement
> - kick-start and attend design and modeling meetings
> - capture and manage knowledge being generated during the project and share it across the team.

5.2.2 Level of detail

The level of detail needed from BIM depends on how the contractor wishes to use it on the project. The design models they receive will not necessarily support the Lean and other construction management operations the contractor wants to use them for. So it is important to communicate these requirements early to the designers or to ensure that the contractors develop/extend their own models to support the functions. Some of the main functions a contractor may wish to use the model for are:

- collaborative planning with BIM
- to check the dimensional accuracy of the design as well as the 'as-built' structures
- clash detection
- first run studies
- model based quantity take-off
- safety analysis
- fit-out and handover tracking
- offsite fabrication.

5.2.3 Involving the supply chain

The Lean construction process puts a significant emphasis on the collaboration aspect. Also, collaboration and model sharing is equally as important from BIM point of view. So, it is important to make the models available to all main subcontractors on the project. Also, where possible it is recommended to involve the specialist subcontractors in the design meetings to capture their feedback to design (see Section 2.3.5).

5.2.4 Considering field technologies

Mobile workstations and hand-held devices

On the Marie Curie Medical Centre (Chicago) project, Mortensen designed a special self-contained mobile workstation (installed on a trolley) that could run the Building Information Models required on the project. This workstation was made available to work crews who could interrogate the model to get up-to-date information. The on-site BIM manager ensured that the models were kept up-to-date. Use of tablet computers such as iPad and others and smart phones are also increasing on the construction project. Many BIM software providers such as Bentley, Autodesk and Tekla have released mobile viewers for their main BIM offering on such platforms. The uses of such devices is set to increase as more providers release sophisticated versions of their field applications, taking the use beyond just visualisation. It is also possible to use devices such as from Motion Computing, which feature integrated barcode scanner (and optional RFID scanner). This allows contractors to use full BIM applications in the field and use the integrated scanners for various functions such as material tracking, component fit-out and snagging.

Using smart-boards and virtual collaboration platforms

Collaborative planning is important for any Lean and BIM project. It is strongly advised to have all key members of the team taking part in the BIM enabled collaborative planning (look ahead and weekly) meetings. However, it may not always possible for all the members to be present and using technologies such as SmartBoards and virtual collaboration platforms provides all members (physically and virtually present) of the team to visualise the model collaboratively and interact with it.

Long-term strategy and continuous process improvement

One of the key principles of Lean construction is continuous process improvement that is very strongly linked with problem solving and knowledge management. It is well understood and known that construction projects bring a temporary project organisation together. Those members may move on to new projects once the current project is completed, taking with them the knowledge gained. It is important to capture knowledge gained about Lean and BIM and reuse it in other projects. Having predefined knowledge capture processes and a dedicated team of Lean and BIM co-ordinators will help achieve the task of knowledge management and continuous improvement more efficiently.

5.3 DESIGNERS

Designers can achieve diverse benefits from the implementation of Lean and BIM. Such benefits will start from efficiency and performance gains, which are internal to the design office, leading to increased competitiveness, reduced costs and better value creation for clients. There are many design offices around the world adopting what is referred to as 'lonely BIM' to tap onto productivity gains and also be able to offer better services, even when the benefits of integrated, collaborative BIM are not possible at the specific project.

One main consideration for the designers is related to the concept of integrated processes, which involves the ability to share and use data between team members of the same discipline and also the ability to share and use data between members of different disciplines. So, designers do need to consider the appropriate means and protocols to enable such data sharing, internally at the office and externally with other design offices and businesses.

Also, consideration needs to be given to the different possible ways to apply BIM, eg through the use of a single platform or through the use of Open BIM. This is a universal approach to the collaborative design, realisation and operation of buildings based on open standards and workflows. Open BIM is an initiative of buildingSMART and several leading software vendors using the open buildingSMART data model. It is widely recognised that Open BIM is the best way forward for enhanced collaboration between the supply chain.

SmartBIM solutions have proposed distinct phases for the adoption of BIM, which are shown in Figure 5.3.

In Figure 5.3, Phase 1 replicates normal processes across the industry, however efficiency gains are achieved by working faster. It represents lonely BIM, and involves considerations for office based work processes and office based data exchange protocols. Phase 2 involves the re-organisation of existing processes as well as the introduction of new processes, such as the appropriate use of thermal analysis in early design. Phase 3 reflects new business processes and the redefinition of the value systems across a project so that it can be leaner and more cost effective. At this integrated level, roles and responsibilities will also change.

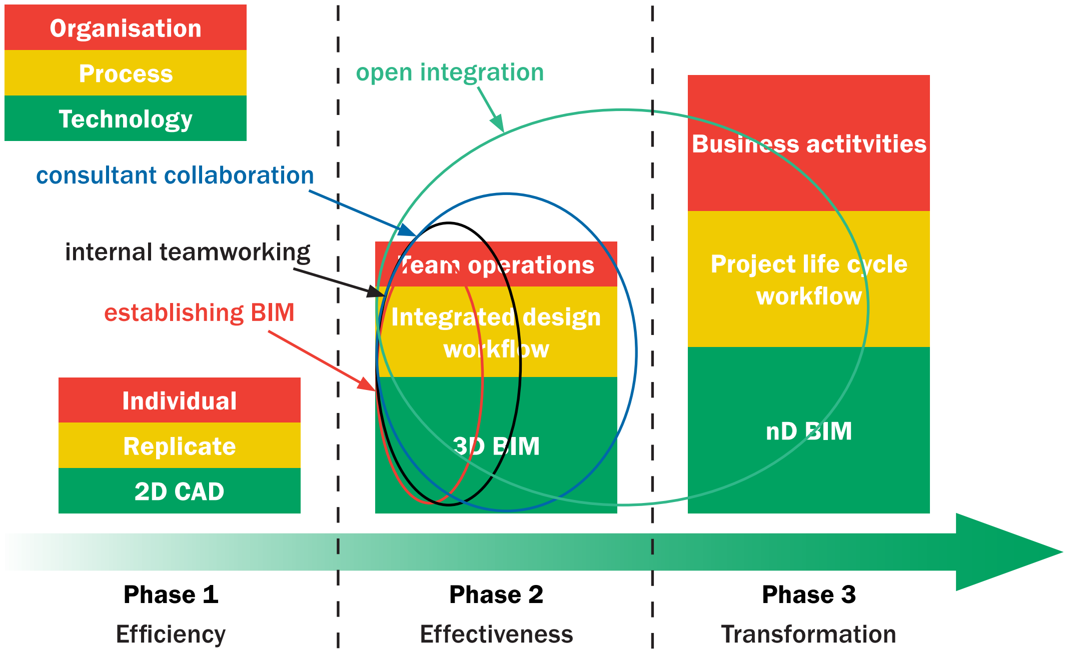


Figure 5.3 ***Recommended BIM adoption strategy from SmartBIM solutions (courtesy Graphisoft UK Ltd)***

Integrated BIM processes will enable also the consideration of nD in a project, ie diverse and different perspectives and dimensions for analysis can be considered (3D, 4D scheduling, 5D costing, structural analysis, environmental analysis, life cycle costs assessments etc). In this way, designers need to strategically consider how their services may be extended or changed to address these new possibilities.

For instance, architectural consultants would provide input to a project up to RIBA stage D. The opportunity for architects is to provide value across the later stages of design, including additional services that are not part of the current standard scope of services.

Other considerations for designers include (Eastman *et al*, 2011):

- focus on value creation to support the achievement of benefits for clients and their businesses over the life cycle of a building
- innovate and help integrated design and delivery solutions, ensuring that organisations are producing the model to the right level of detail needed to support project Lean/BIM activities
- ensuring compatibility with other project systems
- terms on BIM appointments and IPR
- building contracts, including an alignment of fees with work outside the scope of standard services
- professional indemnity insurance issues
- adopt collaborative planning during design stages, mapping the design workflow to identify key handovers with other designers
- hardware and software considerations, including requirements and organisation of data storage in file or database structures
- develop, review and authorise protocols, both for the office (generic) and for the specific project at hand so protocols will need to remain flexible. Also, it is advisable to base office standards on national standards (ie BS 1192:2007). Protocols are important to enable successful Lean and BIM adoption.

6

Conclusion

This guide aims to help readers gain a better understand the basics of Lean and BIM, how they are related, and how to take those first steps towards their joint implementation. Given the current economic situation in the UK and globally, both public and private sector clients are trying to ensure that they get the maximum value out of their investment and that waste is squeezed out from the process. Here, Lean and BIM are very opportune. Also, with the UK Government's BIM initiative, there will soon be a requirement for the whole industry to trial and learn about this significant technological process change. This provides an excellent opportunity to consider a deeper process change and to consider an integrated approach to both Lean and BIM. The processes and methods that are described in this guide should serve the reader as a blueprint to develop their own tools and methods, suited to the processes and culture within their respective organisations.

As observed in exemplar case studies around the world, to succeed with Lean and BIM implementation means the freedom and eagerness to experiment and improve. Construction is understood to be somewhat conservative about innovation and wants proven solutions, however, the platform provided by these recent technological and process change initiatives will inspire and enthuse towards trying new things. Many new tools have already emerged and new applications in the realm of BIM (and computing in general) are appearing faster than in previous decades. Through such innovation and experimentation, it is hoped that new functions, tools and processes will emerge that will provide a foundation for an even more efficient construction industry.

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