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BIM as a strategic tool for supply chain in main projects in the United Kingdom

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“Perseverance is not a long race; It is many short races one after the other.”

Walter Elliot

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Cheers to all!

Abstract

The need to achieve more efficiency and quality, reduce costs, cut carbon dioxide emissions and faster delivery were demanding for a vast change in the construction industry in the United Kingdom. To helping achieve these aims, as well be and remains in the vanguard of smart construction and digital design, UK made the decision to embrace Building Information Modelling (BIM), underpinned with the Government's mandate launched in 2011, for Level 2 BIM compliance as minimum for all their centrally-procured projects by 2016. That decision resulted in a Government push to upskill the construction industry with the intention of reducing the capital and revenue costs associated with the procurement and use of buildings and infrastructure.

For the public sector, BIM is offering the Government the opportunity to industrialise and reform its built environment through a digitally enabled procurement. Indeed, this Level 2 BIM programme already helping significant savings of circa £2.2bn between 2013 and 2015, making it a significant tool to meet the Government's target of 15-20% savings on public construction costs (Cabinet Office, 2015).

To support the industry to comply with Level 2 maturity, BIM Task Group and British Standard Institute, have developed several standards, documents and guides to explain clearly how BIM should be applied. The Level 2 programme is a key enabling strategy for the UK developing processes for data deliveries, classification and open data definitions. Certainly, the UK BIM standards and processes are working as a world-wide acknowledged benchmark for industry digitisation. By 2020, economists estimated that the UK market for BIM-related services will be an annual £30bn; in a global context, UK-based firms already export £7bn of architectural and engineering services; develop BIM capabilities and have a leadership position regarded to BIM, will provide UK further export growing and enable the industry to deliver higher quality and a more sustainability built environment for the future generations.

This dissertation aim to encourage everyone to learn more about building information modelling and to explore the success example of the UK strategy Government related to BIM level 2 mandate. For that purpose, this document first explains the fundamental concepts of BIM and then explores the context in the UK: BIM maturity levels, the existing codes and standards, addresses the named "8 pillars of Level 2 BIM" and explains the information delivery cycle process. It also becomes relevant discuss in this paper, the current situation of the BIM adoption by the AEC industry and address some of the benefits and limitations of BIM adoption in the country. Furthermore, we look beyond and investigate the BIM level 3. The research has been conducted by an extensive review on the literature related to the topic of interest, collecting and analysis of surveys that have been conducted related to BIM in the UK

and experienced working in a UK based contractor. A case of study is showed to recognise the importance of use BIM for a large project such as the High Speed 2, and additionally it is suggested a process map for BIM execution planning.

Keywords

Building Information Modelling; Construction Industry; UK Government Mandate; Information Delivery Cycle; Supply Chain; Upskilling.

Resumo

A necessidade em obter mais eficiência e qualidade, reduzir custos, diminuir as emissões de carbono e de prazos de execução, exigiam uma enorme mudança na indústria da construção no Reino Unido. De forma a alcançar estes objetivos, bem como a pertencer e permanecer na vanguarda da construção inteligente e projeto digital, o Reino Unido tomou a decisão de adotar o BIM (*Building Information Modelling*), impulsionado pelo mandato do Governo para cumprimento do Nível 2 de maturidade como mínimo, lançado em 2011 para todos os projetos lançados centralmente, a partir de 2016. Essa decisão resultou num impulso do Governo para melhorar a indústria da construção, com a intenção de reduzir os custos de capital e receita associados à aquisição e uso de edifícios e infra-estruturas.

No setor público o BIM está a proporcionar ao Governo, a oportunidade de industrializar e reformar o seu sector da construção através do *procurement* digital. De fato, este programa de BIM Nível 2 já ajudou a atingir poupanças significativas de cerca de £2.2 bilhões entre 2013 e 2015, tornando-o numa ferramenta significativa para atingir a meta de redução de custos com a construção pública entre os 15-20% (*Cabinet Office*, 2015).

De forma a apoiar a indústria a cumprir com o Nível 2 de maturidade de BIM, o *BIM Task Group* e o *British Standard Institute*, desenvolveram várias *standards*, documentos e guias para explicar claramente como o BIM deveria ser aplicado. O programa Nível 2 é uma estratégia chave potenciadora para o Reino Unido desenvolver processos para a entrega de dados, classificação e definições de dados abertos. De fato, as *BIM standards* e os processos do Reino Unido estão a ser reconhecidos mundialmente como uma referência para a digitalização da indústria. Por volta de 2020, os economistas estimam que o mercado para serviços relacionados com BIM sejam £30 bilhões; num contexto global, as firmas baseadas no Reino Unido já exportam £7 bilhões de serviços de arquitetura e engenharia; desenvolver as capacidades e ter uma posição de liderança em relação ao BIM, fará com que esta exportação cresça e permitirá que a indústria entregue com mais qualidade e sustentabilidade as construções às gerações futuras.

Esta dissertação pretende encorajar todos os interessados a aprender mais sobre o BIM e explorar o caso de sucesso da estratégia tomada pelo Governo do Reino Unido no que diz respeito ao mandato do BIM Nível 2. Para isso, este documento explica primeiro os conceitos essenciais do BIM e depois explora o contexto no Reino Unido: os níveis de maturidade de BIM, os códigos e *standards* existentes, aborda os chamados “8 pilares do BIM Nível 2” e explica o ciclo de entrega de informação. Torna-se também relevante discutir neste trabalho, a situação atual da adoção do BIM por parte da indústria AEC e abordar os benefícios e limitações na adoção do BIM no país. Adicionalmente, olha-se para o futuro e explora-se o BIM

Nível 3. A pesquisa foi levada a cabo através de extensa revisão da literatura relacionada com o tópico, de recolha e análise de inquéritos realizados no Reino Unido relacionados com BIM e a experiência trabalhando numa construtora baseada no Reino Unido. É apresentado um caso de estudo para demonstrar a importância do uso do BIM num grande projeto como *High Speed 2*, e adicionalmente é sugerido um mapa de processo para o planeamento de execução BIM.

Palavras-chave

Building Information Modelling; Indústria da Construção; Mandato do Governo do Reino Unido; Ciclo de Entrega de Informação; Cadeia de Suprimentos; Melhoria de competências.

Resumo Alargado

Mundialmente o sector da construção tem progressivamente vindo a mudar, adaptando-se à era digital que atravessamos. A aceitação e adoção crescente por parte da indústria AEC (Arquitetura, Engenharia e Construção) do BIM (*Building Information Modelling*) é disso um exemplo.

Durante muitos anos, arquitetos e engenheiros projetistas desenvolveram os seus projetos com recurso à modelação 3D relativamente a partes específicas do projeto apenas - a que chamamos de “BIM solitário”. No entanto, a revolução e a mudança atual a que estamos a assistir usa o BIM durante todo o ciclo de vida do projeto, desde a conceção até à demolição, e reutilização da construção. A transformação passa também pelo fato do BIM englobar uma abordagem colaborativa de troca de informação ao longo de todo o processo.

O BIM sendo uma representação digital das características físicas e funcionais de uma construção num modelo 3D muito rico, permite obter retirar informação crucial para basear decisões importantes sobre o empreendimento a construir ou construído. O BIM não é apenas uma tecnologia, mas também um conjunto processos, *standards* e protocolos para a troca da informação, de forma colaborativa. Apesar do acrónimo BIM conter o “B” de *Building* não é só aplicável para edifícios, BIM pode ser usado para estradas, pontes, vias ferroviárias, instalações industriais e infraestruturas, igualmente é extensível a novos projetos ou a reabilitações / reconstruções.

A construção durante muito tempo foi sendo ultrapassada quando comparada a outras indústrias (como a automóvel, energia ou aeroespacial) no que toca à inovação, produtividade, qualidade e custos. Com a introdução do BIM temos vindo a experienciar uma forma de trabalhar que “promete” que a fase de projeto e construção se façam de forma mais sustentável, económica, rápida e com qualidade, assim como o património construído tenha uma melhor performance.

Foi com estas metas em mente, que em 2011 o Governo no Reino Unido lançou a Estratégia para a Construção (*Construction Strategy 2011 2015*) que delineou a intenção de reduzir os custos com a construção no sector público em 15-20% bem como as emissões de carbono.

Um dos potenciadores estratégicos identificado para alcançar esses objetivos foi a utilização do BIM, assim o governo britânico mandatou o cumprimento do BIM com o mínimo de nível de maturidade 2 em todos os projetos públicos lançados centralmente a partir de 2016.

O programa governamental de implementação do BIM no Reino Unido tem vindo a atrair o interesse da comunidade global, desde governos, organismos públicos de *procurement*,

investidores privados e de decisores de políticas, com o objetivo de adotar os seus princípios e aprender com o sucesso britânico e a mudança que se está a verificar no sector da construção.

Decorridos estes anos desde o início do processo de introdução, os benefícios de uso do BIM no sector público da construção estão já provados, tendo contribuído entre 2013 e 2015 para uma redução na construção pública de cerca de £2.2 bilhões, fazendo do BIM uma importante ferramenta para atingir a meta do Governo de 15-20% de redução de custos.

Com esta dissertação pretende-se dar a conhecer a estratégia que o Governo do Reino Unido tomou para adoção do Nível 2 BIM no sector público, abordando as principais *standards* e processos no qual se baseia, contribuindo assim para a divulgação, dinamização e formação do processo BIM na comunidade académica.

Sendo visto como um caso de sucesso de implementação por parte de um Governo, que arrastou igualmente o sector privado a reconhecer as potencialidades do BIM em todo o ciclo de vida de um projeto, é objetivo também deste trabalho de pesquisa abordar os benefícios que uma cadeia de fornecimentos (*supply chain*) pode obter com a adoção do BIM. Por outro lado, torna-se também relevante investigar quais são os principais entraves que as organizações sentem existir para adoção do processo.

A implementação do BIM no Reino Unido é vista como um processo contínuo, feito de forma sequencial e faseada, pelo que o desígnio do Governo para o Nível 3 de maturidade BIM por volta de 2025 é também abordado neste trabalho, com o objetivo de entender que mais valias poderá trazer para a indústria no futuro.

Adicionalmente é apresentado o caso de estudo do HS2 (*High Speed Two*), o grande projeto para a linha de caminho de ferro de alta velocidade com vista a melhorar a ligação entre Londres, Birmingham, Leeds e Manchester. Trata-se de um projeto técnico complexo, que envolverá infraestruturas elétricas, comunicações, movimentos de terra, estruturas, linhas ferroviárias, sistemas de controle, mitigação de ruído, entre outros. O projeto inclui também um enorme número de intervenientes, maior do que um projeto corrente, e o alcance nacional e impacto que terá nas cidades e zonas rurais será significativo. O BIM é central para contribuir para a entrega do projeto de forma eficiente, cumprindo o prazo de execução e orçamento. A empresa HS2 Ltd. identifica uma poupança potencial de cerca de £0.5 bilhões só através da utilização do BIM, assim como de que será vital o seu uso para além da fase do projeto e construção, focando-se também nas vantagens que trará na fase de operação ao longo dos mais de 150 anos do seu ciclo de vida.

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List of Abbreviations and Acronyms

2D	2-dimensional
3D	3-dimensional
4D	4-dimensional (Time)
5D	5-dimensional (Cost)
6D	6-dimensional (Building lifecycle management / Sustainability)
7D	7-dimensional (Facility and asset management)
AEC	Architectural, Engineering and Construction
AIA	American Institute of Architects
AIM	Asset Information Model / Modelling
AIR	Asset Information Requirements
AVANTI	(UK Government sponsored to assist collaboration)
BCF	BIM Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Model / Modelling / Management
BIMXML	Building Information Model Extended Markup Language
BIS	UK Department for Business, Innovation and Skills
BOQ	Bill of Quantities
BrIM	Bridge Information Model
BS	British Standard
bsDD	buildingSMART Data Dictionary
BSI	British Standards Institution
BSIM	Building Services Information Model
CAD	Computer Aided Design
CAFm	Computer Aided Facilities Management
CAPEX	Capital Expenditure
CDE	Common Data Environment
CEO	Chief Executive Officer
CIC	Construction Industry Council
CIOB	Chartered Institute of Building
CMS	Content Management System
CNC	Computer Numerical Control
COBie	Construction Operations Building information exchange
CPD	Continuing Professional Development
CPIC	Construction Project Information Committee
DfMA	Design for Manufacturer and Assembly
DMS	Document Management System
dPoW	Digital Plan of Works
DWFx	Design Web Format (native Autodesk file format)
DWX	Drawing Interchange Format or Drawing Exchange Format
ECI	Early Contractor Involvement
EIR	Employer Information Requirement
ERDC	Engineer Research and Development Center
FAIA	Fellow of the American Institute of Architects
FIM	Facilities Information Model

FM	Facilities Management
FOSS	Free and Open Source Software
gbXML	Green Building XML
GCS	Government Construction Industry
GPS	Global Positioning System
GSL	Government Soft Landings
HM	Her Majesty
HPC	Highpower computing
HS2	High Speed 2
IAI	International Alliance for Interoperability
Ibim	Integrated Building Information Modelling
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IFCxml	Industry Foundation Classes Xml File
IFD	International Framework for Dictionaries
IoT	Internet of Things
IPA	Infrastructure and Projects Authority
IPD	Integrated Project Delivery
ISO	International Organisation for Standardisation
JV	Joint Venture
KPI	Key Performance Indicator
LD	Lead Designer
LOD	Level of Definition or Level of model Detail (in the US this can be Level of Development)
LoF	Learning Outcomes Framework
LOI	Levels of Information
MC	Main Contractor
MEP	Mechanical, Electrical and Plumbing
Mgt	Management
MIDP	Master Information Delivery Plan
MoJ	Ministry of Justice
MPS	Model Progression Specification
MVD	Model View Definition
NBIMS	National Building Information Modeling Standard (US)
NBS	National Building Specification
NEC	New Engineering Contracts
OGC	Office of Government Commerce
OIR	Organisational Information Requirements
ONS	Office for National Statistics
OPEX	Operational Expenditure
PAS	Publicly Available Specification
PCSG	Professional Construction Strategies Group
PDF	Portable Document Format
PIM	Project Information Model
PPM	Programme and Project Management
QTO	Quantity Take-Off
RIBA	Royal Institute of British Architects
SCCS	Supply Chain Capability Summary
SIM	Structural Information Model

SMART	Specific, Measurable, Achievable, Responsible, Timely
SME	Small and medium enterprises
UBI	Universidade da Beira Interior
UK	United Kingdom
US	United States

Chapter 1 - Introduction

Building Information Modelling (BIM) is becoming a global language for the construction and infrastructure sitting at the heart of digital transformation, allowing better collaboration and transference of capabilities across borders.

Nowadays we are experienced with BIM that the project teams are communicating about design and coordinate information across different levels that has been unseen before. That information remains with the project, from inception before beginning construction, right throughout its lifetime until the demolition or renew. BIM is a process that involve a large group of stakeholders from design and construction to operations and maintenance, allowing the users to work collaboratively and share project and asset information by mapping that data onto 3D representations of asset components that reside in the data-rich model.

Hamil & Smith argue that the interoperability of the BIM model involves that drawings, master specifications, standards, regulations, manufacturer product specifications, cost and procurement details, environmental conditions, (emissions data) and submittal processes all work together (Hamil & Smith, 2012).

The UK is now widely recognised as one of the key countries in invigorating of BIM within the construction industry, with likely wood of become a standard process soon. For the construction industry, a major part of the UK economy, it provides a critical opportunity to significantly improve performance (BIM Level 2, 2016).



Figure 1 - BIM Process

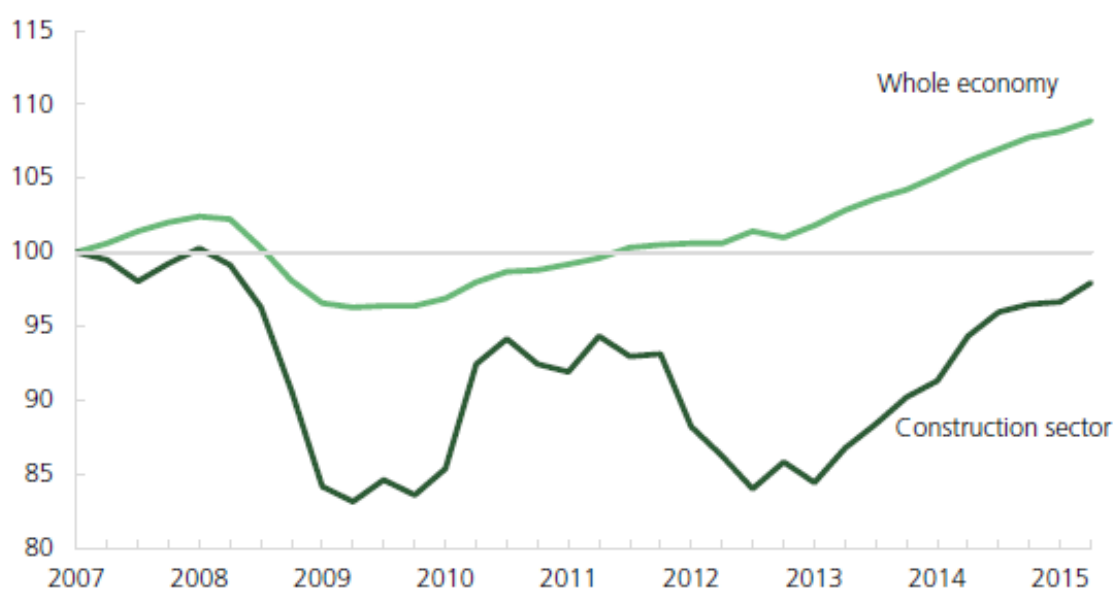
(Image retrieved from http://www.bimalliance.se/library/2174/3f_em_di_giacomo.pdf)

According to the UK Government in 2015, the construction industry's output was £103 billion, 6.5% of the total economy, accounting for 2.0 million jobs - circa 8% in over 956,000 businesses¹.

As below graph 1 shows during the years of recession, between 2009 and 2010, construction industry experienced a huge drop comparing to the whole industry economy. While other industries were delivering a step change in productivity and performance, construction was being left behind. The construction industry was needing a vast performance improvement revolution.

Economic output (Gross value added)

Index where Q1 2007=100; ONS series L2N8 and L2KK



Graph 1 - Construction industry: statistics and policy
(Image retrieved from <http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN01432>)

In May 2011, the UK Government published the Construction Strategy² intended to reduce the cost of public sector assets by up to 20% by 2016. To reach this strategy, the government required construction suppliers tendering for centrally-procured government projects to be working at BIM Level 2, in which separate disciplines create their own models, but all project data is shared electronically in a common environment. As a minimum, they require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic).

¹ Parliament.uk-Briefing paper Oct 2015 from:
<http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN01432#fullreport>

² Details can be found at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61152/Government-Construction-Strategy_0.pdf

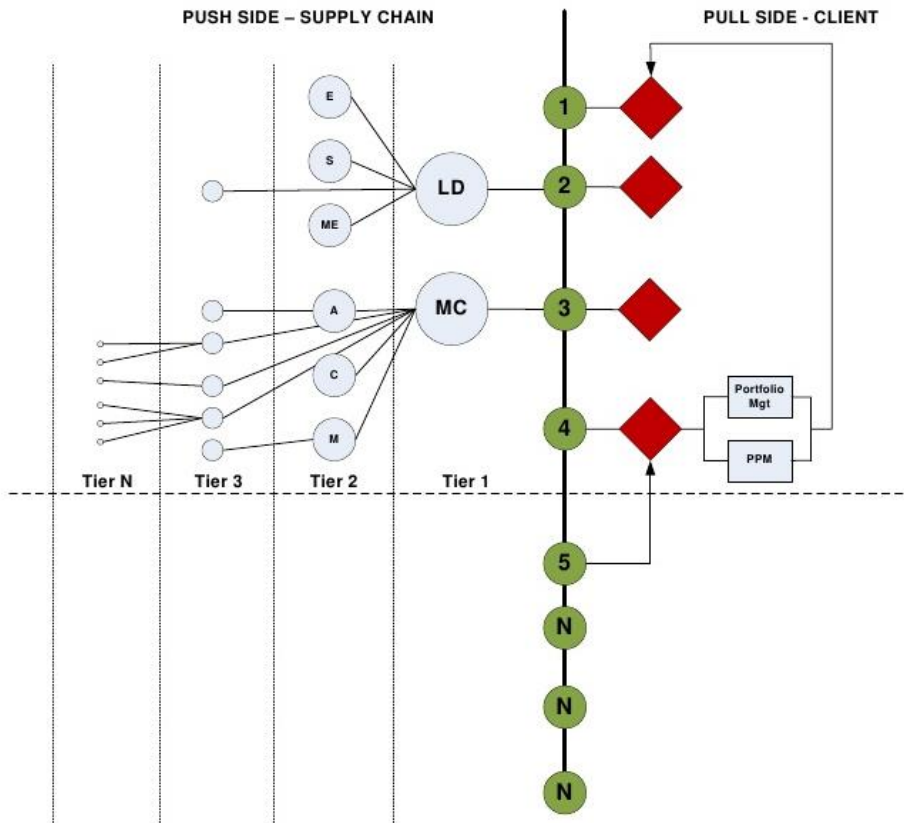
The government requirement has been introduced to drive the adoption of BIM processes throughout the public and private sector: while the requirement was introduced initially for government projects, the benefits of utilising BIM Level 2 processes and information management practices can also be realised by private sector clients and projects within the construction industry.

Embracing the requirements of BIM mean different things to different organisations depending on where they are in the construction supply chain.

Also, clients must understand how to set their EIRs (Employer's Information Requirements) and how to work collaboratively with their supply chains. They will have to adapt their procurement processes and develop approaches to supply chain assessment. This is on top of having to understand the processes for Pre-and-Post contract BIM Execution Plans (BEP) as well as how BIM can support asset management. Designers and contractors, need to understand what clients are enquiring for; how to interpret and deliver against the EIRs and develop and manage the Pre-and-Post contract BIM Execution Planning processes; how to develop the processes to deliver the specific requirements of Task and Master Information Delivery Plans (MIDP); setting up, managing and working with the Common Data Environment (CDE), COBie (Construction Operations Building Information Exchange) and Asset Information Models (AIM).

Taking the Tier 2 sub-contractors as an example, in a procurement process using BIM they need to understand the specific information requirements for them and the way they will be required to work collaboratively with the Tier 1 contractor and other suppliers. That includes to understand the process requirements, the BEP and the CDE.

The selected supply base supplying data up to the Tier 1 (who is responsible for its coordination use and submission to the Employer) must be engaged consistently to ensure data can be created and re-used, rather than repeatedly re-typed. Also it is incumbent on the Employer to only ask for information that is needed at each stage of the project (NBS, 2015). The graph below (Graph 2 - Supply chain management) by the UK Government helps to understand the process of the data supply chain management: 'Data drop 1' relates to the model that is representing the requirements and constraints, 'data drop 2' means the model for the outline solution, 'data drop 3' is where the model represents the construction information and 'data drop 4' is the model for the operations and maintenance information.



Graph 2 - Supply chain management
 (Image retrieved from <https://www.slideshare.net/SoBEVPSeries/hmg-bim-strategy-mark-bew>)

1.1. Subject background

In the early summer of 2011, a defining document was issued by the UK Government - *'BIM Management for value, cost & carbon improvement: 'A report for the Government Construction Client Group - Building Information (BIM) Working Party'*³. This Strategy Paper informed the construction industry regarding a new way of working in government procured projects. It laid out a set of guidelines explaining how this would be achieved. Central to the strategy was the adoption of collaborative working practices, effectively driven by adopting BIM process and technology. The target was to achieve a level of process maturity defined as 'Level 2 BIM'. The target date for all government departments' projects to achieve this level of maturity on projects was by 2016. For most of the UK construction industry, this meant a radical re-think of their working practices. The responsibility for early implementation fell onto large Tier 1 contractors.

³ The report can be accessed at <http://www.bimtaskgroup.org/wp-content/uploads/2012/03/BIS-BIM-strategy-Report.pdf>)

1.2. Scope and objectives

The purpose of this dissertation is to address the process of implementation of BIM in the United Kingdom (UK) driven by the BIM level 2 mandate of the government and to explain the existing standards and processes. In addition, this document seeks to address the actual status of BIM adoption in the country and likewise analyse the benefits and challenges that the supply chain's companies are encountering in BIM programme implementation.

This paper aims also to look beyond BIM level 2, understand the strategy for going further to Level 3 and the benefits that can bring to the construction industry in the UK.

The research has been conducted by an extensive review on the literature related to the topic of interest, collecting and analysis of surveys that have been conducted related to BIM and the on-the-job experience in a construction company based in the UK (Barhale plc⁴).

In order to understand the potential that BIM technology can have particularly in the field that I am working - tender and pre-construction - I had the opportunity to use BIM software for academic purposes related to 3D, 4D, 5D BIM management, namely the Vico Office and also interfaced with other BIM software such as Autodesk Navisworks and Autodesk Revit.

The company Barhale is at the moment involved in some main projects as a potential Tier 2 sub-contractor, it is noted that it is increasing the requirement of BIM Level 2 compliance by the clients. Nevertheless, although Barhale has yet some BIM technology in place (see Appendix 5), BIM processes, standards and protocols for information exchange are not yet implemented in the company, hence don't have yet BIM certification. There are some steps being taken to implement BIM processes with a steering group within the organisation tasked with establishing the overall BIM strategy, development of BIM processes as well as training programmes, showing that there are some positives developments.

As case study is presented related to the High Speed 2 project (HS2), exploring the matter of the relevance of BIM adoption in the projects throughout all lifecycle (procurement, delivery and operation), this case for a large and complex project with vital importance to the UK. Additionally, we investigate the results from the supply chain upskilling study to understand where the supply chain stands to meet the requirements of the client HS2. Particularly, the company 'Barhale' where I am working, as it was mentioned previous in this dissertation don't have yet BIM processes in place, therefore an aim of this dissertation is outline and propose a process map for a BIM execution planning process that could be adopted within the organisation.

⁴ The company Barhale is a civil engineering and infrastructure specialist with over 35 years' experience in the construction industry. More details can be found at <http://www.barhale.co.uk>

1.3. Methods

This dissertation uses predominantly bibliographic research as technical procedure. The research was made through national and international publications, including internet information, specialised and non-specialised articles, press contents, conferences presentation, codes and standards, explanatory video visualisation related to BIM, webinars and e-learning. Support and come interface using some BIM software tools, such as Vico software, Autodesk Navisworks and Autodesk Revit was also carried out. The experience at Barhale also contributed for some of the findings and conclusions of this dissertation. The company is working as a Tier 2 subcontractor for main projects and is currently in a process of implementing BIM.

1.4. Structure

This dissertation comprises five chapters:

Chapter 1 briefly introduces the project background, objectives, methodology and structure of the dissertation.

Chapter 2 is divided in two sub-sections:

- First sub-section deals with the theoretical part of BIM, explaining the fundamental concept and parametric modelling, interoperability and LOD. In this sub-section, it is presented some of the software BIM tools available, examine in more detail the software Vico Office. Moreover, is addressed main advantages that BIM can potentially offer;
- Second sub-section addresses the implementation of BIM in the UK, introducing the background basis for the adoption of BIM with the Government Construction Strategy, explores the BIM Maturity Levels, provides an overview of the called “8 pillars of BIM Level 2”, codes and existing standards and explains the Common Data Environment. This chapter also explores beyond BIM level 2 with the whisper of BIM Level 3 adoption.

Chapter 3 deals with the panorama of the actual relation of UK construction supply chain and BIM, explaining the information delivery cycle in a Level 2, the main existing tools, platforms and guides to support BIM adoption. Chapter 3 also addresses the current situation of the construction industry regarded to awareness and levels of collaboration in BIM, and the benefits and challenges that the supply chain is facing in adapting BIM. In this chapter it is also discussed major education and training needs to work with BIM.

Chapter 4 sets out the case of study of High Speed Two (HS2) to demonstrate the potential of BIM as an important process for the construction projects, even more for a large and complex project like this. Includes a brief of the project, explores the reason of the client to choose BIM and the UK BIM standards in relation to HS2. Likewise, the chapter explores what main supply chain's upskilling needs related to BIM and it is presented the tool BIM upskilling platform available from HS2. It is presented a suggestion of a process map for BIM execution planning within the organisation Barhale, that can be followed in delivery for example a project of HS2 scheme.

Chapter 5 presents the conclusion of the work and future developments.

Chapter 2 - State of Art

2.1. Introduction to BIM

2.1.1. BIM Concept

Computer-aided design (CAD) techniques have been in use by the construction industry since the early 1980s. In the mid-1990s it was introduced the Building Information Modelling (BIM) in the AEC - Architecture, Engineering and Construction industry. In the Era of the digital revolution BIM is called by many as the next paradigm shift in the AEC industry, with expectations that this new methodology can increase efficiency, productivity, sustainability, quality, value and reduce lifecycle costs.

As AEC industry expectations for analysis using a model-based approach keep increasing, nowadays the information contained in 2D CAD drawings is in fact not sufficient to meet the requirements of a model-based design process.

First let's understand what Building Information Modelling is. There are a lot of definitions from different sources about BIM, here is the NBS definition:

BIM is a rich information model, consisting of potentially multiple data sources, elements of which can be shared across all stakeholders and be maintained across the life of a building from inception to recycling (cradle to cradle). The information model can include contract and specification properties, personnel, programming, quantities, cost, spaces and geometry.

(NBS, 2010)

Second, we need to comprehend how BIM works. BIM is based on data sets that describe objects virtually in the same way as they will be handled physically. Likewise, the real difference against the traditional drawings is in the interoperability and capability for integration, where the input of the various specialists come together harmoniously (Hamil & Smith, 2012).

For example, taking BIM in terms of measurement and costing, we can consider three main parts of the process:

1st - execute the 3D modelling to generate the geometry of the design;

2nd - define the scope of the BOQ (Bill of quantities) and complete this with quantities from the model;

3rd - auto-annotate the 3D and 2D drawings from the model and dynamically link the descriptions to the specification.

This fundamental process gives a model that can be used for further construction sequencing (4D BIM), cost assessment (5D BIM), clash detection, printing physical models, presentation and visualisation. The information builds in richness as the project stages progress until that complete data set is handed over to the Client and/or end user at completion.

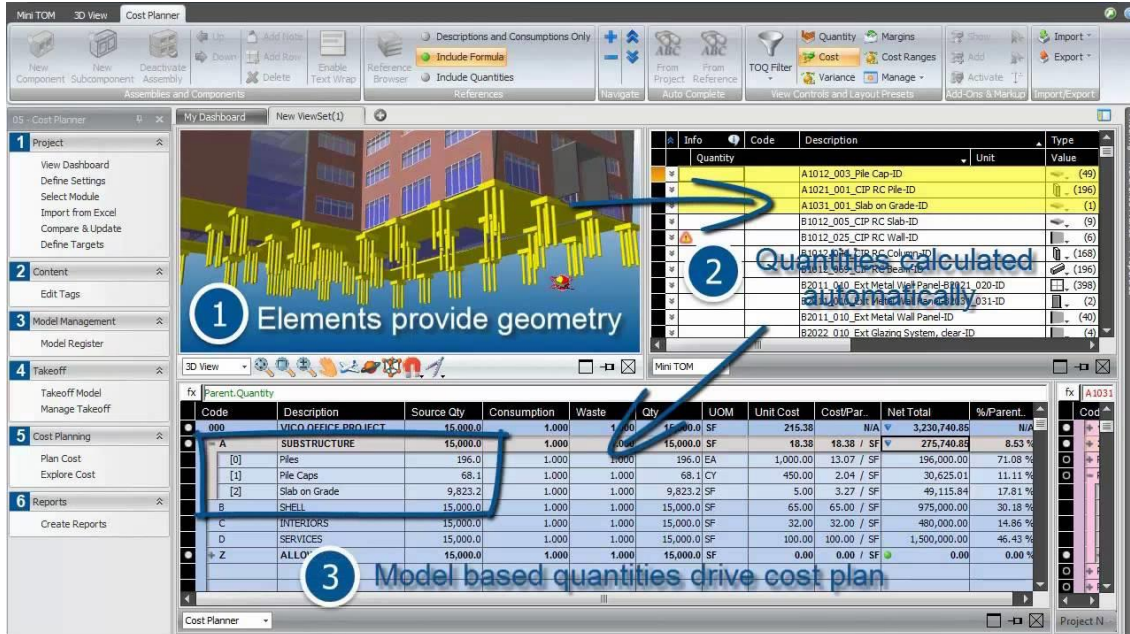


Figure 2 - Vico Office: Integrated 2D, 3D, 4D and 5D BIM Construction Management
(Image retrieved from https://www.youtube.com/watch?v=qcepd_AJANo)

Therefore, we will explain in more detail the other dimensions that BIM have beyond the 3D:

- **4D BIM:** As it is creating an information model, it is possible add scheduling data to different components, generating accurate programme information and enabling step-by-step visuals of the project's development.

4D BIM involves time-related information being associated to different components of an information model. For a specific element or work area, that can include details on its lead-time, construction and installation period, curing and drying allowances, sequencing or its interdependencies with other areas (The B1M, 2016).

- **5D BIM:** BIM allows linking in cost data in order to support cost planning and produce accurate cost estimates from the components of the information model. With the graphical model and its attribute data developed, Cost Managers can very quickly determine the quantity of a particular component, applying rates to those quantities to reach an overall cost for that package. Those packages costs are then combined to build an overall picture of a project's cost. With 5D BIM the estimates can consider

the capital cost of purchasing and installing a component, likewise the running costs associated with it once in usage and the predicted price of renewing it in the future (The B1M, 2015).

5D BIM can also be applicable on delivery phase on site, having a solid 4D programme data and a robust contract sum it is possible to track predicted and actual spend over the progression of the project. This is principally useful for monthly cost reporting and budgeting.

- **6D BIM:** is the as built model with all the product data sheets, every type of information put inside the model as well as maintenance and lifecycle strategies. 6D BIM is often interchanged with 7D BIM, which focuses solely on Facilities Management.
- **7D BIM:** is used by managers in the operation and maintenance of the facility throughout its lifecycle. The seventh dimension of BIM allows participants to extract and track relevant asset data such as component status, specifications, maintenance/operation manuals, warranty data etc.

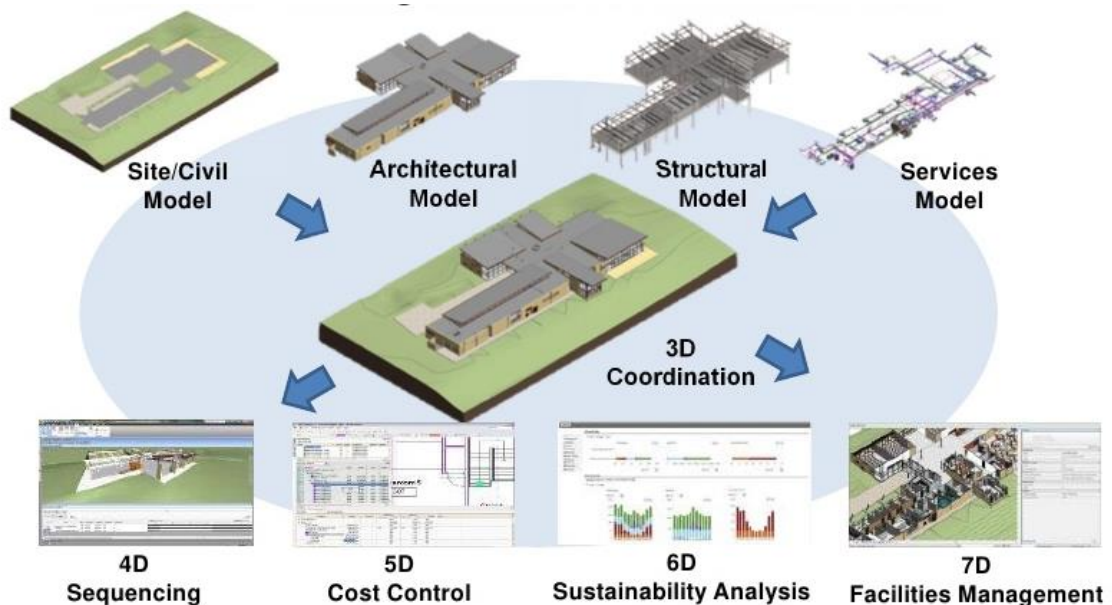


Figure 3 - The seven dimensions of BIM
(Image retrieved from <https://www.arcdox.com/>)

In terms of software, BIM introduces exchangeable information formats, i.e., International Foundation Classes (IFC) developed by buildingSMART. IFC can be described as “a language

for transferring information between BIM applications while maintaining the meaning of different pieces of information in the transfer” (Solibri, 2017).

BIM allows that the design information becomes more unambiguous, the design intent and program is easily understood and assessed. BIM as we have been realising is much more than drawings, it is a data repository for design, construction and maintenance information combined in one convenient model to share with all the stakeholders and that have several uses (see below Table 1).

Table 1 - Available BIM uses
(Image retrieved from <http://www.building.co.uk/procurement-update-bim/5077116.article>)

Gather	Generate	Analyse	Communicate	Realise
Capture Collection of data and geometry to record the current status and condition of a facility - for instance, 3D laser scan	Prescribe Causing functional specification requirements of a facility - for instance, levels of information	Co-ordination Finding and correcting spatial conflicts in different design models - for instance, clash detection	Visualise Providing a realistic, understandable image of the design - for instance, 3D "walk throughs"	Fabricate Directly using detailed, co-ordinated model objects for manufacture - for instance, direct use of BIM data for CNC
Quantify Structured, model-based measurement of the components of a facility - for instance automated quantity take-off	Arrange Configuring spaces and components in 3D space - for instance, spatial modelling and 3D design	Forecast Predicting asset performance based on model analysis - for instance, environmental performance modelling	Transform Reformatting data and information for use by other applications - for instance, COBie data exchange	Assemble Using detailed, co-ordinated model objects as the basis for modular components - for instance, standard library objects
Monitor Collection of data recording the performance of an asset and asset system - for instance, integrated BIM and BMS data	Size Determining component sizes based on defined attributes - for instance, parametric design processes	Validate Confirming that technical solutions meet specification requirements - for instance, automated model-checking	Draw Generating annotated drawings from a single source of truth - for instance, 2D drawing production	Control Using detailed, co-ordinated model data to set out works and direct plant operation - for instance, BIM and GPS controlled excavation
Qualify Collection and updating details of the condition and status of components of a facility - for instance, asset data held as object attributes			Document Collating a comprehensive record of facility information - for instance, FM and PPM documentation	Regulate Controlling the performance of the asset in real time, using data derived from BIM - for instance, integrating BIM and BMS data

As these stakeholders increase their commitment to project success using BIM, they should also profit from BIM combined with IPD (Integrated Project Delivery⁵).

IPD is the process where all stakeholders share in the risk of the design and build process, and share in the rewards of productivity increases (see Graph 3 - IPD graph: The “MacLeamy Curve”).

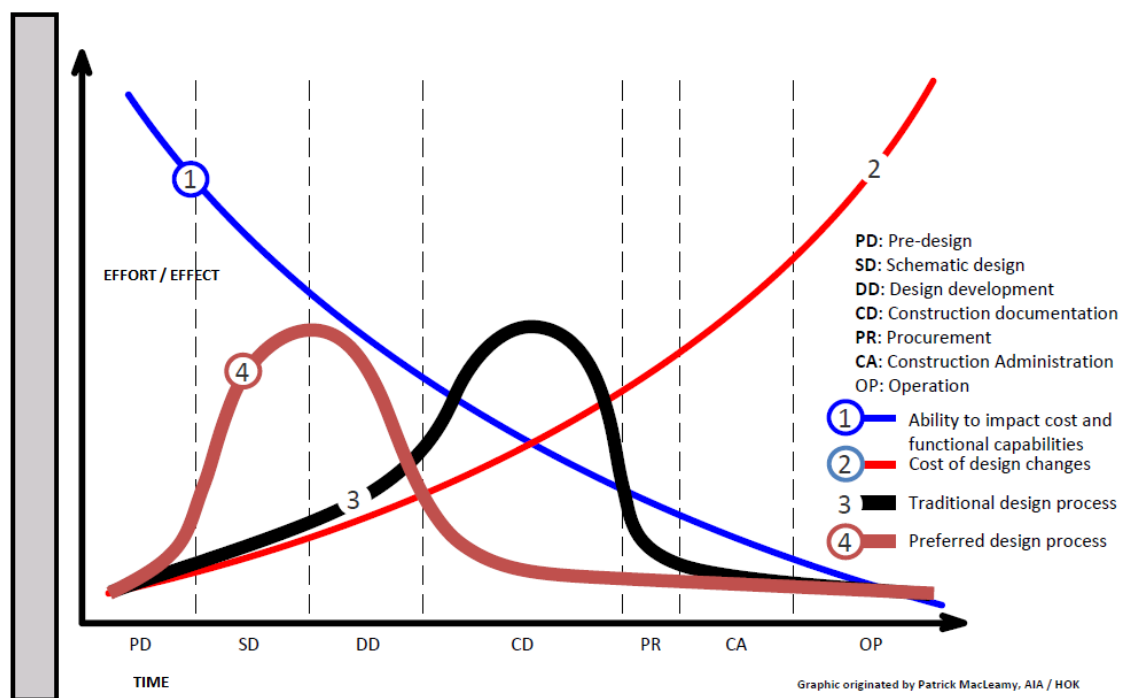
The MacLeamy Curve diagram highlights that the further we are through the design process, the higher the cost of design change. This also has a direct correlation with potential project

⁵ Integrated Project Delivery is a trademark of the Lean Construction Institute <http://www.leanconstruction.org>

delays, wastage and increased deliver costs. For this reason, the BIM process pulls the project stakeholders together earlier so that the individual parties can coordinate their design input, encouraging a more integrated approach to project design and delivery.

Mossman argues that integrated projects are those led by a highly effective collaboration between the client, [...] designer and [...] constructor from early in design through to project handover and use lean thinking throughout the process (Mossman, 2009).

BIM brings better communication and coordination between the different stakeholders of a project with a single, connected model where the parametric elements of the model create a robust database.



Graph 3 - IPD graph: The "MacLeamy Curve"⁶
(Image retrieved from <https://www.slideshare.net/StephenAu/lean-construction-bim>)

Likewise, BIM can be used in the stage of operation & maintenance: The asset owner and facility manager can utilise the data within the model during the occupation and using of the building or other asset. Collecting the information in that database can help everyone be more efficient and also create new opportunities for revenue expansion. Modelling, instead of drawing, is considered the new paradigm, encouragement new cooperation, innovation and asset lifecycle savings.

⁶ Original concept by Patrick MacLeamy, FAIA, CEO, HOK Group, © HOK Group, Inc., 2009 all rights reserved

As Harty *et al.* said BIM is not just applicable to the delivery of large and complex building and infrastructure developments, structured and efficient use of digital data is equally valid for developing small projects (Harty, Kouider, & Paterson, 2016).



Figure 4 - BIM is more than a 3D model
(Image retrieved from http://enews.scia.net/en/eNewsDec09_EN.html)

2.1.2. Parametric modelling

Parametric modelling is characterised by designing with objects having real-world behaviours and attributes, using parameters (numbers or characteristics) to determine the behaviour of a graphical entity and define relationships between model components.

Sections, elevations and three-dimensional views can be created instantly, reducing the need for check plots. Changes to any one of these elements affect all of the others, including materials, costs and construction schedules.

Parametric elements allow for the creation of large, versatile sets of building components with less effort. One generic element can serve as a template with predefined ranges of characteristics. This parametric data allows the element to be easily reconfigured to suit the unique requirements of implementation in various areas of the model.

The parametric data in a collaborative model can save time during the design process by creating and editing multiple design portions simultaneously, and also save time during the construction administration phase by improving coordination and reducing the need for additional site visits, printing and manual drawing checks.

Parametric elements that are changed in one location change in all corresponding views and locations. Warnings and flags can also be created between elements to allow managers to see element changes in any view. These warnings can be arranged into an element change report to facilitate coordination.

2.1.3. Software BIM

BIM software platforms are used to create the 3D graphical information for the project, and as the project progresses increasing amount of non-graphical building information can be stored inside the model (such as planning information, costs and estimates, communications, project updates, among others). The model will become a centralised electronic repository for the project information, often considered as a large collection of interconnected smart objects each with large amounts of information and with the same 3D representation as in real life (Watson M. , 2016).

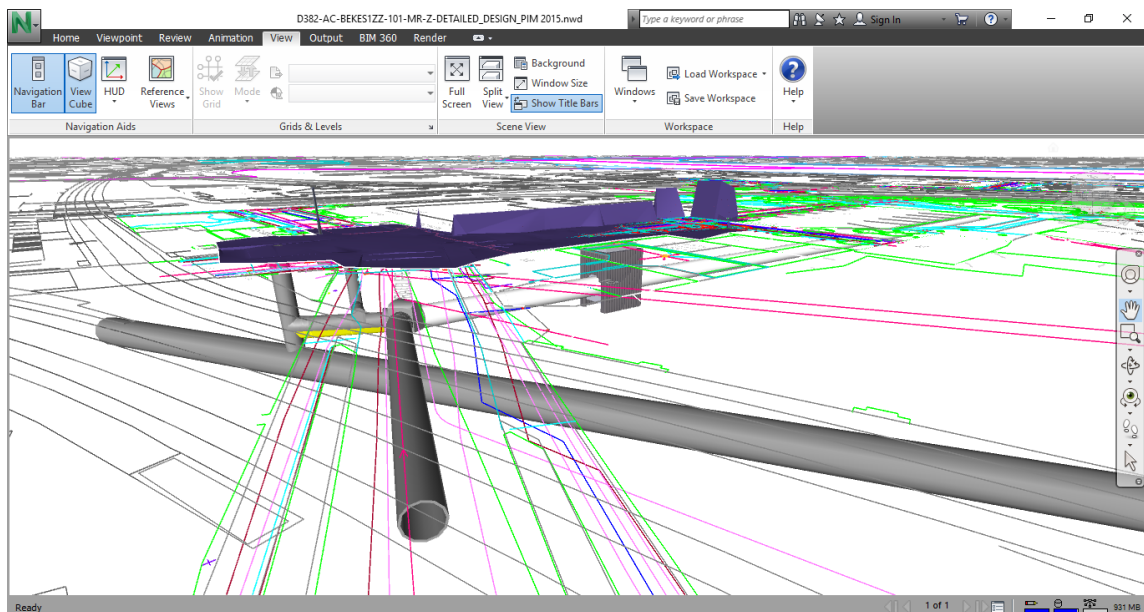


Figure 5 - BIM Model in Autodesk Navisworks Manage 2018
(Source: Courtesy of Barhale plc)

The BIM tools are distinguished into three basic categories depending on the licence: commercial, educational and free and open source software (FOSS). Additionally, they can be classified into other three types depending on the software purpose and use:

1. Visualisation software (authoring tools and viewers):

This type includes all the tools which enable the users to provide a 3D virtual representation of the objects. These tools can provide renderings, walkthroughs and

sequencing of the model for better understanding of what the final structure may look like. The software is divided into BIM authoring tools and BIM viewers.

BIM authoring tools are specific software that allow users to produce structural models that consist of parametric objects for creating the actual model. They also include all the tools that are used during the design phase until the documentation phase (Eastman et al., 2008). BIM authoring tools are essential for exporting building information and data in a suitable format to align with 'data drops' at various stages of the project.

BIM viewers are software that can access data connected to the BIM structural model without the need to extract the entire model. The most common file used is IFC to provide an interoperability solution between different software applications. The format establishes an international standard to export and import objects and their properties (Eastman et al., 2008).

2. Tools for file sharing - collaboration (BIM servers):

As a collaborative platform, a BIM server manages, archives asset data and permits applications to export and import files from the database so the model can be checked, visualised, modified and updated (Figure 6 - Example of a cloud-based workspace). Also allow the exchange of 3D model data between the various applications along a BIM project lifecycle, from the design tools, analysis tools, Document Management Systems (DMS), Facility Management (FM) tools, etc.

3. Analysis tools:

This category comprises the software used for modelling behaviour analysis and for modelling validation to be compliant with specific standards. Normally, these tools are used in the preliminary design phase up to the construction phase or the final 3D reconstruction model. BIM analysis tools provide easy access to the 3D model, measuring project performance, save energy, reduce the operating costs, etc.

Examples of a few BIM software tools are listed in table 2:

Table 2 - BIM software tools ⁷

ARCHITECTURE	STRUCTURES	MEP
Autodesk Revit Architecture	Autodesk Revit Structure	Autodesk Revit MEP
Graphisoft ArchiCAD	Bentley Structural Analysis Software	Bentley Hevacomp Mechanical Designer
Nemetschek Allplan Architecture	Bentley Structural Analysis Software	4MSA FineHVAC + FineLIFT + FineELEC + FineSANI
Digital Project Designer	Tekla Structures	Digital Project MEP Systems Routing
Nemetschek Vectorworks Architect	CypeCAD	CADMEP (CADduct / CADmech)
Bentley Solutions for Architecture and Engineering	Graitec Advance Design	
4MSA IDEA Architectural Design (IntelliCAD)	StructureSoft MWF (Metal Wood Framer)	
CADSoft Envisioneer	Nemetschek Scia	
Softtech Spirit	4MSA Strad and Steel	
RhinoBIM (BETA)	Autodesk Robot Structural Analysis	
CONSTRUCTION (SIMULATION, ESTIMATING AND CONSTRUCTION ANALYSIS - 4D, 5D)	SUSTAINABILITY	FACILITY MANAGEMENT (BIM-FM)
Autodesk Navisworks	Autodesk Ecotect Analysis⁸	Bentley Asset Lifecycle Information Management Solution
Solibri Model Checker	Autodesk Green Building Studio	FM:Systems FM:Interact
Vico Office Suite	Graphisoft EcoDesigner	Vintocon ArchiFM (For Graphisoft ArchiCAD)
Autodesk BIM 360 Field (formerly "Vela Field BIM")	IES Solutions Virtual Environment VE-Pro	Onuma System
Bentley ConstructSim	Bentley AECOSim Energy Simulator	EcoDomus
Tekla BIMSight	Bentley Hevacomp	
Autodesk BIM 360 Glue⁹	DesignBuilder	
Synchro Professional		
Innovaya		
DProfiler		

⁷ Adapted from: www.cad-addict.com/2010/03/list-of-bim-software-providers.html

⁸ After March 20, 2015 Autodesk had discontinued Ecotect Analysis. Autodesk has integrated functionality similar to Ecotect Analysis into the Revit product family.

⁹ Formerly "Glue (by Horizontal Systems)". In January 22, 2015 Autodesk completed acquisition of Horizontal Systems, Inc.

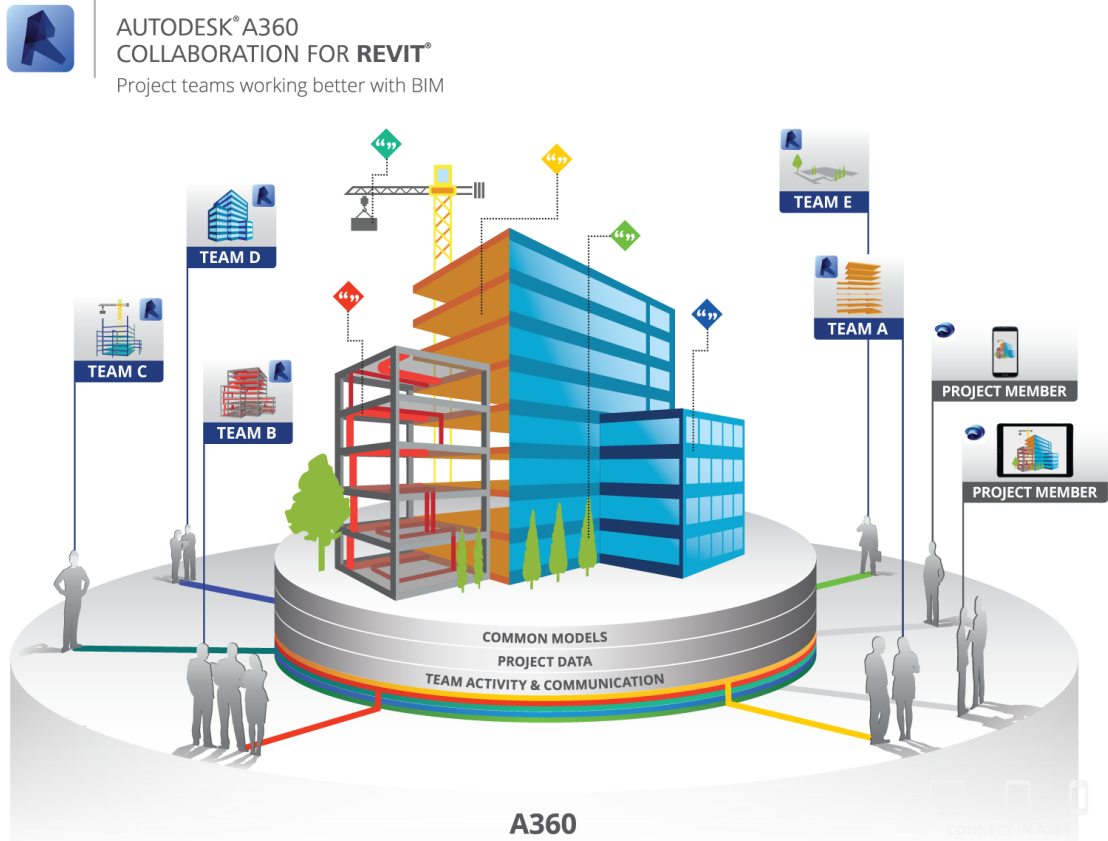


Figure 6 - Example of a cloud-based workspace
(Image retrieved from <http://inthecloud.autodesk.com>)

2.1.3.1. Vico Office

As mentioned previous in this dissertation, during this study I had the opportunity to use Vico Software, with an educational licence requested as a student of UBI, kindly granted by Trimble. The main purpose for requesting a licence for that program was to have the opportunity to use an awarded and recognised software which includes 2D, 3D, 4D and 5D BIM interfaces, allowing me to realise the potentials of BIM within my area of working experience, such as estimating and planning.

Vico Software, Inc. is a company established in the year 2007 and that was acquired by Trimble Navigation in the year 2012. Vico Software Inc developed Vico Office, a management software which includes 2D, 3D, 4D and 5D BIM interfaces. The software contains many sub programs to aid and assists in coordination, quantity take-off (QTO), cost estimation, project scheduling and production control. Some of the solutions of this software include:

a) Vico Office Document Controller:

Vico Office Document Controller is a 2D/3D change management solution. This tool is able to compare and identify the changes, deletion, and/or additions of 2D and 3D model

versions. It is built specifically for design managers, document managers, BIM managers, and field engineers who need to reduce project risk by locating otherwise missed changes very early in the project. Once located, the changes can be clouded and annotated and logged in the Vico Office Issue Manager. These issues can then be directed for discussion, or even to estimators or modelers to consider the impact of changes. The new model versions can be activated for quantity take-off and those new quantities will update schedule and cost plan.

b) Visualisation 3D

Vico Office allows for opening 3D models with popular BIM authoring tools such as Autodesk Revit, AutoCAD Architecture, AutoCAD MEP, ArchiCAD, Tekla Structure, Graphisoft. The software has also additional importers for the use of Google SketchUp, CAD Duct, 3D DWG and IFC files.

c) 3D BIM for Clash detection

The feature known as 'Vico Constructability Manager' is able to make clash detection in the models and also can coordinate resolution for the issues. The clash detection that Vico does is different from the traditional one, they propose a new solution for the typical preconstruction challenges: the coordination can be quickly and effectively analysed in terms of its effect on quantity counts, schedule and estimate.

d) 3D BIM for quantity take-off

Vico Office has the 'Takeoff Manager' tool that enables to produce automatically take off items, with construction calibre quantities that then can be use for construction cost and schedule planning. The 'Vico Takeoff Manager' generates quick and highly accurate model and location based quantity take-offs derived from 3D models created with leading BIM authoring tools.

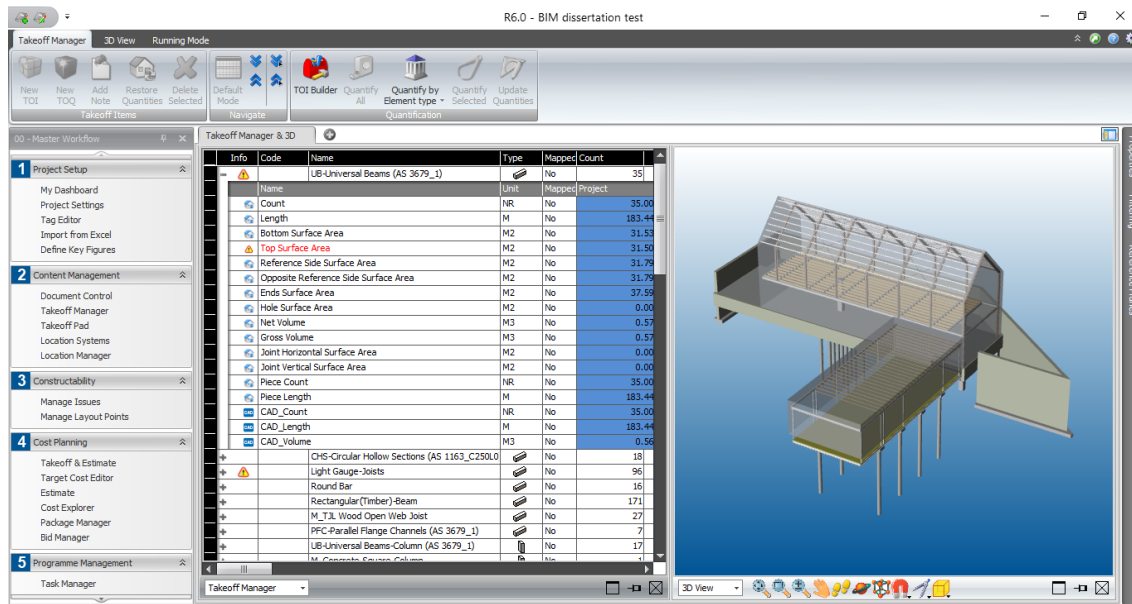


Figure 7 - Vico Takeoff Manager

(Source: from the author using Vico Office with sample project imported from Revit)

e) 4D BIM for construction scheduling and production control

For the scheduling, Vico Office provides a combination of quantities by location, flowline, on-site production control, and communication:

- Quantities by location: the feature used is the ‘Vico LBS Manager’, that enables to divide up the site into manageable areas per trade. All trades are scheduled to optimise location in order to produce a sequence and continuous workflow of the project. These locations are used to perform location-based quantity take-off which is the input for location-based cost and schedule planning.
- Flowline scheduling: this method of scheduling is based on uninterrupted workflow for trades and works along with the locations. The tool used is the ‘Vico Schedule Planner’, that is a scientific derivation of the BIM model geometry for quantities, combined with locations and crew productivity rates.
- On-site production control: ‘Vico Production Controller’ is mostly used during construction phase and helps to manage on-site production. This feature enables measuring work done by location and comparing actuals to planned, helping the Superintendent of the works to see potential problems and conflicts far in advance.
- Communication: with ‘Vico 4D Manager’ a 4D simulation presentation from the 3D visualisation is generated based on quantities by location and crew productivity, based on the schedule that was produced using ‘Vico Schedule Planner’. This feature of communication and analysis can be used to illustrate the schedule to both Owners and sub-contractors.

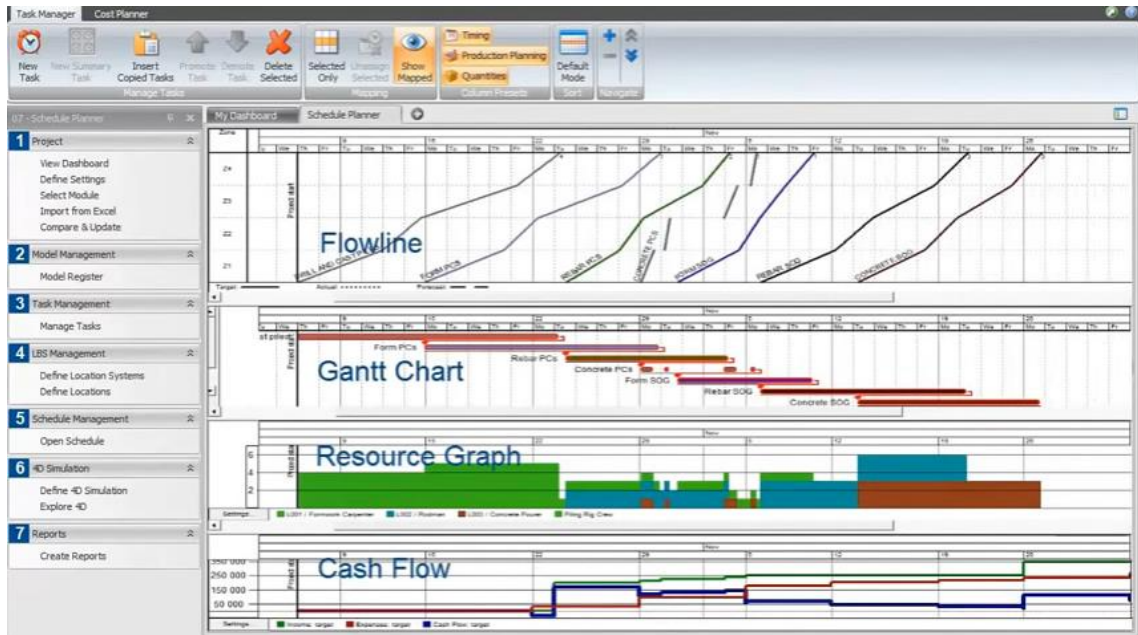


Figure 8 - Vico software 4D BIM scheduling
(Image retrieved from <https://www.youtube.com/watch?v=5I4F4loqk7s>)

f) 5D for estimating

The 'Vico Cost Planner' is a tool that enables a model-based cost estimate, it collaborates with 'Vico Takeoff Manager' to produce estimating, cost calculation faster. With this feature, the estimating team is able to alert the project stakeholders when a design change impacts the cost and by how much, the estimate progresses as more and more details are refined for the project. It includes a library manager, which stores the historical data of the company and used in estimating.

For visualisation of the 3D model in relation to the budget or the schedule there is the 'Vico Cost Explorer'. This tool enables the project team to visually understand where the budget is being impacted due to the changes of the project.

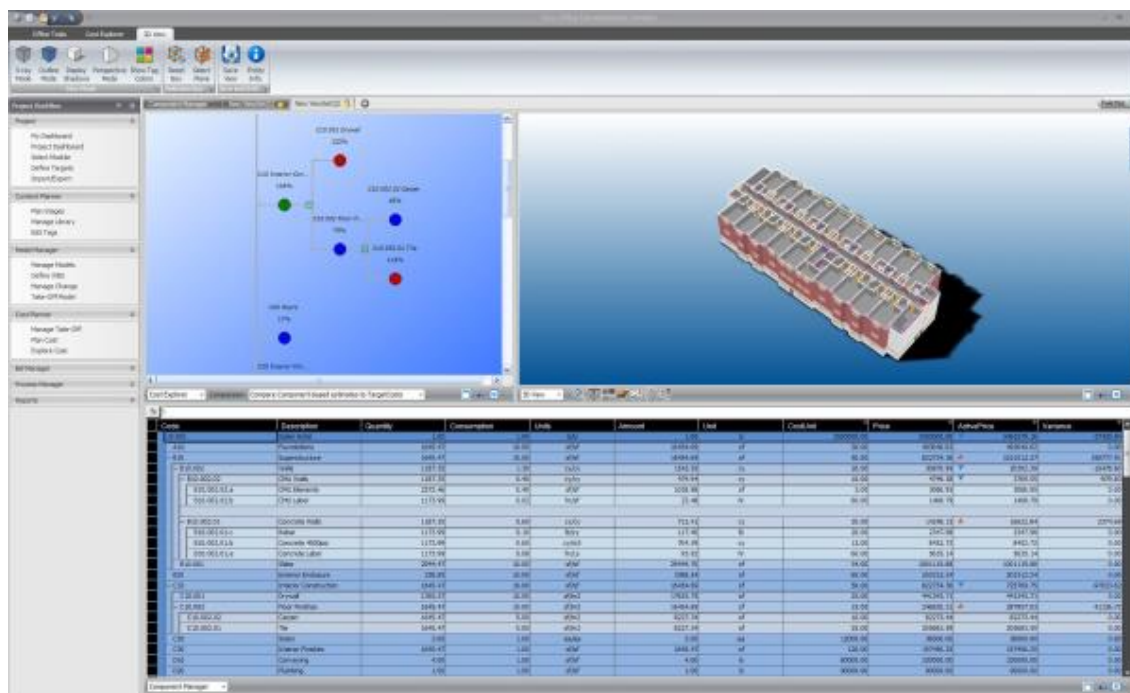


Figure 9 - Vico Cost Explorer
(Image retrieved from <http://www.vicosoftware.com/Vico-Blogs>)

2.1.4. Interoperability

Autodesk defines Interoperability as the “*capacity offered to users of a software to share data with other software tools via a common standard data exchange method [...] these are interoperable, said another way participate in openBIM®. Since these software offerings use the open IFC import and export format and this allows architects, engineers or contractors to integrate data on to BIM objects and to share models*” (Autodesk, 2017).

openBIM® is an initiative of buildingSMART and several leading software vendors using the open buildingSMART Data Model and can be defined as “*a universal approach to the collaborative design, realisation and operation of buildings based on open standards and workflows* “ (buildingSMART, 2016) that allow different stakeholders of a project to share their data, with any BIM compatible software.

buildingSMART is an international, neutral and non-profit organisation that supports, develop and maintain international standards openBIM®.

In 1995, Autodesk organised a private alliance of twelve companies to prove the benefits of interoperability—full information exchange—between the many object-oriented software programs being used in the AEC industry.

The International Alliance for Interoperability (IAI) was established in 1996 and changed its name to buildingSMART in 2008 to better reflect the nature and goals of the organisation:

"Building" applies to the entire built environment and SMART identifies the way to build with intelligence, interoperability, and teamwork to design, build and operate the built environment (buildingSMART, 2016).

Several openBIM® formats include IFC (Industry Foundation Classes), Construction Operations Building Information Exchange (COBie) for BIM data, gbXML, LandXML, and more.

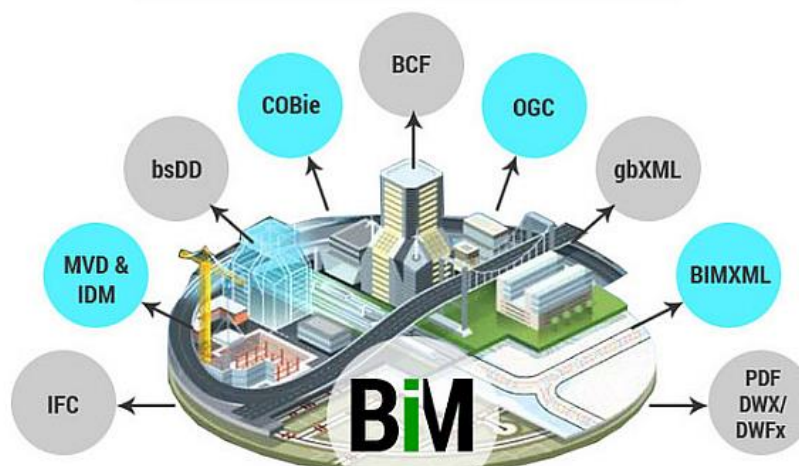


Figure 10 - Open Standards for BIM
(Image retrieved from <https://thebimhub.com/2016/06/26/what-interoperability-really-means-bim-context>)

IFC standard is the leading interoperability standard, for sharing and exchanging BIM data across different software and it is developed and maintained by buildingSMART International as its "Data standard". Since IFC4 it is accepted as ISO 16739 standard.

The IFC data model comprises both geometry and properties of 'intelligent' building elements and their relationships within a building model, to support multi-disciplinary, integrated, open BIM workflows, both desktop and cloud-based, throughout the entire project lifecycle (Autodesk, 2017).

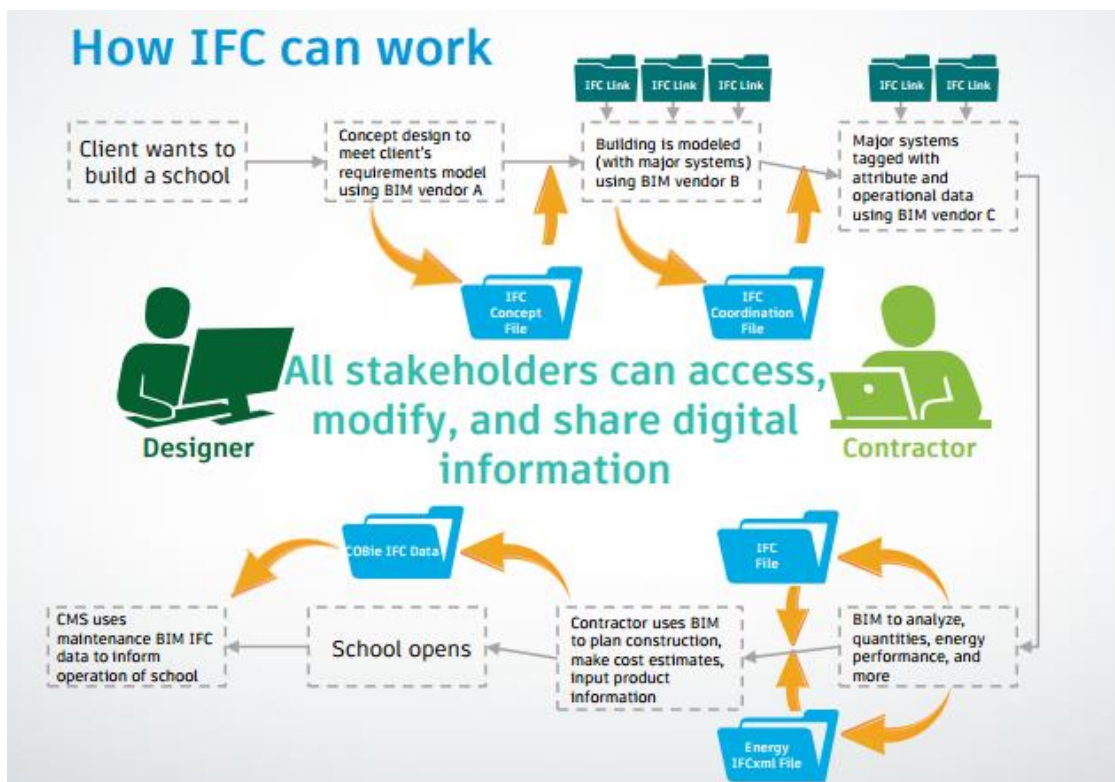


Figure 11 - Interoperability and IFC
 (Image retrieved from http://www.bimalliance.se/library/2174/3f_em_di_giacomo.pdf)

2.1.5. Level of development (LOD)

The Level of Development (LOD) is a concept that have varying definitions and implementations. Essential to the concept is that the level of development defines the content and reliability of BIM elements at different stages or milestones, or in another words describes the level of detail to which a Model is developed and its minimum requirements.

The history of ‘LOD’ started in 2004, when Vico Software (now part of Trimble®) introduced the Model Progression Specification (MPS) concept to facilitate the management of information within BIM models. The ‘LOD’ acronym was thus used for the first time to indicate ‘Level of Detail’ and to establish the progressive reliability of information over a period of time.

In 2008, an analogous concept was adopted by the American Institute of Architects (AIA). The AIA introduced five ‘Levels of Development’ (LOD100 to LOD500) in the *E202™-2008. Building Information Modeling Protocol Exhibit*, which was updated in 2013. Also in 2013, the BIMForum published the Level of Development Specification based on the AIA protocols.

The acronym LOD as “Level of development” it is used in the US national BIM standard, while in the UK BIM standards LOD is an acronym for “Level of Definition”, but both are similar in the concept.

Next it will be explained in more detail how this is implemented in these two common “BIM frameworks”:

- **UK BIM standard - PAS 1192-2**

The UK LOD is defined PAS 1192-2 (Specification for information management for the capital/delivery phase of construction projects using building information modelling) and defines two components to the 'level of definition':

- Levels of model detail (LOD), which relates to the graphical content of models.
- Levels of model information (LOI), which relates to the non-graphical content of models (this defines the development and trustworthiness of the structured data part of the model elements).

The levels of model detail and model information are generally defined for key stages of the project, at which 'data drops' (information exchanges) take place, allowing the employer to verify that project information is consistent with their requirements and enabling them to decide whether to proceed to the next stage. This is analogous to a stage report on a conventional project (Designing Buildings Wiki, 2016).

The levels of model detail and model information defined in the PAS 1192-2 are:

1. Brief: If a graphical model exists it is likely to have been developed from an existing asset information model. Other information might relate to existing buildings and structures (there may also be schedules of requirements).
2. Concept: The graphical design may show massing diagrams and 2D symbols to represent generic elements.
3. Definition: Objects are based on generic representations, and specifications and attributes allow the selection of products.
4. Design: Objects are represented in 3D with the specification attached along with information about space allocation for operation, access, maintenance, installation and replacement.
5. Build and commission: Generic objects are replaced with manufacturers objects, with essential information re-linked to the replacement objects and manufacturer information added.
6. Handover and close-out: The model represents the as-constructed project and all necessary information is included in handover documentation, including maintenance and operation documentation, commissioning records, health and safety requirements and so on.
7. Operation and in-use: Performance is verified against the Employer's Information Requirements and the project brief and if changes are necessary, the model is

updated. Information about maintenance, replacement dates, and so on may be added.

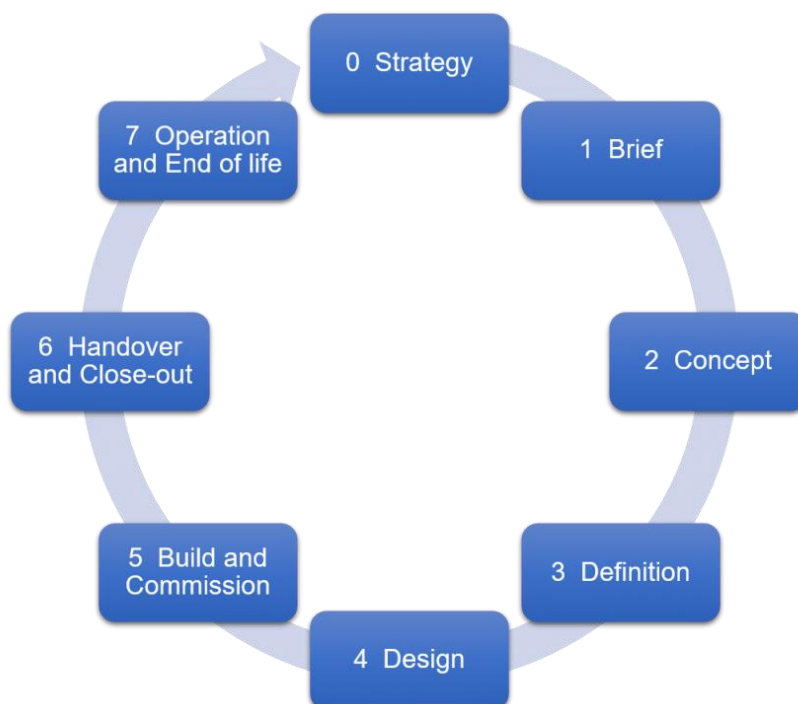


Figure 12 - The work stages defined in PAS 1192: Part 2 and Part 3
(Image retrieved from <https://atkin.co.uk/briefing-for-design>)

The PAS 1192-2 do include a matrix that describe the different levels and their characteristics, for more information see Appendix 1 - Levels of model definition for building and infrastructure projects (Source: PAS 1192-2, p.35-36).

- **The US National BIM standard - NBIMS v3**

In 2011 the BIMForum initiated the development of this LOD Specification and formed a working group comprising contributors from both the design and construction sides of the major disciplines. The working group first interpreted the AIA's basic LOD definitions for each building system, and then compiled examples to illustrate the interpretations¹⁰.

The Level of Development is accumulative and should progress from LOD 100 at Conceptual Design through LOD 400 at completion of Construction. At LOD 500, the Model is capable of being utilised for operations and maintenance.

¹⁰ Last version released by BIMForum is the 2016 version of the LOD Specification and can be found at <http://bimforum.org/LOD/>

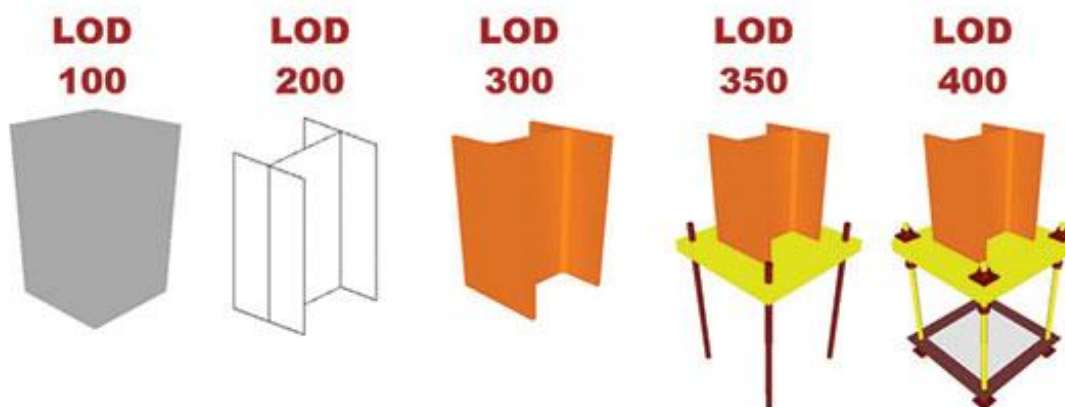


Figure 13 - BIM Level of Development
(Image retrieved from http://sabs.in/sabs_bim/BIM_Model_Development_at_varying_LOD.html)

Following an explanation about the contents of each LOD:

LOD 100:

Level 100 Models include elements such as masses and are used for preliminary studies, such as Conceptual Design and Overall Project Phasing. Analysis based on their location and orientation can be performed. Quantities based on overall area and overall volume can be obtained.

LOD 200:

Level 200 Models include elements in which masses have been replaced with generic components. Analysis based on overall systems can be performed. Quantities based on specific elements can be obtained.

LOD 300:

Level 300 Models include elements in which generic components have been replaced with fully defined assemblies. Analysis based on specific systems can be performed. Quantities based on materials can be obtained.

At LOD 300 the Model can be pulled for the generation of traditional construction documents and shop drawings. The Model can be used for analysis such as: energy performance, clash and cost.

LOD 350:

Level 350 Models include a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

LOD 400:

Level 400 Models include elements that are accurate in terms of size, shape, location, quantity and orientation with complete fabrication, assembly and detailing information. At this level, the Model may also have non-geometric (3D) information such as text, dimensions, notes, 2D details, etc.

At LOD 400 the Model is a representation of the proposed elements. Analysis can be performed such as: energy performance, clash detection, sequencing and cost.

LOD 500:

LOD 500 Models includes elements modelled as constructed. Elements are modelled to accurate size, shape, location and orientation. Non-geometric or physical attributes are included as parameters to the geometric shape. At this level, Model granularity is similar to LOD 400 with exception that elements are as-constructed.

2.1.6. The benefits of BIM

BIM as a collaborative resource of knowledge, can bring a lot of benefits to a project, some are already proofed in various fields of the AEC industry. Following are listed some of the key benefits that can be gained in various areas through the use of BIM:

- Faster and efficient design process - Automated processes and content with linked schedules and quantities ensures that drawings, schedules and bills are produced quickly and accurately enabling the design team to focus on adding value to the design and meeting client goals.
- Quality of Design - Having an intelligent design data from the outset of a project enables a much higher degree of design review with automated scheduling of room areas, dynamic thermal modelling and accurate assessments of project costs from the outset. With BIM it is easier to get design right first time and resolve technical issues which enables designers to focus on quality of design and information produced and minimises unsuccessful work.
- Add value to the Client - Improved views and understanding of the building or infrastructure design, producing realistic 3D images of a building or other asset as required. Also the rapid preparation and exchange of visual information mitigates the time needed for communicating complex ideas and allows more time to be creative for the clients.



Figure 14 - Liverpool Street Station utilities BIM model
(Image retrieved from <http://www.crossrail.co.uk/construction/building-information-modelling/>)

- Prevent errors and avoid problems - With BIM there is an improving of clash detection between all the numerous members of the design team, because there is a linked data that ensure better coordination (drawings and specifications linked), so the problems can be spotted and solved in advance of abortive work on site. When areas of conflict are identified earlier, conflicts over space allocation are initiated and resolved sooner. Earlier clash detection therefore shortens the time required for project design and reduces costs associated with correcting clashes that were undetected during design reviews. Interference detection with BIM is as simple as identifying the elements that need to be checked and running a report. Clash detections also happen as elements are moved or added.
- Better planning - BIM allows for planning, phasing and programming in 3D, what gives the possibility of the construction process happen virtually and plan the build and monitor progress against the plan.

The 4D modelling, that is the integration of a 3D model with a construction schedule, in order to visualise the sequence of construction can be created to various levels of detail, from high-level zone analysis during the design phase, to detailed subcontractor coordination during construction. The same model can be updated and maintained throughout the project based on the updated schedule and 3D model.

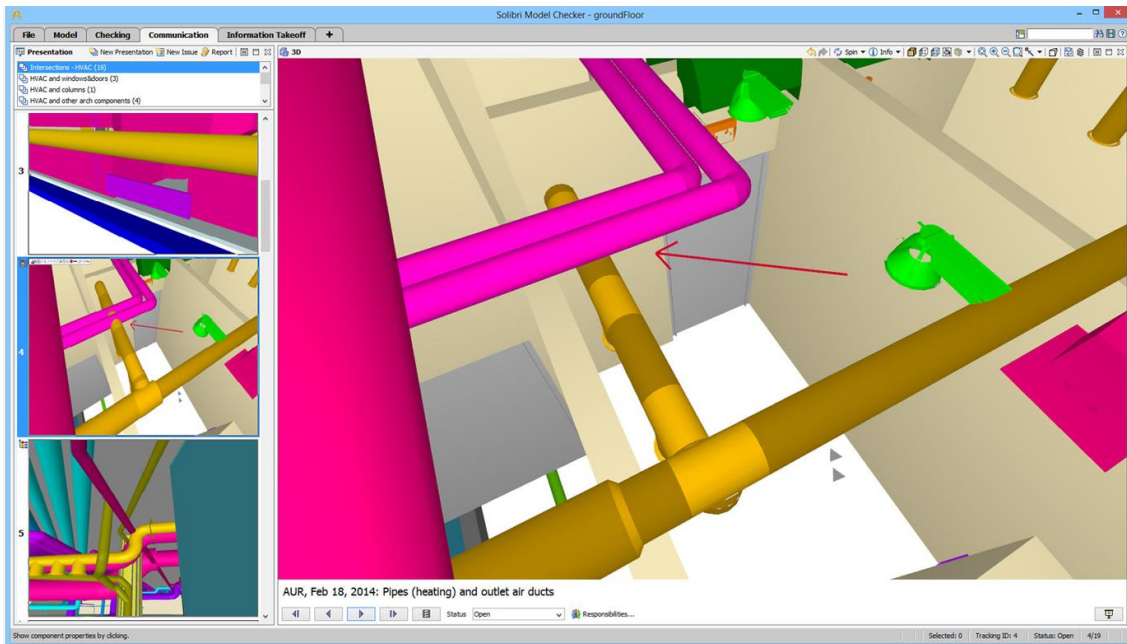


Figure 15 - Clash detection with Solibri Model Checker
(Image retrieved from https://www.solibri.com/wp-content/uploads/2014/01/Solibri_Feature_4.jpg)

- Improved accuracy and efficiency - BIM affords integrators increased accuracy for quantity take-offs. Metadata attached to objects allows for accurate counting and price modelling, improving the accuracy of tenders and project pricing. Integrator scheduling based on material availability and construction progress can be mapped visually. This allows project managers to quickly optimise construction schedules with ever-changing material deliveries, seasonal costs and availability.

BIM helps reduce errors and omissions (E&O) which should in turn reduce E&O claims and professional liability. A reduction in insurance costs, bonding fees and a positive impact on firm reputation should increase the number, scale and variety of opportunities available.

- Add value on site - More intelligent construction information, being all data linked that improves safety, efficiency and understanding of site managers. BIM allows for example to schedule off requirements and components linked to detailed specifications, produce room data sheets or schedules or additional details to order.
- Reduce onsite waste - With BIM there is accurate take-off of quantities, what leads to more efficient management on site, improving waste management and cost savings on site. Being the construction model linked that allows better planning for more efficient ordering and procurement schedules. BIM processes increase productivity, speeds up delivery and avoids rework costs.

- Recognise running costs - BIM permits to understand how the asset such as a building will perform just like comfort levels, running costs and the implications of design changes as they happen.
- Control project costs - With specific type of BIM software it is possible to link the 3D model to property cost planning (5D), which means that the cost of design changes or design options can be continuously reviewed and updated, giving an updated control over project costs. With 5D it is possible to have automated Quantity Take-Offs (QTO) and cost estimating, including the relationships between quantities, costs and locations.
- Better management - Asset management, BIM allows for better understand of the building or other asset, stocking and holding all data about the assets in a central intelligent 3D database. Be able to pull off asset registers of furniture, equipment, lighting etc. in a building for example as and when required, gives a major benefit to understand maintenance requirements. BIM can link data from manufacturers, construction data and communications into one fully integrated and robust facility dashboard, allowing export project data directly into facilities management software using agreed protocols such as COBie.
- Mobile Technology - Access information on the go with the use of cloud based storage of data accessible by all parties over secure access.



Figure 16 - Autodesk® BIM 360™ Docs
(Image retrieved from <https://bim360.autodesk.com/bim-360-docs>)

2.2. Context of BIM in UK

2.2.1. Government construction strategy

In May 2011, The UK Government released the Construction Strategy (now referred to as GCS 2011-15) aimed at reducing the cost of public sector assets 20% by 2016. The major problems identified by the UK Government in the public projects were:

- 10% of construction claims caused by incorrect or incomplete data;
- £2 billions of construction re-work each year;
- Over-design at many stages;
- Data re-created multiple times with process breaks.

To achieve the savings, the government outlined that they will require fully collaborative 3D BIM (also known as BIM Level 2) as a minimum by 2016 for all public projects regardless the size.

Back to 2010, the Department for Business Innovation and Skills (BIS) formed a Working Party to advise the government as the construction client of this national policy to evolution to BIM. They released the “*Strategy Paper for the Government Construction Client Group*” and in this report the BIM adoption is presented as maturing through different stages, called BIM Maturity Levels (more details in the section 2.2.2 of this dissertation).

The major plan for BIM adoption in UK was innovative and pretty much unique in the world: instead of just develop 3D modelling standards, as has been done in other countries, the Report recommended the creation of model process standards and guidance across the entire lifecycle of an asset. Since then this has developed into what is now known in the UK as the 8 pillars of Level 2 BIM (these are explained in the section 2.2.3).

The first public sector scheme to be executed using BIM was a new build of the Cookham Wood Youth Justice Board New Young Offenders Institution¹¹. The client was the Ministry of Justice (MoJ) and the target cost was £20 million including constructions cost, fees and escorts. The main contractor was “Interserve” and the lead designer was “Interserve” supported by “Arup”. MoJ identified BIM as having enabled cost savings of 20% from the rate of £2,910 per square metre anticipated for a comparable project and the rate of £2,322 per square metre achieved in relation to Cookham Wood by the time of establishing the £13,917,505 agreed maximum price.

¹¹ A report from this trial project using BIM can be found at <http://www.bimtaskgroup.org/wp-content/uploads/2013/07/HMYOI-Cookham-Wood.pdf>

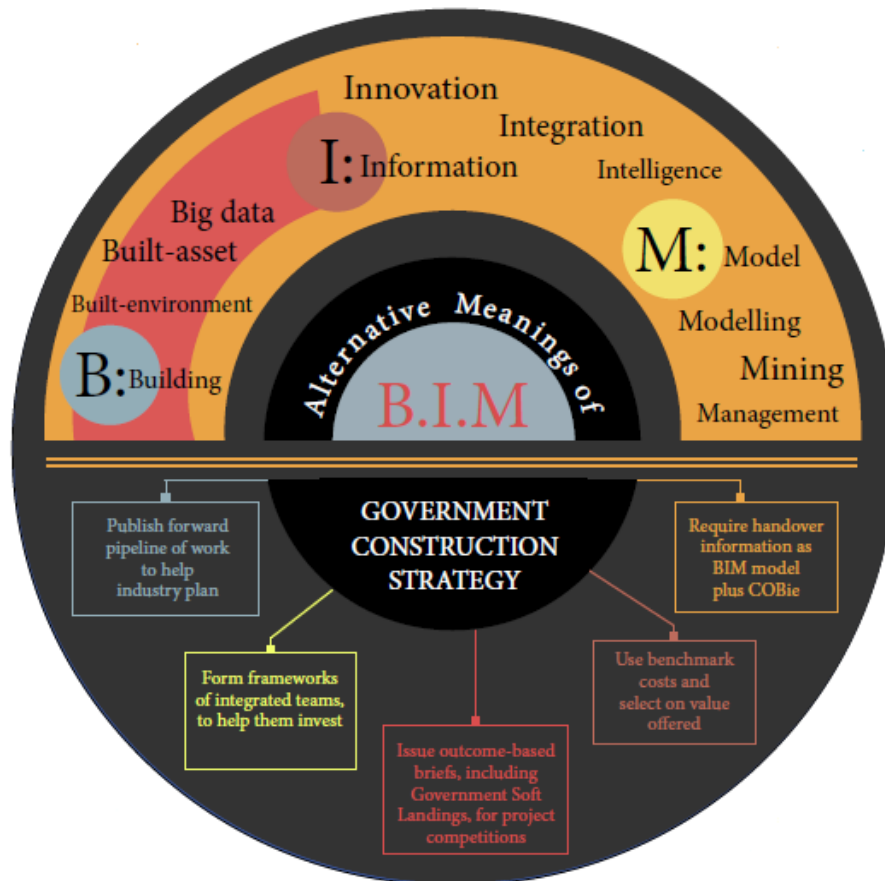


Figure 17 - The different meanings of BIM and the Government strategy
(Source: G Saxon, 2013, p. 7)

In July 2013, the Government published a new Construction Strategy¹², called *Construction 2025, Industrial Strategy: government and industry in partnership* that sets out a series of ambitious plans to ‘radically transform the industry’ until 2025, that are:

- Faster Delivery: 50% reductions in the time taken from planning to completion of projects.
- Lower costs: 33% reduction in the initial costs of construction and whole life costs of assets.
- Improvement in exports: 50% reduction in the trade gap between total exports and imports for construction materials and products.
- Lower emissions: 50% reduction in greenhouse gas emissions in the built environment.

For improve productivity and reduce costs in the industry, BIM processes are once more appointed as essential, promising major benefits through delivering fully transparent data sharing capabilities across the supply chain and pitching BIM beyond level 2. As mentioned in the strategy document “*between 2016 and 2025 it is expected that the UK Government and*

¹² More details can be found at <https://www.gov.uk/government/publications/construction-2025-strategy>

industry will move to Level 3 BIM, which is deeply embedded in the wider digital economy” (for more details in the section 2.2.6 BIM beyond level 2).

The report also refers that with the availability of digital information, the design for manufacture and assembly will be more effective, leading to offsite constructions solutions to be more used in the future. Offsite construction will become a more attractive option, as the demand for low carbon and sustainable construction is keep increasing, the potential of offsite construction to deliver assets with half the waste and 25% less energy in use.

The *Construction 2025* report also talks about “*investing in low carbon technologies, driving up safety standards on smaller projects, focusing on occupational health, creating apprenticeships, clarifying the employment routes into the industry, changing procurement routes and promoting innovation - amongst a number of other areas*”. (The B1M, 2013)

The *Government Construction Strategy: 2016 - 2020* was published by the Cabinet Office and the Infrastructure and Projects Authority (IPA) on March 2016, setting out plans to deliver £1.7 billion of efficiencies and 20,000 apprenticeships.

This strategy is built on the original *Government Construction Strategy* published in May 2011 (GCS 2011-15) and in line with the strategy *Construction 2025, Industrial Strategy: government and industry in partnership*, published in July 2013, which set out a long-term vision for how industry and government would work together to put Britain at the forefront of global construction.

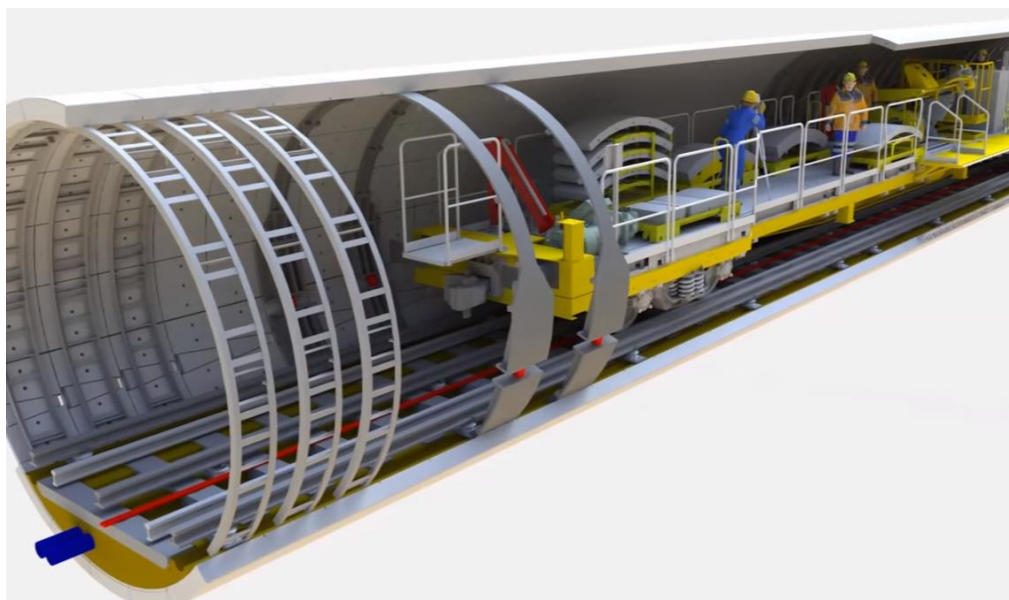


Figure 18 - BIM model render of London Underground renovation
(Image retrieved from <http://www.caddigest.com/bim-101-what-is-building-information-modeling/revamping-london-underground-tunnel-courtesy-of-bentley/>)

2.2.2. BIM Maturity Levels

The UK maturity model - also known as the iBIM model (the name of its highest level) or the BIM Wedge (due to its famous shape) - was developed by Mark Bew and Mervyn Richards in 2008, where are defined three levels of BIM, based not only on the level of technology used to design a built asset, but on the level of collaboration within the process (Bew & Richards, 2008).

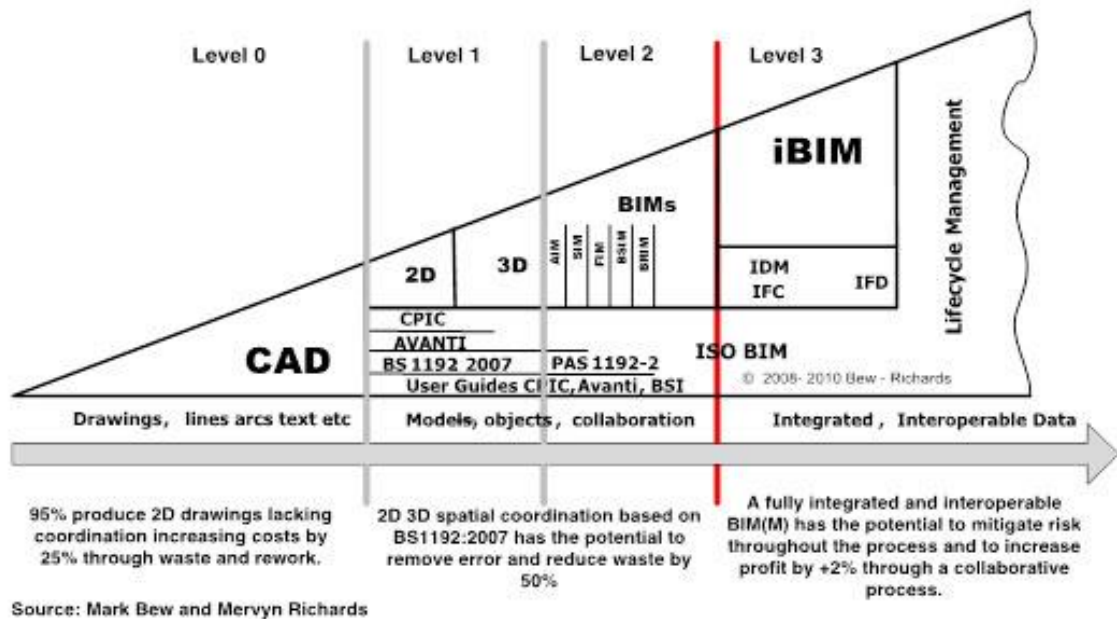


Figure 19 - BIM Maturity Levels (Bew and Richards, 2008)
(Image retrieved from <http://www.bimtaskgroup.org/pas1192-3/>)

In summary, the BIM maturity levels are defined as follows:

Level 0 - as defined by this diagram, is the use of unmanaged 2D CAD files for production information (paper, pdf): a process that most design practices has used for many years. The important point to be resultant from the diagram (from the horizontal line separating data and process management which does not commence until level 1 BIM) is that common standards and processes in relation to the use of CAD have not been able to gain strength as CAD developed.

Level 1 - consists of managed CAD in 2D or 3D format with a collaborative tool providing a common data environment with a standardised approach to data structure and format. Commercial data will be managed by standalone finance and cost management packages with no integration (Mace, 2014). For architects, 3D software had gradually been used as a conceptual design tool during the early project stages and for visualisation of the finished project for presentation to the client. This form

of BIM where only one party utilises the benefits of the model is frequently referred to as 'Lonely BIM' - the BIM model is not used collaboratively between team members.

Level 2 - is a series of domain and collaborative federated models, consisting of both 3D geometrical and non-graphical data, prepared by different parties during the project lifecycle within the context of a common data environment. These models need not co-exist in a single model, the project participants provide defined, validated outputs via digital data transactions using proprietary information exchanges between various systems in a structured and reusable form.

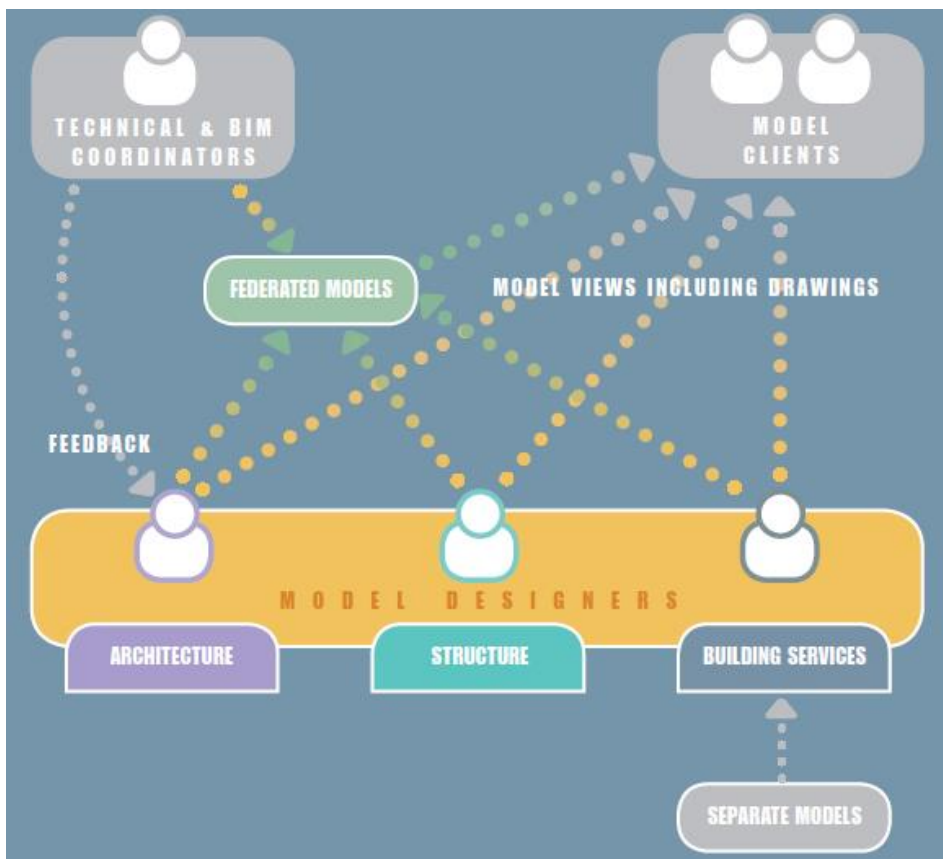


Figure 20 - BIM Level 2 collaboration using a federated model (Shepherd, 2015, p. 55)

Level 3 - is a fully open and collaborative integrated process with a single, shared project model shared between all the disciplines and contributors to a project on a web-enabled BIM hub and compliant with Industry Foundation Class (IFC) standards. Level 3 envisages that all the stakeholders can access, modify and transact using a single, shared project model, held centrally, which would remove the remaining risks of conflicting information and support the development of whole-life approaches.

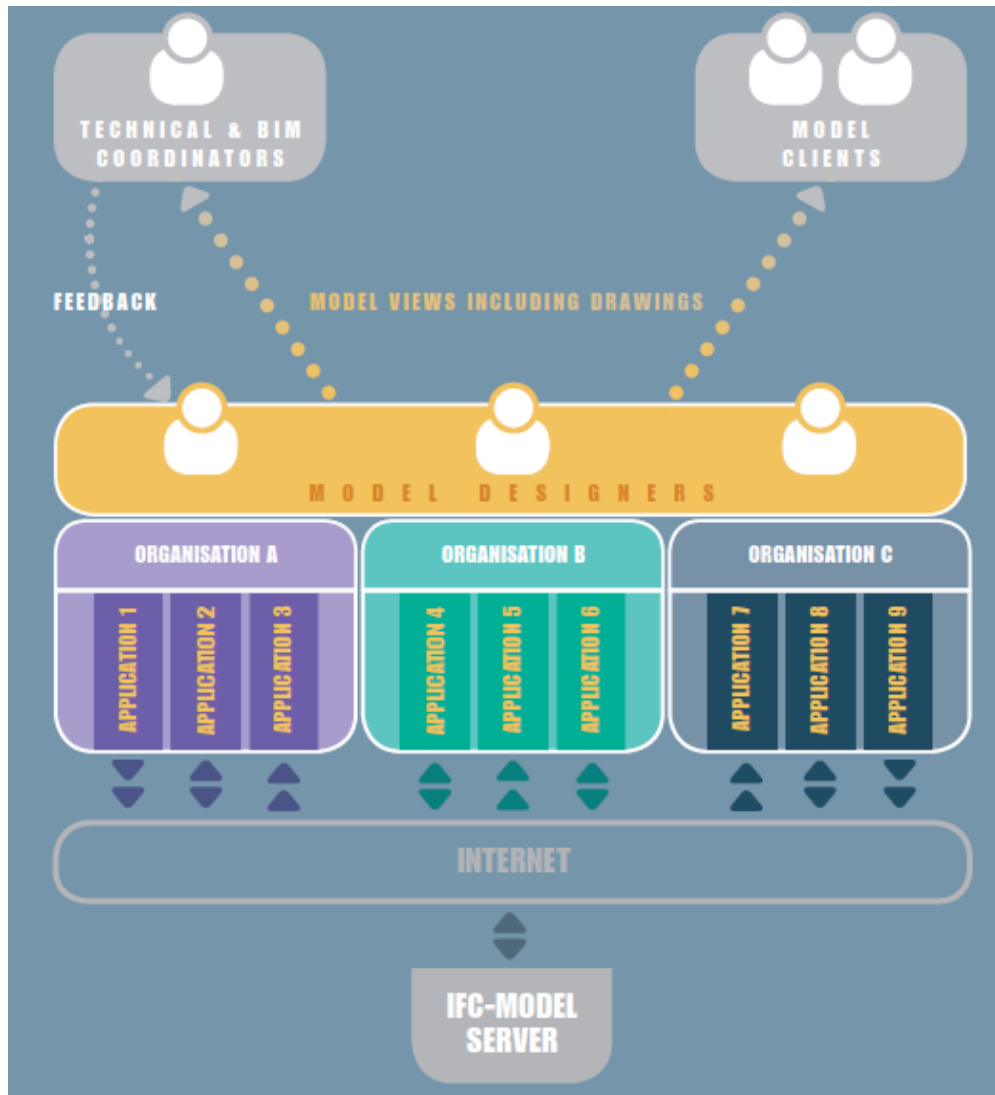


Figure 21 - Collaboration via single shared building model (Shepherd, 2015, p. 58)

RIBA - Royal Institute of British Architects refers that to facilitate the shift from lower BIM levels to level 3 should occur the following:

- collaborative and integrated working methods and teamwork with closer ties between all designers on a project, including designing trade contractors;
- knowledge of databases and how these can be integrated with the building model to produce a data-rich model, incorporating specification, cost, time and FM information;
- new procurement routes and forms of contracts aligned to the new working methods;
- interoperability of software to enable concurrent design activities, for example, allowing environmental modelling to occur concurrent with orientation and façade studies;

- standardisation of the frequently used definitions and a rationalisation of the new terms being developed in relation to BIM; and
- use of BIM data to analyse time (4D), cost (5D) and FM (6D) aspects of a project.

Although Level 3 is related to work on the same single model, that will not be a 'free for all' model, as the software already exists to give read and/or write authorities to each user. Likewise, with more sophisticated design management programming techniques it will be possible to prevent designers working on the same area at the same time: for example, ensuring that the M&E engineer is not adding the grilles to the ceiling plan at the same time that the architect is amending it (RIBA, 2012).

Although BIM Level 3 is still some far, with a number technological obstacles that must to be overcome. Expect to be the future for the UK Construction Industry, following the strategy report published in February 2015 branded as *Digital Built Britain*. In section 2.2.6 of this dissertation it is addressed the subject of BIM beyond level 2 maturity.

2.2.3. The 8 pillars of BIM level 2

Following the original government report in 2011 the definition of Level 2 in the UK has been defined by the publication of 8 documents. These documents are as follows:

- BS 1192:2007
- PAS 1192-2:2013
- PAS 1192-3:2014
- BS 1192-4:2014
- BIM Protocol
- Government Soft Landings
- Classification
- Digital Plan of Works

This suite of documents, the BS 1192 family plus additional documents, have been created to allow customers and all parties involved in the creation of physical assets, to define processes and procedures around the electronic exchange of data sets.

To fully deliver Level 2 BIM on a project the team should adopt these documents. In many cases, all the documents are often considered but not necessarily adopted and so the project is often described as working 'in the spirit' of Level 2. Equally there is not a single version of

Level 2 as these guidance documents allow project teams to pick and choose the precise way they decide to deliver on the requirements.

In the next section, it will be explained what these 8 documents cover and address other relevant codes and standards in force in UK.



Figure 22 - The “8 pillars” of BIM Level 2
(Image retrieved from <https://www.slideshare.net/BIMUserDay/5th-qatar-bim-user-day-perspectives-on-uk-bim-standards-local-adoption>)

2.2.4. Codes and standards

- **BS 1192:2007 - Collaborative production of architectural, engineering and construction information. Code of practice**

This is the foundation document to UK BIM processes. It describes the collaboration management processes that a project team are required to adopt for issuing information and provides a numbering system template so that information can be searched on electronic data bases.

- **PAS 1192-2:2013 - Specification for information management for the capital/delivery phase of construction projects using building information modelling**

This document builds on the processes described in BS 1192 and defined how data is to be managed during the construction phase of a project; also known as the CAPEX - or capital

expenditure phase. It gives guidance on the processes required and recommends the use of several template document documents like:

- the Employers Information Requirements (EIRs): comprises the employer’s expression of what information they require from the project and the format it should be presented
- the BIM Execution Plan (BEP): that is the supply’s chain response to the EIR showing how it will meet its requirements

It also describes the project information model (PIM), i.e. the information model developed during the design and construction phase of a project. It is developed initially as a design intent model and then becomes a virtual construction model.

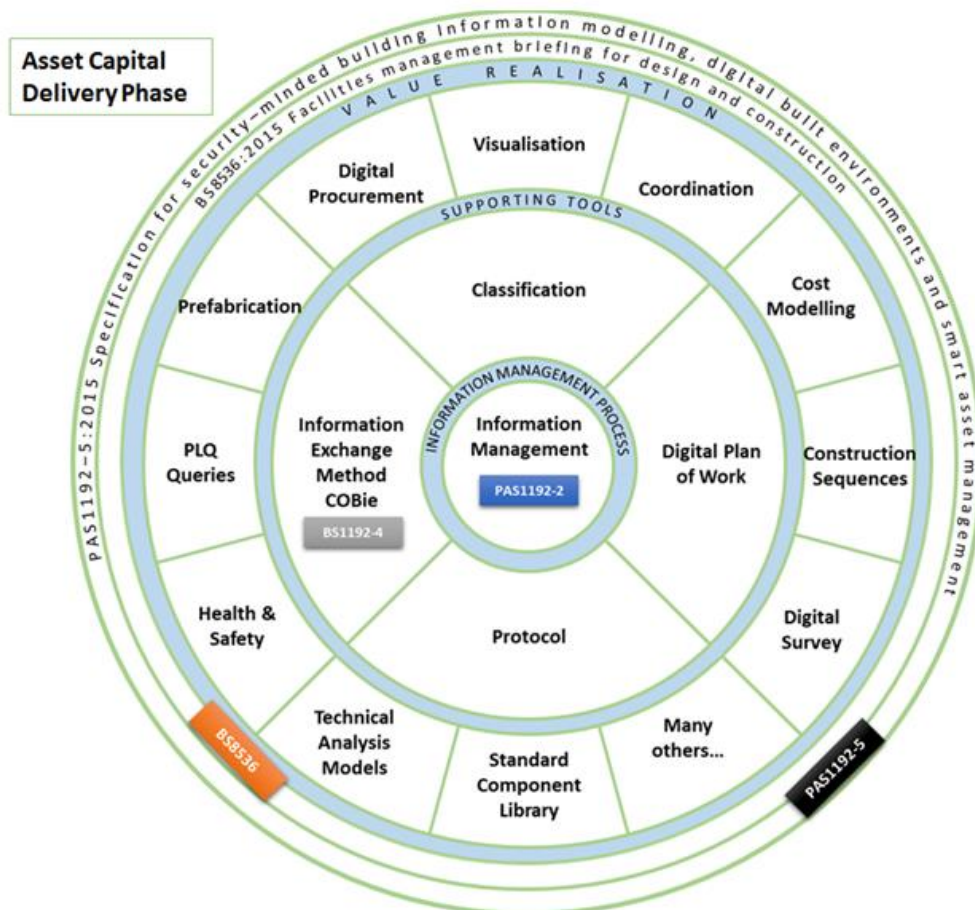


Figure 23 - Some of the components of Level 2 BIM (CAPEX)
 (Image retrieved from <https://www.thenbs.com/knowledge/completing-bim-level-2>)

- **PAS1192-3:2014 - Specification for information management for the operational phase of assets using building information modelling (BIM)**

PAS 1192 is the partner document to PAS 1192-2 above but deals with the Operation Phase of an asset - OPEX and therefore the management teams should access construction information

and built upon the data set for the operational lifecycle of the asset. Nevertheless, this isn't after Practical Completion - it's also about setting out the data requirements right from the commencement of a project. New concepts appear in this PAS such as:

- Organisational information requirements (OIR) - i.e. the information which the organisation needs to know to run the business.
- Asset information requirements (AIR) - that includes the information that the organisation needs about the asset it is responsible for.
- Asset information model (AIM) - comprises the information or data set which describes the asset.

This document is very important for the FM industry since it establishes the need for comprehensive and accurate information (the AIM), which can be used as the basis for all asset-related decision making. Yet, it also requires that the AIM is maintained to accurately reproduce the asset condition.

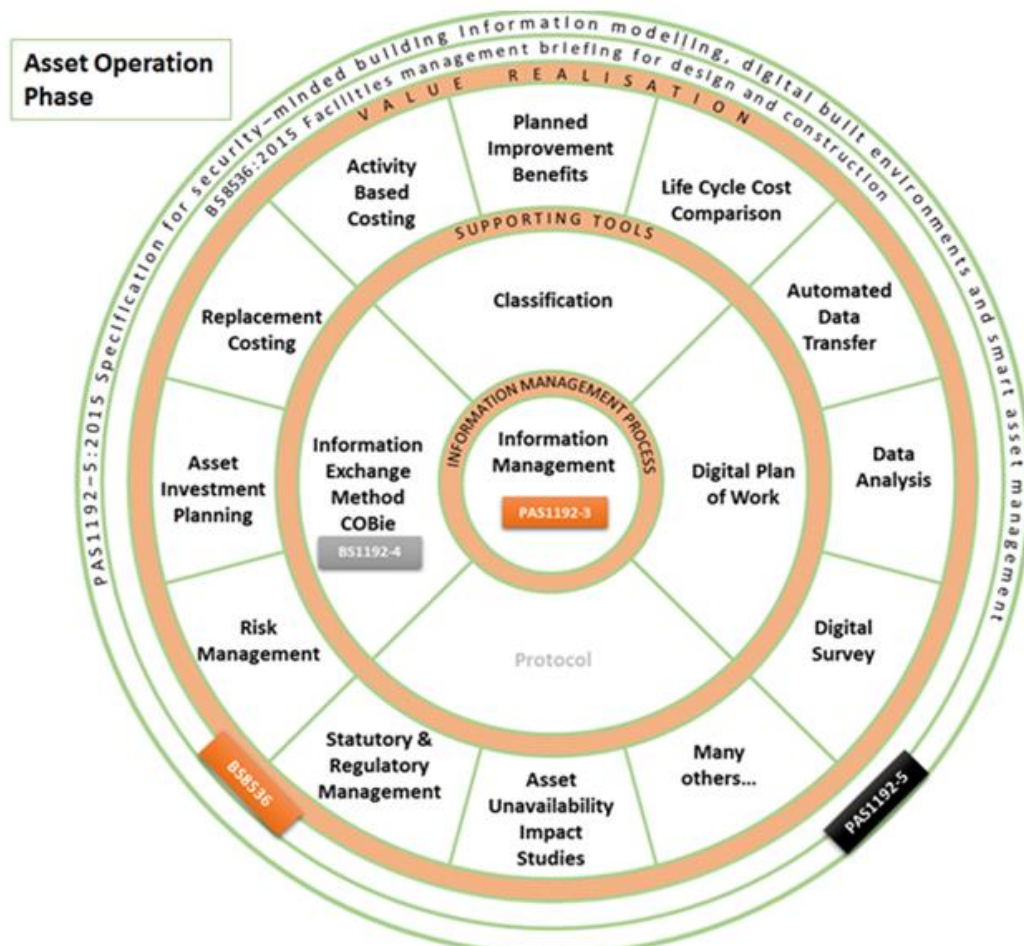


Figure 24 - Some of the components of Level 2 BIM (OPEX)
 (Image retrieved from <https://www.thenbs.com/knowledge/completing-bim-level-2>)

- BS 1192-4:2014 - Collaborative production of information. Fulfilling employer’s information exchange requirements using COBie. Code of practice

This document defines requirements for the exchange of information throughout the lifecycle of an asset, and includes requirements for reviewing and checking for compliance, continuity and completeness.

COBie¹³ is the UK Government’s chosen method of exchanging data, primarily the non-graphical portion, for federated BIM Level 2.

A federated model means a model consisting of linked but distinct component models, drawings derived from the models, texts, and other data sources that do not lose their identity or integrity by being so linked, so that a change to one component model in a federated model does not create a change in another component model in that federated model (Mace, 2014).

COBie captures the information created during design, construction and commissioning and allows this information to be passed directly to the building operator (client) often in the form of a Excel neutral spreadsheet for the Operations and Maintenance (O&M) and Facilities Management (FM) of the asset. COBie is defined internationally in ISO 16739:2013.

Name	CreatedBy	CreatedOn	Category	ExtSystem	ExtObject	ExtIdentifier	Description	Elevation	Height
First Floor	bjerold@je.com	2009-11-04T11:08:38	Floor		IfcBuildingStorey		First (primary) floor	0.00	44.25
Roof	bjerold@je.com	2009-11-04T11:08:38	Roof		IfcBuildingStorey		Roof and roof space	44.25	0.00
Site	bjerold@je.com	2009-11-04T11:08:38	Site		IfcBuildingStorey		Surrounding site	0.00	0.00

Yellow: Required, checkable data

Purple: Required if linked with applications

Green: Requirable Fields (see contract specs)

Salmon: Keyed in from other sheets

Figure 25 - Extract from a COBie spreadsheet and colour meaning (Wallbank, 2016) (Image retrieved from <http://blog.viewpoint.com/category/bim/cobie/>)

¹³ COBie (Construction Operation Building Information Exchanger) format data scheme was developed in the USA and used worldwide as a sub set of IFC, Industry Foundation Class

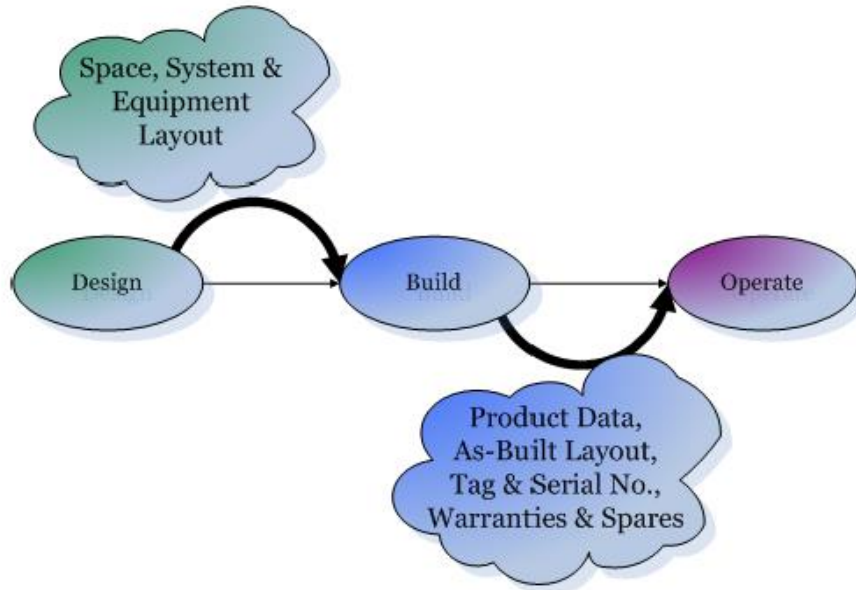


Figure 26 - COBie flow diagram (BIM Industry Working Group, 2011, p. 60)

- **PAS 1192-5:2015 - Specification for security-minded building information modelling, digital built environments and smart asset management**

This document specifies requirements for security-minded management of BIM, digital built environments and smart asset management. The purpose is to help all those involved in providing and operating assets understand the security implications - both physical and cyber - that sharing increasing amounts of data may have.

The PAS addresses the stages essential to create and encourage an appropriate security mind-set and secure culture within an organisation, including the need to monitor and audit compliance.



Figure 27 - British Standards and PAS from BIM Level 2
 (Image retrieved from <https://www.slideshare.net/thenbs/supporting-the-digital-construction-industry-empowering-you-in-a-bim-world>)

- **BIM Protocol**

To enable introduction of BIM to the construction industry it was important to produce a supplementary legal document that is incorporated into professional services appointments and construction contracts by means of a simple amendment. The BIM Protocol published by the Construction Industry Council (CIC), creates additional obligations and rights for the employer and the contracted party. The Protocol is based on the direct contractual relationship between the employer and the supplier. It does not create additional rights or liabilities between different suppliers.

The Protocol identifies the Building Information Models that are required to be produced by the project team. It puts in place specific obligations, liabilities and associated limitations on the use of those models. The role of Information Management is mandated in the BIM Protocol. The Information Manager has no design related duties.

The CIC BIM Protocol has been designed to be used by Construction Clients and Contractor Clients. It is possible that consultants and contractors will use a version of the Protocol to manage the work of sub-consultants and sub-contractors.

Professional Indemnity Insurance Guidance has been prepared for the CIC following extensive consultation with the Insurance Industry.

- **Government Soft Landings (GSL)**

Soft Landings is a form of graduated handover for new and refurbished buildings, where the project team is contracted to watch over the building, support the occupant and fine-tune the building's systems, for up to three years post-completion (Sands, 2015).

The UK Government has taken the principles of Soft Landings and developed it for use within its own procurement strategy, named Government Soft Landings, or GSL, and its key objective, as stated in The Government Soft Landings Policy is "*aligning the interests of those who design and construct an asset with those who subsequently use it*".

Designers and contractors will be involved with the building beyond its construction completion to ensure that handover becomes a smooth process, operators are trained, and optimum performance outcomes become a focus of the whole team (Mace, 2014).

GSL has identified four focus areas where measurements, key questions and outputs have been identified along the project timeline¹⁴. These four areas are as follows:

1. **Functionality and Effectiveness:** Buildings designed to meet the needs of the Occupiers; effective, productive working environments.
2. **Environmental:** Meet government performance targets in energy efficiency, water usage and waste production.
3. **Facilities Management:** A clear, cost efficient strategy for managing the operations of the building.
4. **Commissioning, Training and Handover:** Projects delivered, handed over and supported to meet the needs of the End Users.

- **Classification and Digital Plan of Works (dPoW)**

The standard classification is based on Uniclass, a common language of communication which enables better exchange and aggregate information for the project teams. This classification of data is a critical process and must to be consistent.

Taking this example, if a designer and a specialist contractor are using the same names to describe their objects it will be easier to substitute one for the other, reducing rework and enabling wider use of the model (Rawlinson, 2015). In other words, Standard Classification of data enables software systems to read accurately and quickly all the data that a BIM involves. In the UK the Uniclass 2015 tables (see Table 3 - Extract of The Uniclass 2015 tables) currently are available in beta version (April 2017 update)¹⁵.

The Digital Plan of Works (dPoW) seeks to define what information is required at what point in the lifecycle of an asset and can be used to allocate responsibilities for creating and issuing this data. The standards built into it enables project teams to collaborate effectively as all parts of the team know what information will be produced and who will be responsible (Rawlinson, 2015).

The output of these two elements is an online tool¹⁶, published by the NBS, which enables clients to prepare a plan of work for a project, which can then be exported for use in other documents such as EIRs. This plan of work allows the user to identify the different outputs required at each stage of the project process, and also to assign the delivery of those outputs to a member or members of the project team (see Figure 28 - Design responsibilities against the project deliverables for a stage .

¹⁴ From the "The Government Soft Landings Policy. September 2012"

¹⁵ Further details can be found at <https://toolkit.thenbs.com/articles/classification#classificationtables>

¹⁶ An overview of the NBS BIM Toolkit can be found at <http://www.thenbs.com/bimtoolkit/>

Table 3 - Extract of The Uniclass 2015 tables

Code	Group	Sub group	Section	Object	Title
Ee_20	20				STRUCTURAL ELEMENTS
Ee_20_05	20	05			Substructure
Ee_20_10	20	10			Frames
Ee_20_20	20	20			Beams
Ee_20_30	20	30			Columns
Ee_20_50	20	50			Bridge piers
Ee_25	25				WALL AND BARRIER ELEMENTS
Ee_25_10	25	10			Walls
Ee_25_55	25	55			Barriers
Ee_25_60	25	60			Dams and levees
Ee_30	30				ROOF
Ee_30_10	30	10			Roofs
Ee_30_20	30	20			Floors
Ee_30_60	30	60			Pavements
Ee_30_70	30	70			Bridge decks
Ee_35	35				STAIRS AND RAMPS ELEMENTS
Ee_35_10	35	10			Stairs
Ee_35_20	35	20			Ramps
Ee_37	37				TUNNEL
Ee_37_50	37	50			Vessels
Ee_45	45				FLORA AND FAUNA ELEMENTS
Ee_45_10	45	10			Planted elements
Ee_45_20	45	20			Grassed elements
Ee_45_30	45	30			Fauna elements

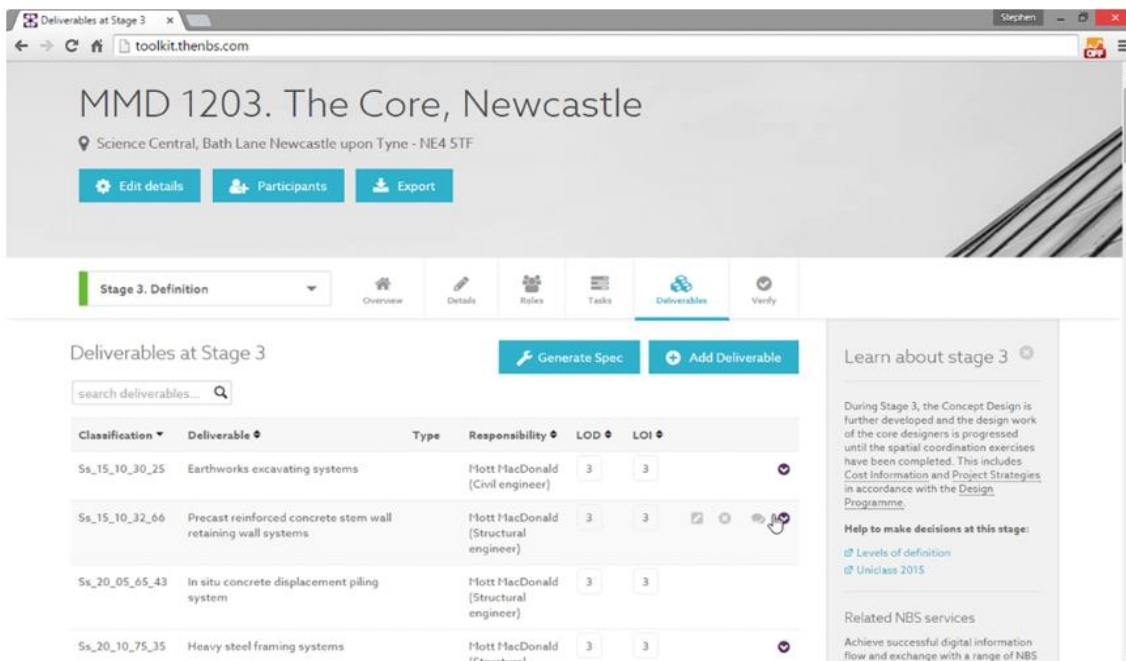


Figure 28 - Design responsibilities against the project deliverables for a stage
 (Image retrieve from <https://toolkit.thenbs.com/articles/an-introduction-to-the-toolkit>)

2.2.5. The Common Data Environment (CDE)

The common data environment is described in PAS 1192-2 as a “*single source of information for any given project, used to collect, manage and disseminate all relevant approved project documents for multi-disciplinary teams in a managed process*”. This digital single source of information is essential to make best use of the potential benefits of collaborative working, where all information created being managed and, when validated and verified (key parts of the process) so they will be made available for use in the future.

The CDE process, according to BS 1192 and further in PAS 1192-2 and PAS 1192-3, includes four major categories:

1. Work-in-progress: where each company or individual works.
2. Shared: output from a company or individual is approved and shared with the wider team.
3. Published: verified and validated information is authorised by the client for contractual use.
4. Archived: store a record of the project history including all transaction and change orders.

The next diagram in Figure 29 shows the CDE process to be followed:

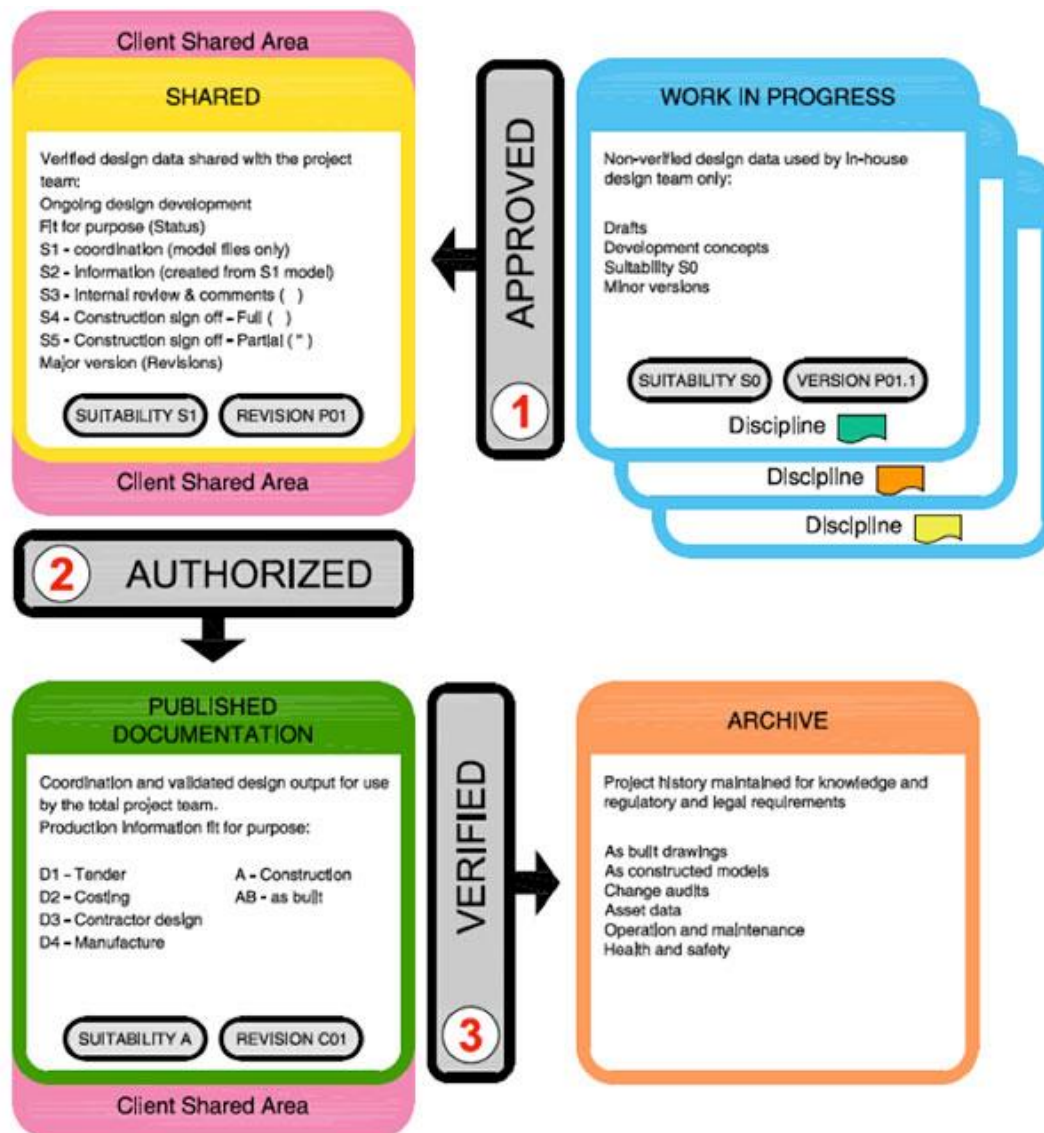


Figure 29 - Document and data management repository

(Image retrieved from <http://blog.viewpoint.com/2016/02/pas1192-process-and-workflows-within-the-common-data-environment-cde/>)

John Sands refers that the CDE process in the design stage, acts as an interface between the client and the design team, capturing documents and data related to the design intent such as client requirements, scheme design reports and the final design solution in the form of 3D models and specifications. In the construction phase, the CDE is used by the constructor as the way for information exchange, in line-up with the exchange points agreed in the EIRs. The in-built validation and verification process ensures that all information received into the CDE is processed and controlled, with only the ‘acceptable’ information or data being passed to the ‘published’ area and made available for wider use (Sands, 2015).

CDE can also provide benefits in the process of the whole asset’s life and increase management efficiency of the asset. CDE should be always available during the asset life so the information hold can be used for helping on making decision on a various aspect of the asset or the surround site, such as providing data to the asset databases.

2.2.6. Beyond BIM Level 2

The delivery of the Level 2 BIM programme in the UK enabled the government to help secure 20% savings on investment focused on the delivery of new assets (CAPEX) as recorded by Cabinet Office case studies against the 09/10 benchmarks (HM Government, 2015).

The Government Construction Strategy: 2016 - 2020 (GCS 2016-20) published in March 2016 suggests the “increasing BIM Level 2 maturity across government will enable departments to gradually move to BIM Level 3, which would support a fully integrated and collaborative process”.

The next generation of digital standards will be developed to facilitate BIM Level 3 under the remit of the *Digital Built Britain* Strategy¹⁷, and early adopter departments will be sought to help understand the full potential benefits of BIM Level 3.

The *Digital Built Britain* strategy (that was released in February 2015) has split BIM Level 3 into logical delivery phases which outline the way that the industry will develop in the coming years. These delivery phases are seen as 4 logical steps:

- Level 3A - Enabling improvements in the Level 2 model
- Level 3B - Enabling new technologies and systems
- Level 3C - Enabling the development of new business models
- Level 3D - Capitalising on world leadership

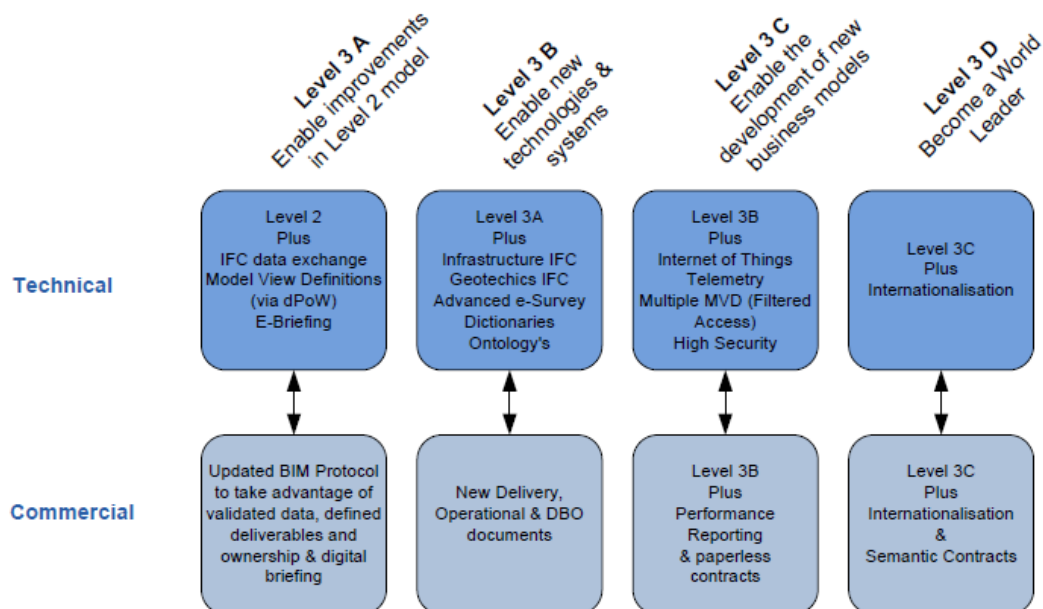


Figure 30 - Deliver model *Digital Built Britain*
(Source: HM Government, 2015, p. 22)

¹⁷ More details in the Digital Built Britain Website <http://www.digital-built-britain.com/>

In each of these steps, we see constant need for the development of digital technologies to enable the improved performance predicted in *Construction 2025* (Watson M. , 2016).

The *Digital Built Britain* Operational Model below helps to demonstrate how *Digital Built Britain* will progress:

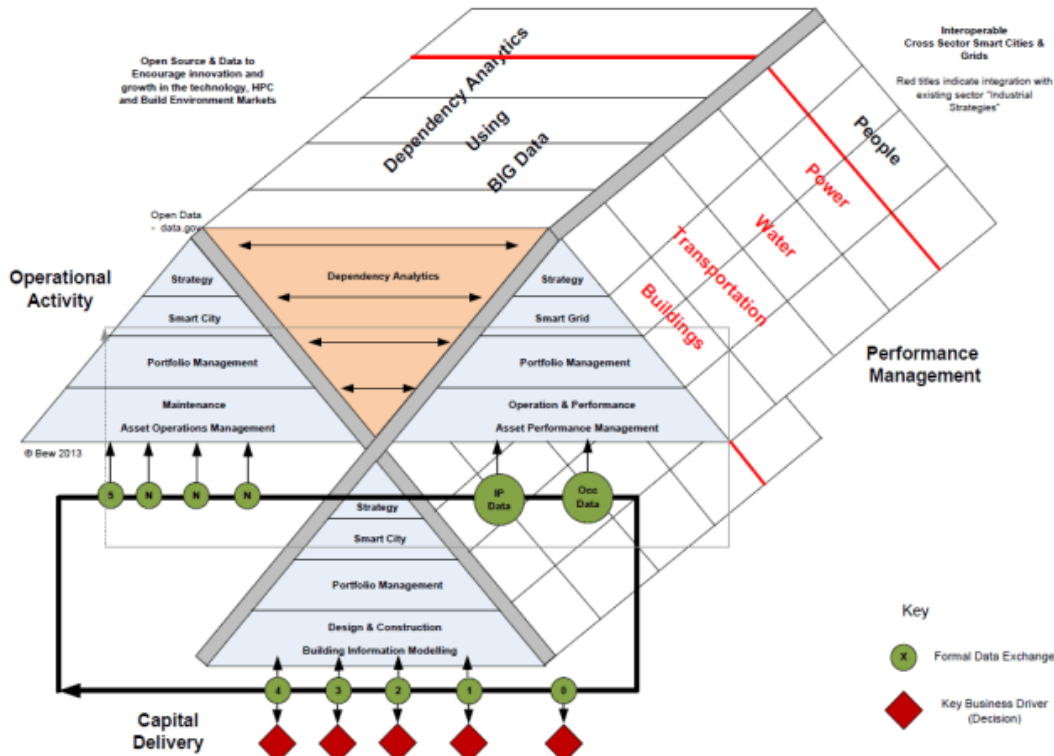


Figure 31 - *Digital Built Britain* Operational Model
(Source: HM Government, 2015, p. 15)

The vision described in *Digital Built Britain* is a completely integrated approach to the management of asset-and project-related data, where information will be seamlessly available to those who need it in a format that allows different stakeholders to reuse it for different purposes. BIM Level 3 will start to make links with other digital innovations and concepts such as building management systems, SMART cities and the Internet of Things (IoT)¹⁸ (NBS, 2017).

Having in mind these predictions, multiple technologies will combine to provide better delivery of more intelligent buildings. RIBA described that with level 3 BIM it will be possible (RIBA, 2012):

¹⁸ IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. (from <http://internetofthingsagenda.techtarget.com/>)

- early ‘rough and ready’ design analysis on environmental performance minimising iterative design time;
- cost models to be quickly derived from the model using new costing interfaces;
- health and safety aspects associated with the construction and maintenance of the building to be analysed parallel with the design; and
- asset management, KPI, and other feedback information to be aligned with intelligent briefing, enabling information in the model to develop during design and to be used as part of a Soft Landings approach, and to inform and improve future projects.

Furthermore, some other technologies that are foreseen today will include (Watson M. , 2016):

- More collaborative and integrated design packages;
- Use of 3D printing and other modern fabrication techniques such as Smart factory automation and DfMA (Design for Manufacture and Assembly);
- Use of embedded sensors to allow us to monitor the condition of our built assets and predict the need for maintenance interventions;
- The availability of performance data sources to enable digital analytics;
- Advances in the internet of things (IoT);
- Connectivity improvements especially in 5G;
- Access to highpower computing (HPC);
- Social Media interfaces and integration;
- Storage and highspeed data access.

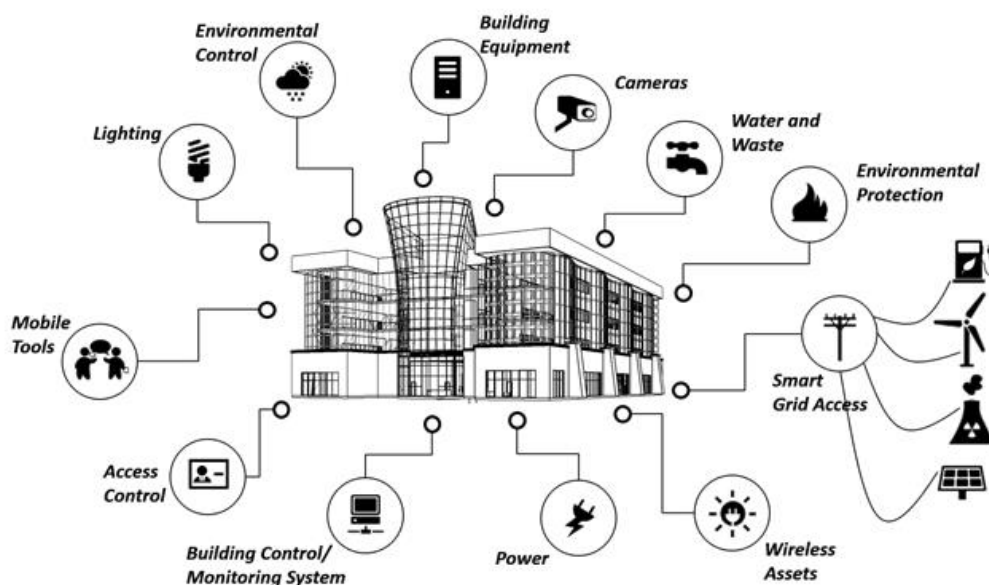


Figure 32 - Buildings and the IoT

(Image retrieved from <https://fmsystems.com/blog/does-bim-have-a-role-in-the-internet-of-things/>)

Chapter 3 - UK Construction supply chain and BIM

3.1. BIM Information Delivery Cycle Process

The approach to BIM in UK involves a ‘Push-Pull’ mechanism, as recommended by the BIM Task Group¹⁹. This means that, as part of the pre-qualification process, the client issues its predefined requirements for the delivery from BIM of coordinate data that will inform its decision to proceed through each project stage (“Push”). Then, the supplier (that can be a lead designer, a main contractor or a supplier) is in charge of coordinate the collection of the information extracted from the combined models of the entire supply chain, in order to comply with the requirements in a capable time frame (“Pull”).

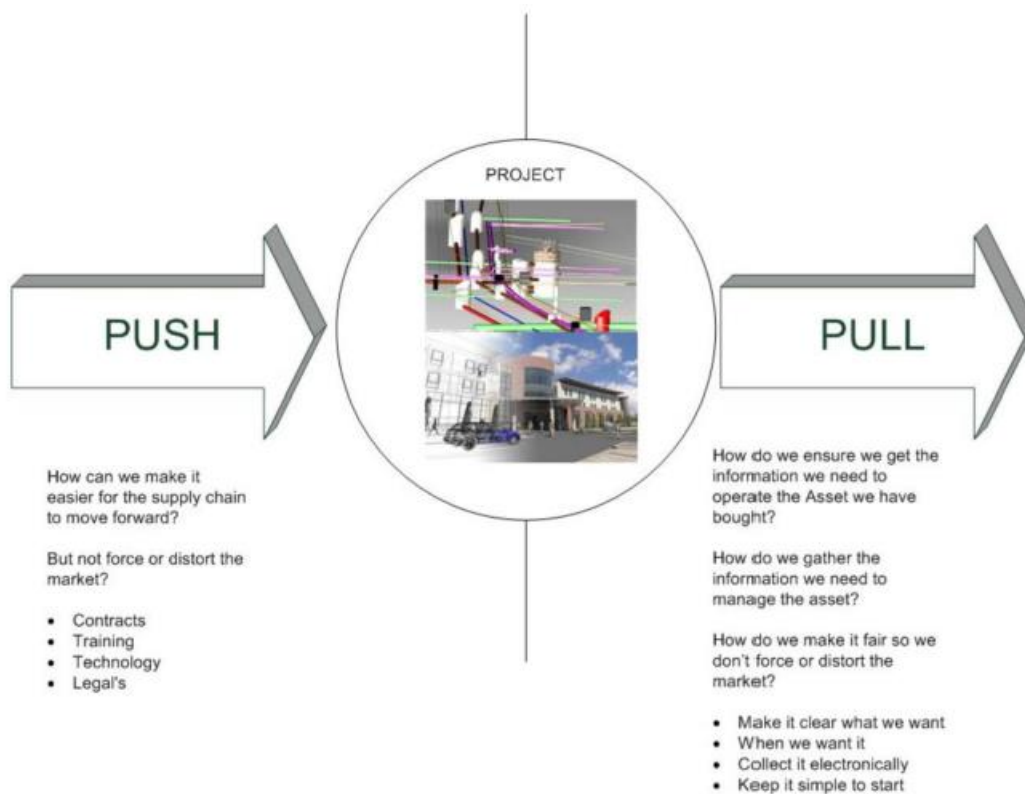


Figure 33 - UK Push-Pull Strategy
(Image retrieved from <http://bim-level2.org/en/guidance/>)

The information delivery and project management cycle (see Figure 34) using BIM process level 2 is defined in **PAS 1192-2:2013**. It is aligned to the latest RIBA plan of work 2013

¹⁹ BIM Task Group is an advisory group established by the UK Government and comprising representatives of major UK construction industry institutions. More details can be found at <http://www.bimtaskgroup.org/>

stages²⁰ (see Appendix 2) and recognises information increasing through the project delivery period to the point of handing over the new asset to the Customer and end user. At this point, with the information at its richest, data is passed to the Customer and end user to enable them to operate their new asset (Handover).

Collectively this data is known as an information model, however it must be noted that a physical 3D model is just one part. BIM is a project delivery process and not just 3D modelling!

The data generated in the project delivery phase sits within the '**Project Information Model**'. After handed over and in operation, this is known as the '**Asset Information Model**'. The model can be continually enriched during the operational phase to assist in managing the asset.

PAS 1192 part 2 covers the project delivery phase (stages 1 to 6) only. The operational phase of a building's lifecycle is covered by a separate PAS, the PAS 1192 part 3.

During the delivery process, all information must be exchanged in a '**Common Data Environment**' (CDE) accessible by whole project team, represented in GREEN elements in the diagram below. In BLUE is the generic process of identifying a project need (which may be for design services, for construction or for supply of goods), procuring and awarding a contract, mobilising a supplier and generating production information and asset information relevant to the need.

²⁰ First developed in 1963, the RIBA Plan of Work is the definitive UK model for the building design and construction process. More details can be found at <https://www.ribaplanofwork.com/>

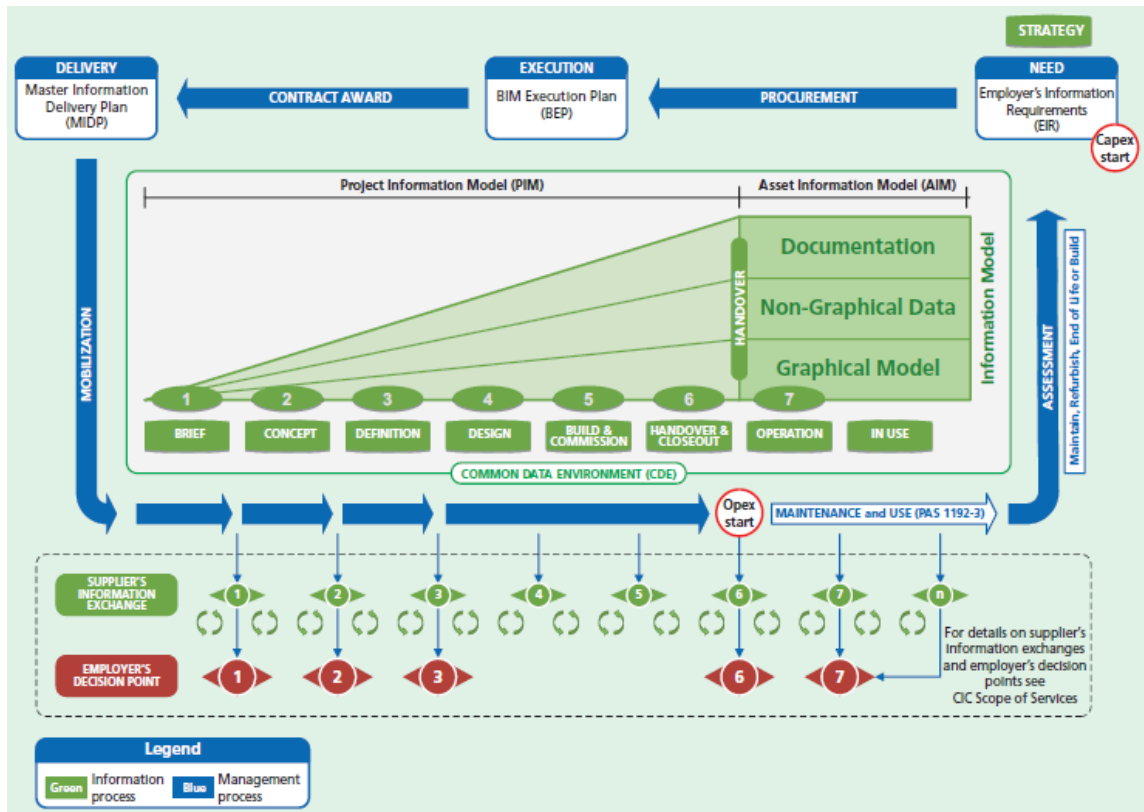


Figure 34 - The information delivery cycle
(Source: PAS 1192-2:2013, p. viii)

PAS 1192:2 sets out clear protocols for the authoring and sharing of information in a CDE once it is ready to be published.

Key documentation is required throughout the project lifecycle to support the process. This starts at the outset of capital expenditure (**Capex**) on an asset with the **Employers Information Requirements (EIR)**. Here the **Strategy** for meeting the Customer's need is determined. The EIR sets out the information that a Customer will require to run their new facility and to make decisions about the development during the project delivery process - in other words, is where is defined the information requirements and how will be managed that information requirements.

Table 4 - Structure of an EIR
 (Source: <http://www.bimtaskgroup.org/bim-eirs/>)

1.1 Technical	1.2 Management	1.3 Commercial
1.1.1 Software platforms	1.2.1 Standards	1.3.1 Data drops and project deliverables
1.1.2 Data exchange format	1.2.2 Roles and responsibilities	1.3.2 Client’s strategic purposes
1.1.3 Co-ordinates	1.2.3 Planning the work and data segregation	1.3.3 BIM-specific competence assessment
1.1.4 Level of definition	1.2.4 Security	
1.1.5 Training	1.2.5 Coordination and clash detection	
	1.2.6 Collaboration process	
	1.2.7 Health and safety/CDM	
	1.2.8 Systems performance	
	1.2.9 Compliance plan	
	1.2.10 Delivery strategy for asset information	

With this strategy in place, **Procurement** can occur and the outline **BIM Execution Plan (BEP)**, based on the EIR, can be created - at this stage is called **Pre-contract BIM Execution Plan**. The BEP demonstrates how, if successful, the bidders will deliver and manage this digital information throughout the project (Pringle, 2015). In another words, is where the potential supplier demonstrates their proposed approach, capability, capacity and competence to meet the EIR in general terms. The BEP is a key document for all parties.

A Supply Chain Capability Summary (SCCS) form should be submitted by prospective suppliers as part of their pre-contract BIM Execution Plan. This will form part of the tender documentation and should respond to the EIRs.

Once the contract has been awarded then the winning supplier is required to submit a further BIM Execution Plan - called the **Post-contract BEP**. This document is where the supplier must set out how the information in the EIR will be provided, and can include items such as: software, roles and responsibilities, CDE, collaborative working, data drops, etc.

Following the process of contract award, the **Master Information Delivery Plan (MIDP)** is also produced. The MIDP sets out the information is to be prepared, who needs to prepare it and the protocols and procedures for its production and release. This can only be developed from the BEP and EIR and it is essential that it is ready prior to the start of the design process.

From this strong basis, the project team can **mobilise** and commence the project delivery process, building their information model in full alignment with the Customer's needs and requirements. This stage of **Mobilisation/Production** includes the following:

- Project information model (PIM) - is developed during the design and construction phase of a project. The PIM should be delivered to the employer containing graphical and non-graphical information.
- Common Data Environment (CDE) - is the single source of information for the project, used to collect, manage and disseminate all relevant documentation, the graphical model and non-graphical data for the whole project team.
- Information exchange: data drops - Generally data drops are carried out at a number of predefined project stages, and the information required reflects the level of development that the project should have reached by that stage. Level 2 compliance requires these to be to the COBie standard.

The cycle is supported by this continual information exchange between the project team and key Customer decisions points throughout: data is extracted from the evolving BIM model and submitted to the client at key milestones ('data drops' or, as referred in PAS1192-2 'data delivery' and 'information exchange'). The nature of data drops should be set out in the EIRs and provides the client with the capability to analyse and check the proposed design at set stages. The Regular COBie Data Drops are produced through all cycle: design, construction and operation phases. The Strategy Paper for the Government Construction Group (2011) identifies when data deliveries should be made - the green circles shows when the data in COBie format is required and what the client benefit (see Appendix 3

At key points in the development of the project, the employer will have to decide whether the project should proceed, whether additional information is required or whether the project should be changed or abandoned. To make this decision such whether to proceed to the next stage or not, the employer will need to answer a series of questions about the developing project (sometimes described as plain language questions - PLQs²¹), which will require that specific information is available.

At the point of **Handover**, operating expenditure (Opex) starts and the **Asset Management** phase begins (this period is ruled by PAS1192:3 as discussed earlier), which includes:

- Asset information model (AIM) - is a maintained information model that compiles the data and information necessary to manage, maintain and operate the built asset.
- Information exchange: data drops
- COBie data (see page 42)
- Government Soft Landings (see page 44)

²¹ For the PLQs see <https://www.thenbs.com/BIMTaskGroupLabs/questions.html>

By possessing a data rich information model, the Customer and end user are able to assess the performance of their built asset and wider property estate over time. This allows them to be better informed when renewing their assets and commencing the delivery process again in the future.

3.2. Support for BIM adoption: Tools, platforms, guides

The definition to adopt Level 2 BIM in the UK as put in place a set of tools and standards that are steadily encouraging the adoption of consistent BIM practice, such as:

- BIM Task Group Website launched:
 - Pilot projects and learning statements
 - Regional BIM Hubs and CPD (Continuing Professional Development) series around UK
 - Standard framework for the BIM curriculum
 - Level2 Website: with all documentation, guidance and support materials

- UK BIM Alliance:
 - Launched in October 2016 and is a cross-industry alliance formed to lead BIM Level 2 and the digital transformation of the construction sector. The focus of the Alliance is the implementation of BIM Level 2 across the wider industry over the next years until 2020, which will establish the essential foundations for BIM Level 3 and digital transformation until 2025.

- Standards and protocols (see section 2.2.4):
 - CIC Protocol
 - Government Soft Landings (GSL)
 - Digital Plans of Work
 - Uniclass 2015

- Standards and protocols - public standards (see section 2.2.4):
 - PAS 1192-2 Specification for information management for the capital/delivery phase of construction projects (Now developing as ISO 19650)
 - PAS 1192-3 Specification for information management for the operational phase of assets
 - BS 1192-4 Collaborative production of information. Fulfilling employers information exchange requirements using COBie - Code of practice
 - PAS 1192-5 Data and process security

- Standards and protocols - BS 8541:

Series of Library Objects for architecture, engineering and construction - provides construction product manufacturers and suppliers with guidance on how to provide product information for inclusion in Building Information Models.

- 8541:1 Identification and classification
- 8541:2 2D symbols
- 8541:3 Shape and measurement
- 8541:4 Attributes for specification and assessment
- 8541:5 Assemblies
- 8541:6 Product and facility declarations

- Standards and protocols - BuildingSMART:

- ISO 16739 Industry Foundation Classes
- ISO 12006-3:2007 Building construction -- Organisation of information about construction works -- Part 3: Framework for object-oriented information
- ISO 29481-1:2010 Information delivery manual -- Part 1: Methodology and format
- ISO 29481-2:2012 Information delivery manual -- Part 2: Interaction framework

- Guides:

- AEC (UK) BIM Technology Protocol | Practical implementation of BIM for the UK Architectural, Engineering and Construction (AEC) industry

- NBS BIM Toolkit (<https://toolkit.thenbs.com/>)

Is a free-to-use digital toolkit for BIM developed by National British Standards (NBS), to help AEC industry to deliver Level 2 BIM, that can be applicable for private or public projects. The NBS BIM Toolkit provides a step-by-step guidance, straight-forward and intuitive way of defining, managing and validating responsibility for information development and delivery through a project's lifecycle. It includes a library of thousands of cross-sector construction level-of-definition templates and a unified classification system. It also includes a free-to-use digital plan of work tool that enables the definition of who is doing what and when throughout a construction project.

Clients can use the toolkit to define their EIR. Potential suppliers (architects, contractors, and so on) can use the toolkit to respond with details of their teams and the services they offer. Once the project moves into the design and construction phases, the toolkit enables teams to grow the digital plan of work, providing information regarding tasks or deliverables to meet the client's requirements. Project teams can also use the tool to digitally verify that a supplier's project data (provided in open standards such as COBie spreadsheets or IFC models) meets the requirements

of the project (containing the appropriate level of information or level of detail for example) (Autodesk BIM 360, 2016).



Figure 35 - NBS BIM tools to support BIM workflow (Source: NBS National BIM Report, 2017, p. 9)

3.3. Current situation of company awareness and levels of BIM adoption

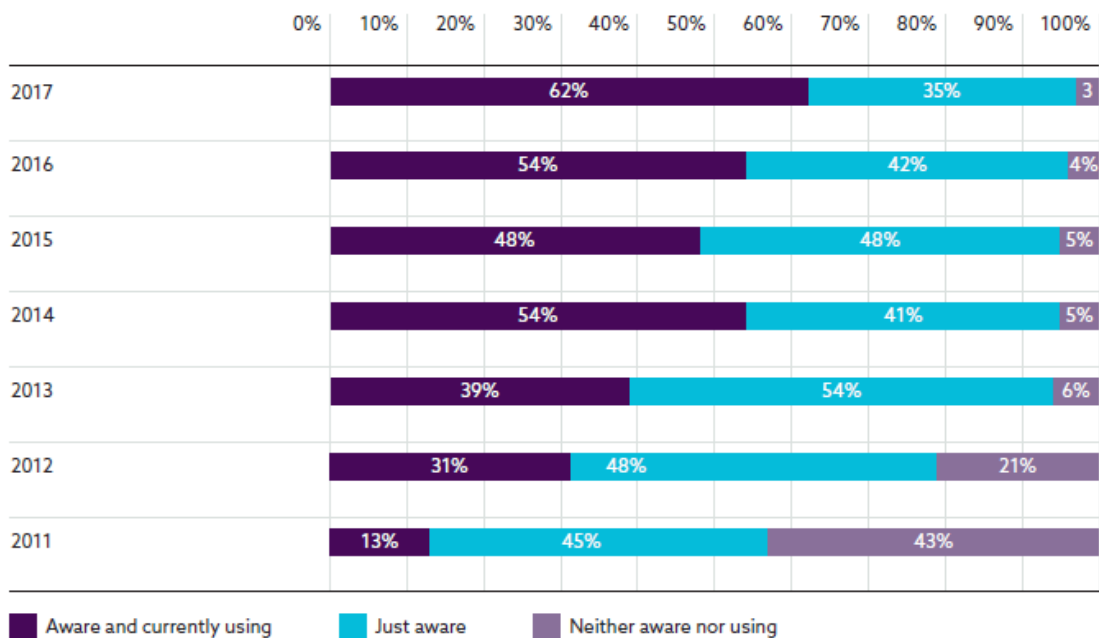
After one year of the mandate of the Government's for Level 2 for central government-funded projects, BIM journey in the UK looks well established according to national NBS report 2017, although there is still work to do.

Taking the current situation of BIM usage and maturity level, the objective is now to move Level 2 BIM to 'business as usual'. Mark Bew says in the 2017 NBS report *"this is where industry needs to lead the transition to BIM Level 2 and spread it across the market, not just centrally-procured public sector projects but local authorities and the private sector"* (NBS, 2017).

Following these years from the 2011 until the 2016 Government’s Mandate, the UK has made a significant change in the industry generating a world-class position in delivering capability, standards and capacity in the sector to decrease cost and growth value.

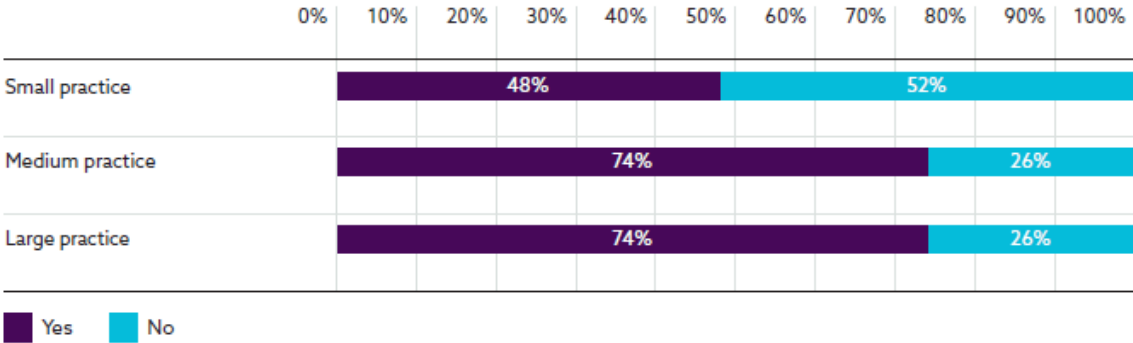
In the survey of NBS 2017, made with more than 1000 professionals across the industry in the UK, the results show that awareness is almost universal, with 97% saying that they aware of BIM where 62% are using BIM on some of their projects and 35% are just aware (see Graph 4 - BIM adoption over the time in the UK).

The graph 4 below shows also the adoption of BIM since 2011, with an increasing over 8% each year, on average, although the rate slowed slightly between 2014 and 2016, which reflects a common adoption curve with the time.



Graph 4 - BIM adoption over the time in the UK (NBS, 2017)

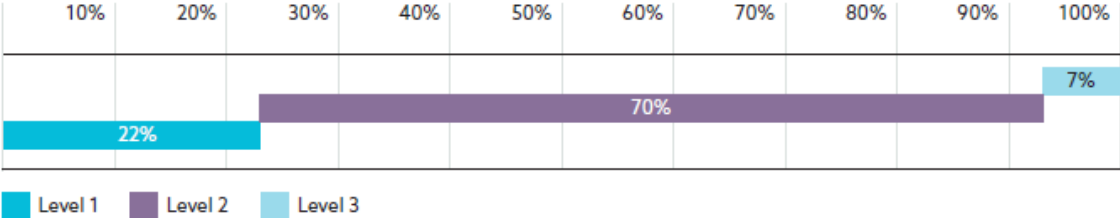
The survey also illustrates that BIM is not only for medium (16 to 50 staff) and larger practices (more than 50 staff), though small practices were less likely to have adopted BIM (Graph 5).



Graph 5 - BIM adoption for the projects by company size (NBS, 2017)

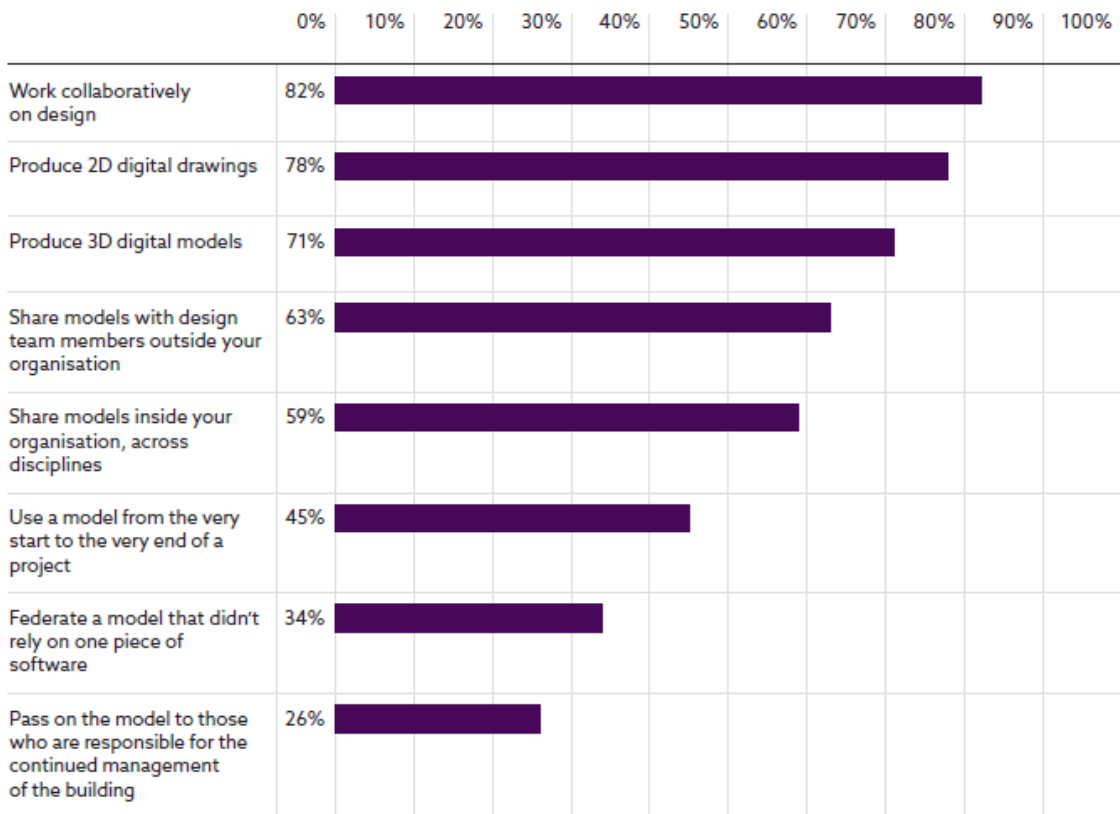
For the coming years for those that are aware of BIM the intent is to adopt BIM, 90% intent to use BIM next year and 95% within three years. Although as mention in the survey report, intentions are not always realised though, and over the last few years it occurred an emerging pattern of actual BIM adoption falling short of what is anticipated.

Regarding to the current levels that people think that reached, the survey reports 22% had reached Level 1, 70% Level 2 and 7% Level 3 (Graph 6). One remark to the Level 3 result, as mentioned in the report probably those who answered Level 3 are perhaps best seen as those pushing collaborative BIM to its fullest current potential, because at this moment Level 3 has yet to be standardised and worked out.



Graph 6 - Highest BIM level that companies recognise to be using (NBS, 2017)

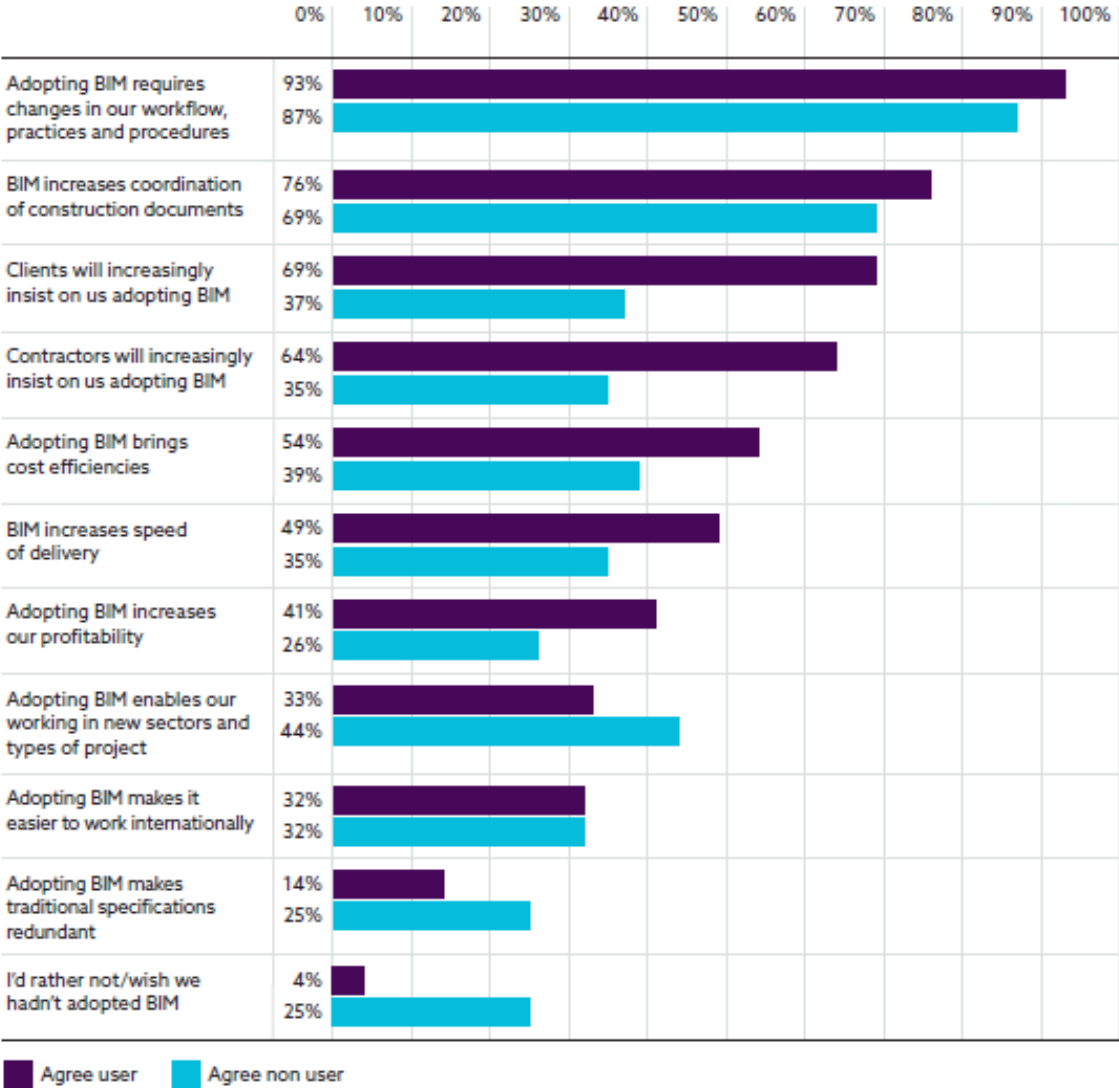
Concerning to those that are using BIM, the survey shows that working collaboratively on design is commonplace (82%) although we can also realise that use a BIM model from the start to the end of a project (45%), or pass a model for building management (26%) are yet not so seen, what confirms that the potential of BIM is yet to be fully realised (Graph 7).



Graph 7 - Main uses of BIM by the companies in the last year (NBS, 2017)

The NBS survey 2017 concludes also that “*experience is better than expectation*”, they looked at the views of those that already adopted BIM and those who haven’t adopted yet. Likewise, most BIM users (93%) agreed that adopt BIM is not an easy task, it involves changes in the workflow, procedures and practices, although majority also see that BIM brings cost efficiencies, and that clients and contractors will increasingly insist on it (Graph 8).

Overall, the findings show that BIM is rapidly becoming the industry standard for developing, delivering and maintaining project documentation (Waterhouse, 2017).



Graph 8 - Views comparison between BIM user and non-user (NBS, 2017)

3.4. Supply chain’s key benefits and challenges involving BIM adoption

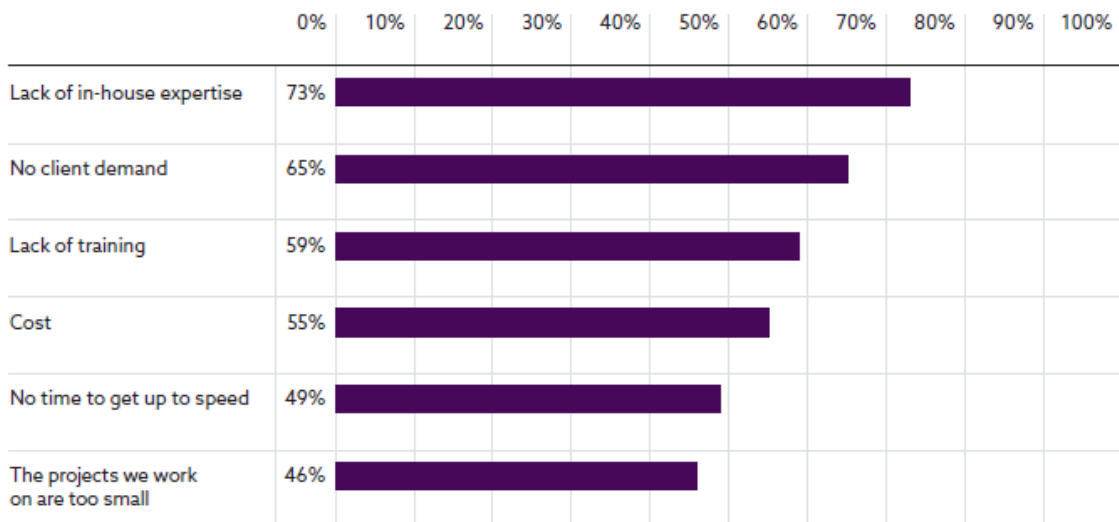
The transition to a BIM collaborative working environment carries a number of challenges and risks, as well as benefits for the supply chain enterprises in the construction sector as a whole. Some of the benefits that BIM can potentially bring have been already addressed in more detail in this dissertation (see section 2.1.6). The key benefits identified by the companies that are using BIM are the following:

- Improved efficiency and collaboration;
- Better design coordination;
- Reduced re-work and fewer errors;
- Improved early decision making;
- Greater certainty of delivery timescales and reduced programs;

- Better management of project risk;
- Lower costs;
- Less waste;
- Reduced health and safety risks - safer projects;
- Better understanding where cost is being occurred;
- Improved coordination and collaboration within the supply chain and with the client;
- Greater client satisfaction.

Regarding to the barriers for those that didn't adopt yet the process (where the majority are small practices), the NBS Survey 2017 identifies and divides in two types (Graph 9):

- Internal, such as a lack of training, expertise, time or available funds to meet the cost of investment.
- External: specifically, a lack of client demand and projects being too small to require BIM.



Graph 9 - Barriers identified by the organisations to using BIM (NBS, 2017)

The above information goes on the same track as Harty, Kouider & Paterson argued, that the technology gap within the construction industry continues to widen between large companies and SMEs/micro-SMEs. The same authors highlighted that working in a dynamic workflow is a major shift in working practices and extends beyond acquiring expensive hardware and software. Furthermore, the learning curve is lengthy and demands sustained training and upskilling of personnel, as well as changes to the organisation's business model (Harty, Kouider, & Paterson, 2016).

3.5. Training and education

BIM is a process for a project delivery or procurement route, not only a technology as we have seen before, thus in addition to the technical software training, there are other different kind of training that will be required to enable this “process-level change” where “the biggest training and education required is that of the mindset” (Kumar, 2015).

To help the training strategy for Level 2, BIM Task Group’s training and education sub-group (BIM Task Group, 2012), published the LoF (Learning Outcomes Framework²²) that provides a checklist of aspects to consider when developing built environment training and education courses (see Appendix 5). In the LoF is defined three distinct categories for any training:

- **Strategy:** this includes training on matters that concern the organisation at the highest levels and should be directed to the top management. Should include the benefits that the organisation may accumulate as a whole in achieving all the key parameters of success that may be working with.
- **Management:** should include training the middle management, both at the organisation and at the project levels. The key aspects of processes and standards that include contractual aspects should be covered.
- **Technical:** this should focus on training related to technological aspects of BIM implementation.

Kumar argued that the LoF does not break down in some other key aspects of training required such as the cultural aspects, in other words, does not cover for example collaborative ways of working such as inter-disciplinary collaboration, teamwork and co-ordination. With effect, imagining a pyramid that represents the key challenges in developing BIM training strategy, he represents in the base the Cultural aspect, followed by the process and protocols and in top the technical training in software, being the easier part.

It is essential that the organisation have a BIM strategy, to enable the required levels of expertise for using the technology and processes. There typically three elements to do this (Kumar , 2015):

- 1st - Have a **‘BIM Champion’**: a person with a passion for BIM and with enough knowledge of the key aspects and issues of BIM;
- 2nd - After the ‘BIM Champion’ be in place, **identify the main challenges** (internal and external) that the organisation might facing related to BIM adoption;
- 3rd - Only after an adequate understanding of the previous issues, develop a **training strategy and policy for the organisation**.

²² More details can be found at <http://www.bimtaskgroup.org/education-and-training/>

Chapter 4 - Case of study: High Speed Two (HS2)

4.1. Introduction to the project

The High Speed Two (HS2) it is the new project in United Kingdom to construct a new high-speed railway that will provide vital transportation links between cities and regions across the UK. The HS2 network will reduce journey times between some of the UK's largest cities and create economic benefits and thousands of jobs.

A company named HS2 Ltd was set up in January 2009 by the Department for Transport (DfT) for the development of the HS2 project.

HS2 line will serve London, Birmingham, Manchester and Leeds and a number of intermediate stations, comprising two phases (Figure 39):

- Phase One: line from central London to the West Midlands. Starting will be at a newly remodelled London Euston Station (Figure 36) Figure 36 - Future new London Euston station platform, it will travel under sections of West London to a new connection at Old Oak Common, to a new interchange outside Birmingham and on to a new Curzon Street Station in central Birmingham (Figure 37).

It is expected to support the creation of around 9,000 construction jobs, 1,500 permanent jobs and 30,000 jobs in station-supported redevelopments.



Figure 36 - Future new London Euston station platform (HS2 Ltd)
(Image retrieved from <https://www.gov.uk/government/news/hs2-plans-can-unlock-euston-potential>)



Figure 37 - View for the new Birmingham Curzon Street Station (HS2 Ltd)
(Image retrieved from <http://www.railway-technology.com/projects/high-speed-2-hs2/high-speed-2-hs25.html>)

- **Phase Two:** The Government's initial preferred route²³ for this phase will run north from Birmingham, forming a Y shape. The eastern leg will connect Birmingham with Leeds (via a new East Midlands Hub and a new station at Sheffield Meadowhall). The western leg will connect Birmingham and Manchester (via a proposed station at Manchester Airport). HS2 Chairman Sir David Higgins has also proposed a hub station (Figure 38) at Crewe to serve North Wales, Merseyside and the North West, and government is considering this.

It is forecast that will support the creation of 48,700 - 70,300 jobs and allow for the building of 5,200 - 7,600 houses.

The HS2 is designed for a maximum speed of 400 km/h (250 mph), although the plan envisages the services will run at up to 225 mph, which is becoming the standard capability for new high-speed trains.

The new stations are planned to accommodate 400m long trains, each capable of carrying up to 1100 passengers. It is expected by the DfT that will be almost 15,000 seats an hour on trains between London and the cities of Birmingham, Manchester and Leeds - treble the current capacity.

²³ The final decision about the alignment of the preferred Phase 2 route is not yet decided



Figure 38 - Crewe: high speed hub proposal (HS2 Ltd)
(Image retrieved from <http://www.building-projects.co.uk/news/farrells-vision-for-northern-gateway-hs2-hub-at-crewe-is-unveiled/>)

The construction of Phase 1 is starting this year of 2017 (with enabling works, utility diversions and demolition) to be ready for the opening to passengers in 2026. The major tunnelling and civil engineering work will start in 2018.

The proposed London to Birmingham line (Phase 1) will be about 225 km (140 miles) long and the total 'Y-shaped' network will be around 531 km (330 miles) long. More than 50% of the 225-km route will pass through cuttings or tunnels, while around 91 km will be partly or completely concealed to reduce noise and visual effects in neighbouring communities. Main civil engineering structures for Phase 1 comprises about 46 km of tunnels, 74 km cuttings, 145 overbridges and 152 underbridges / culverts. It is planned that Phase 1 will need around 31 main compounds and 299 satellite compounds (Charlson & Dunwoody, HS2 Ltd, 2017).

For the Phase 2, the Chairman of HS2 mention in the Report "HS2 Plus" that the route should be accelerated to reach Crewe by 2027 six years ahead of schedule, and serve a new integrated road & rail hub there. The rest of Phase 2 could be accelerated to complete three years ahead of current plans by 2030 (Higgins, 2014).

The first phase of HS2 will cost around £21.4bn to construct and phase 2 has a budget of about £21.2bn. It is estimated that around 26,000 people will work on delivering HS2.

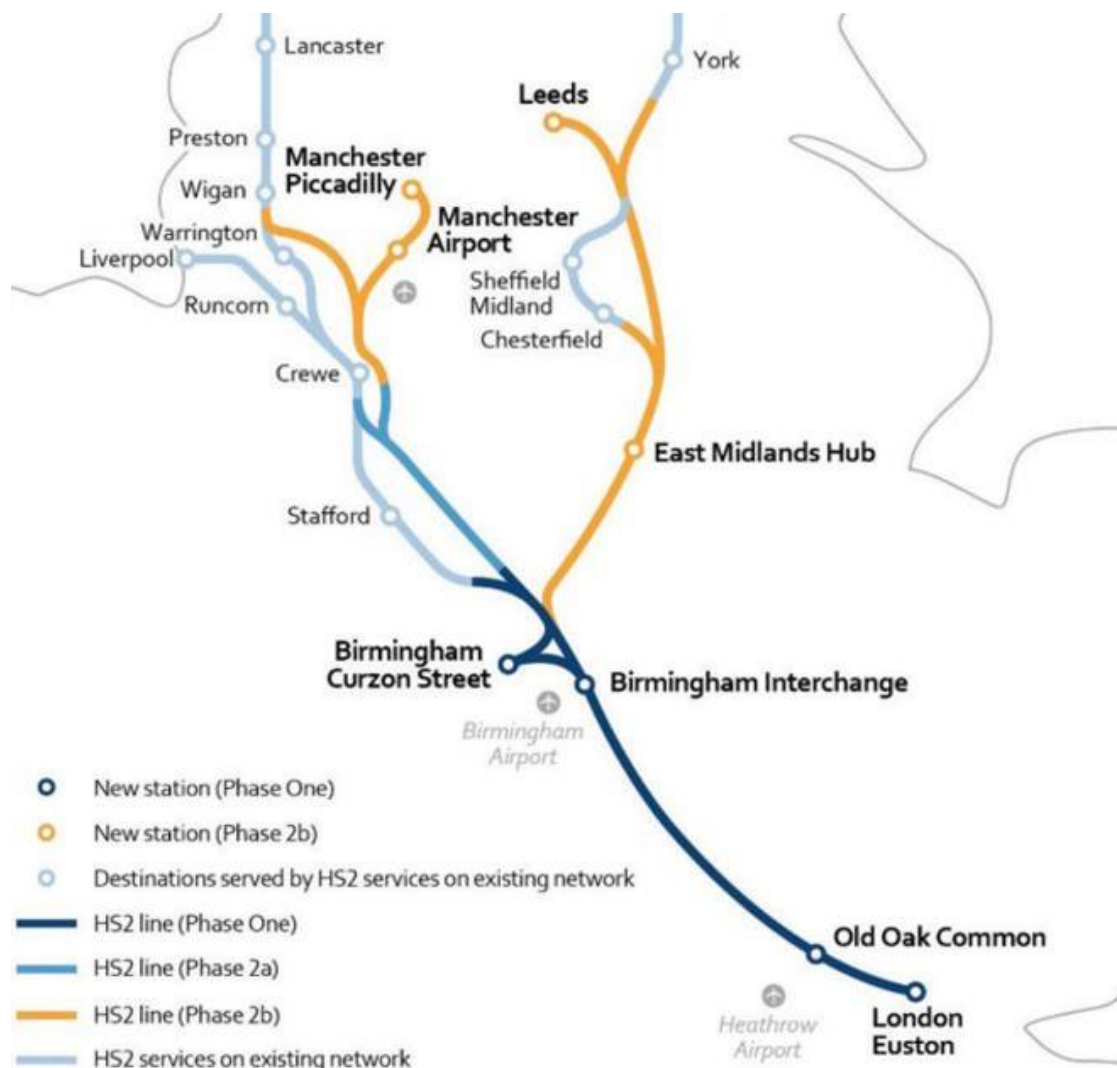


Figure 39 - The new high-speed railway line HS2 (HS2 Ltd)
(Image retrieved from <http://www.bbc.co.uk/news/uk-16473296>)

4.2. BIM in HS2

For procure the first phase of the project, HS2 has defined BIM as a centre stage to delivering the railway, recognising that this serious commitment to use BIM will maximise and ensure that HS2 will delivery on time, on budget and that the project is reliable.

The HS2 Building Information Model will form the “information backbone” of the HS2 network throughout the lifecycle of the project. From feasibility design through implementation and eventual operation of the railway it will grow and evolve with the project, eventually becoming the Asset Information Model for High Speed Two.

The BIM will delivery and manage data in a spatially related and consistent format that encourages interoperability of data and enables collaboration. This consistent and coordinated data will be used to plan, construct, operate and maintain the railway in years to

come. Thus, HS2 consider that the enforcement of BIM within contracts is critical to the long-term success of the project.

HS2 identifies that BIM will facilitate a deeper understanding of the design and its requirements, leading to a better definition and management of the risk and consequently reduction of costs. BIM will be used also to verify and validate project requirements (Oakervee, 2013).



Figure 40 - BIM as a strategic enabler for HS2 objectives
(Image retrieved from <http://www.ontrack4hs2.org.uk/perch/resources/supplier-guide.pdf>)

Beth West (HS2 Ltd) considerer that “*key project enablers will include integrated teams, the use of a common framework, and offsite construction and prefabrication*”. Likewise, Jon Kerbey (HS2 Ltd) identifies that BIM offers a unique opportunity for their whole supply chain to work collaboratively and to share crucial information on design data, stakeholder interactions and asset information before, during and after construction (Kerbey, 2015).

The image below shows the vision of HS2 related to working on a BIM environment: The elements in blues and purples signify the digital railway being created virtually, testing that each aspect of HS2’s proposed plan will go to plan, be reliable and of high quality. Below, in grey colour, is “a road to hell”, building a rail network in an old-fashioned way with cost saving at the forefront of importance (McNaughton, 2015).

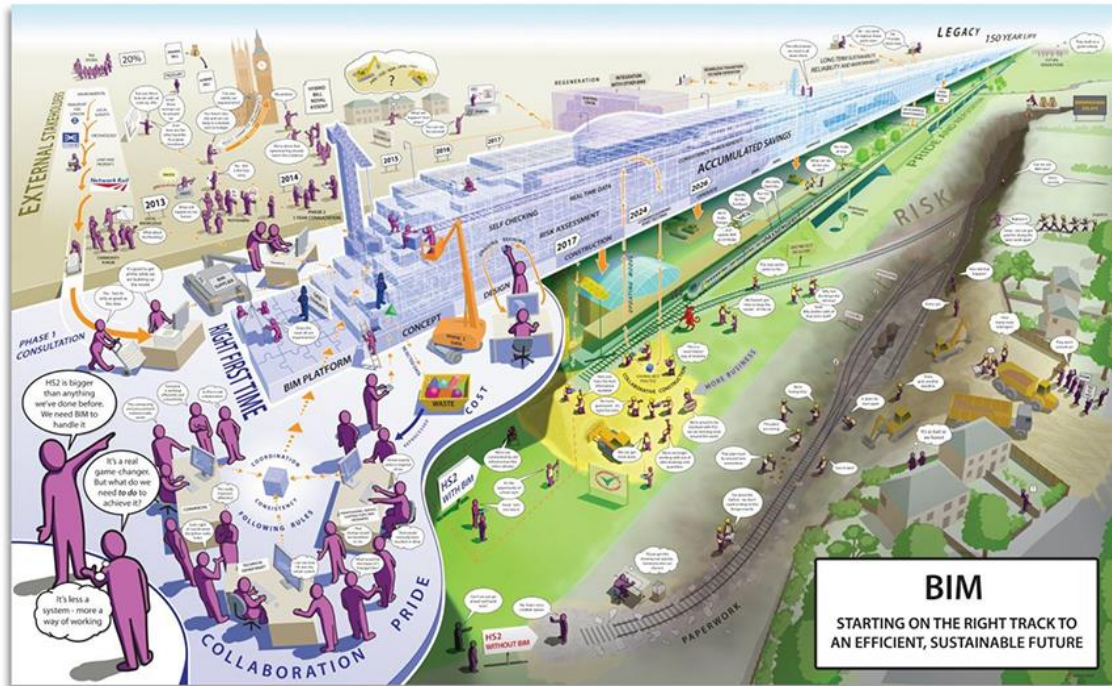


Figure 41 - HS2 vision in a BIM environment (HS2 Ltd)
(Image retrieved from <http://www.bimplus.co.uk/news/hs2-plans-carrot-and-stick-incentivise-contractors/>)

In addition to the importance of using BIM during the design and delivery of the project will be also crucial during the operation and maintenance stage of the high-speed railway.

At present the HS2 team are developing the BIM platform upon which the data for the new railway will be hosted. Every aspect of High Speed Two's operation and maintenance is being built upon one common data environment. That platform will host the safety critical control systems, train control, fleet management, human resource management, scheduling and consumer data (The BIM, 2015).

Professor Andrew McNaughton (Technical Director, HS2) refers that HS2 have this concept of total reliance on our data, being one integrated system and that they are building the BIM platform upon which every aspect of HS2 will operate.

4.3. UK BIM Standards in relation to HS2

HS2 identifies BIM as a key driver for value and they decided that they will required Level 2 compliance as a minimum for the HS2 programme (Figure 42 - Bew/Richards BIM Maturity Diagram with HS2 minimum BIM standard overlay). Their BIM objectives are the following:

- for BIM to be HS2's methodology for electronic storage and usage of data;

- for BIM to help collaboration, off-site, NEC, ECI;
- for HS2 to achieve BIM Level 2 by 2016;
- to buy (and make best use of) data.

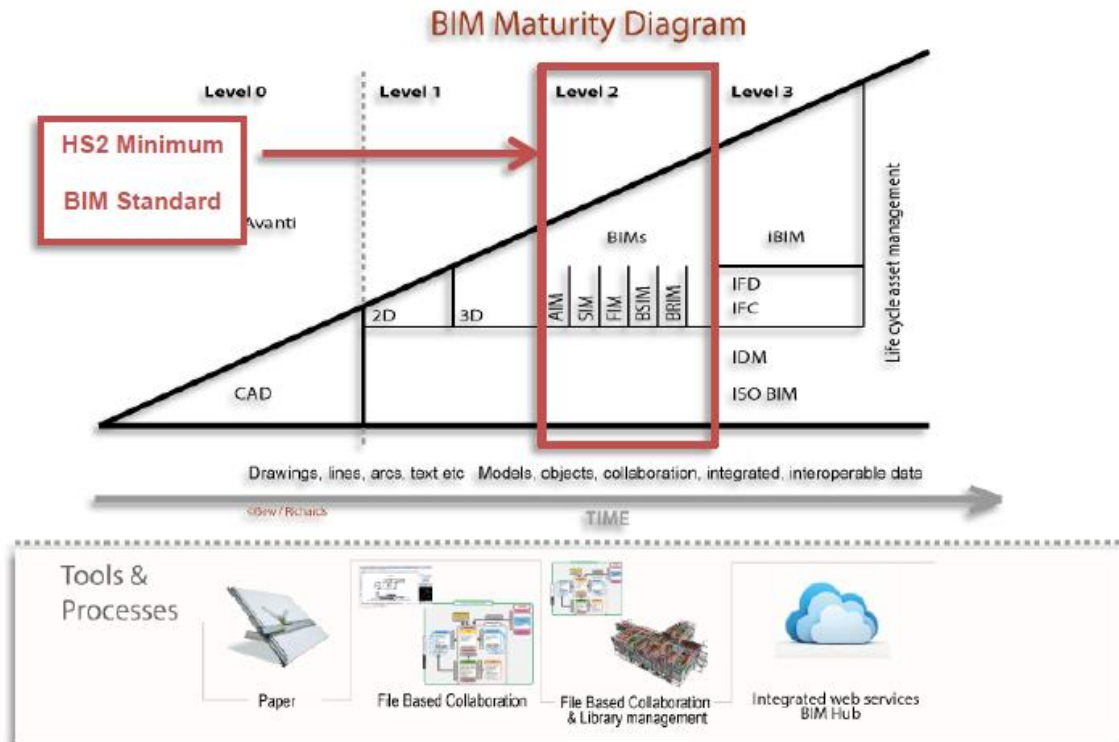


Figure 42 - Bew/Richards BIM Maturity Diagram with HS2 minimum BIM standard overlay (Source: Mace, 2014, p. 15)

The Level 2 BIM documents has been identified before in the chapter 2.2.3 of this dissertation, comprising:

- BS1192:2007
- PAS1192-2:2013
- PAS1192-3:2014
- BS1192-4:2014
- BIM Protocol
- Government Soft Landings
- Classification
- Digital Plan of Works

Use Level 2 BIM on a project like HS2 allows working in a 3D environment, creating structured non-graphical data, data verification and validation, consistent data exchanges, working in a common data environment, connecting Capex and Opex, among others.

Some of the commercial benefits of Level 2 BIM identified by HS2 are (Mace, 2014):

- Encourage collaborative working including early engagement of FM and operation;
- Visualisation and lifecycle solution testing at pre-construction stage;
- Accurate and complete data improving quality of bids - reducing risk allowances in target prices and lump sum bids;
- 3D model input into the assessment of the impact of changes at all stages in a project lifecycle;
- Input of a populated asset data set into CAFM systems - saving time and duplicated.

The HS2 programme will be accompanied by a BIM journey: “Phase One category procurement” will be undertaken using Level 2 BIM maturity (collaborative BIM), likewise the construction and assembly of the initial packages. It is likely however that by 2020 Level 3 BIM maturity will be achieved within (indeed early adopters maybe in this zone by 2018) the industry with the last five years of construction being undertaken in an integrated environment. It is also likely that operational delivery will be executed in Level 4 BIM.

4.4. Supply chain main upskilling needs

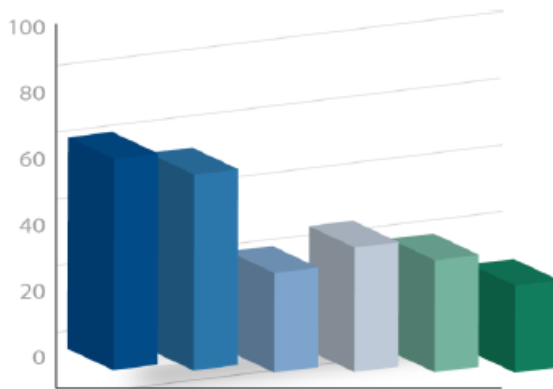
HS2 carried out the BIM supply chain research²⁴ through an online self-assessment questionnaire (around 300 responses at an organisational level), together with workshops and interviews with a selection of capacity.

This survey showed that Tier 1 supply chain organisations were the most evolved in using Level 2 BIM, Tiers 2 and 3 were still constrained within Levels 0-1 (Figure 43 - Results of the HS2 Upskilling survey (Mace, 2014)). This survey concluded also that this BIM maturity was mainly weighted in favour of vertical assets and there was much less in their portfolio in infrastructure or rail.

Moreover, it revealed that over 50% of supply chain members surveyed had some degree of experience of Level 2, although this applied chiefly to major projects as opposed to an overall organisation position (Mace, 2014).

²⁴ More details can be found at:
<http://assets.hs2.org.uk/sites/default/files/HS2%20Supply%20Chain%20BIM%20Upskilling%20Study%2013-06-14.pdf>

Current BIM adoption levels by category:



Tier 1 Contractor	68.0%	●
Tier 1 Designer	63.0%	●
Principal Consultant (PM/POS)	32.0%	●
Tier 2/3 Specialist Trade Contractor	40.0%	●
Tier 2/3 Specialist Designer / Sub-consultant	36.0%	●
Manufacturer	28.0%	●

Current levels of supply chain BIM maturity		
Maturity Level	Description	Study Data
Level 0 BIM	Unmanaged CAD typically 2D, with paper or electronic ink exchanged between participants	8%
Level 1 BIM	Managed CAD in 2D or 3D using BS1192:2007 with a common data environment	37%
Level 2 BIM	Managed 3D environment using separate discipline BIM tools with attached data	55%

Figure 43 - Results of the HS2 Upskilling survey (Mace, 2014)

Supply chain tiers are defined as per the HS2 Supply Chain Conference in November 2013:

- Tier 1 - lead designer, main contractor, joint venture (JV) partner or supplier, contracting directly to client;
- Tier 2 - designer, supplier or subcontractor to Tier 1;
- Tier 3 - supplier to Tier 2;
- Other - specialist.

The study concluded that the upskilling needs of the potential HS2 supply chain, according to the tiers were:

- For Tier 1:
 - Wide awareness and commitment to processes;
 - Information Management and understanding the flow of information and understanding broader project scope;
 - Understanding of scaling of information and also the size and scale of project (Tier 1 said that they need to question whether their existing systems and processes are ready for large scale projects and label components correctly);
 - Upskilling staff in the creation of non-graphical data;
 - HS2 need to ensure all employees and contractors can visualise and understand the project in relation to its overall project goals;
 - Upskilling of staff in rail specific classification and data sets.

- For Tier 2:
 - Upskilling staff in understanding what is meant by Level 2 BIM;
 - Upskilling staff in general regarding BIM classification;
 - Financial support in funding software upgrade / compatibility and training.
- For Tier 3:
 - Financial support and incentives for training and technology;
 - Upskilling staff in use of proprietary BIM tools;
 - Upskilling staff in regard to BIM Level 2 processes.
- For Specialist suppliers:
 - Early support and engagement needed;
 - Clear requirements and be capable to understand project/client requirements;
 - Able to benchmark off competitors or clients learning and knowledge.

Regarded to more specific needs the organisations identified the following upskilling for the staff:

- Use of proprietary BIM tools;
- Level 2 processes such as PAS1192:2 and PAS1192:3;
- Creation or use of non-graphical data;
- Development and use of Level 2 BIM documents such as BEP;
- Rail specific BIM classification and data sets;
- General relation to Information Management.

It is also important to refer what main challenges and barriers identified by the supply chain were:

- Investment in BIM software;
- Investment in staff training;
- Lack of BIM competent staff;
- Software interoperability issues;
- Lack of definition around clients BIM needs;
- Cost of process change, developing new standards and libraries;
- Project culture is not right for BIM (example: adversarial / no collaborative approach);
- Project not set up to encourage a collaborative environment;
- Difficulty of Information exchanges and creation of non-graphical data sets;
- Validation of BIM data set are time consuming;
- BIM processes and data-sets are not mature in the rail sector.

As a result of all the findings in the survey, HS2 recognises that “it is essential that HS2 drives upskilling to meet its programme and projected capacity, especially with regards to Tier 2 and 3 (supply chain) organisations who may not reach Level 2 without the support of HS2 Ltd and the Tier 1 community”.

Kerbey says that HS2 need to make BIM fit for purpose, particularly for the lower levels in the supply chain - making sure they understand what they have to do, and that BIM is not a big “unwieldy beast” that maybe Tier 1 organisations have to cope with.

Being a major project in UK that will require upskilling processes, HS2 is seen as a driver to help UK industry in the journey towards digital leadership in the built environment. HS2 must to create both ‘push and pull’ for realisation of Level 2 BIM and help the supply chain to upskill, in order to achieve maximum benefits of BIM.

4.5. BIM upskilling platform

HS2 have been carefully considering how they can help others work with them in a BIM environment during the delivery and operational phases.

One tool that HS2 launched is the “The BIM Upskilling Platform” (<https://www.bimupskilling.com/>), which objective is to raise awareness of BIM implementation and ensuring that a consistent message is delivered to their Supply Chain and Delivery Partners.

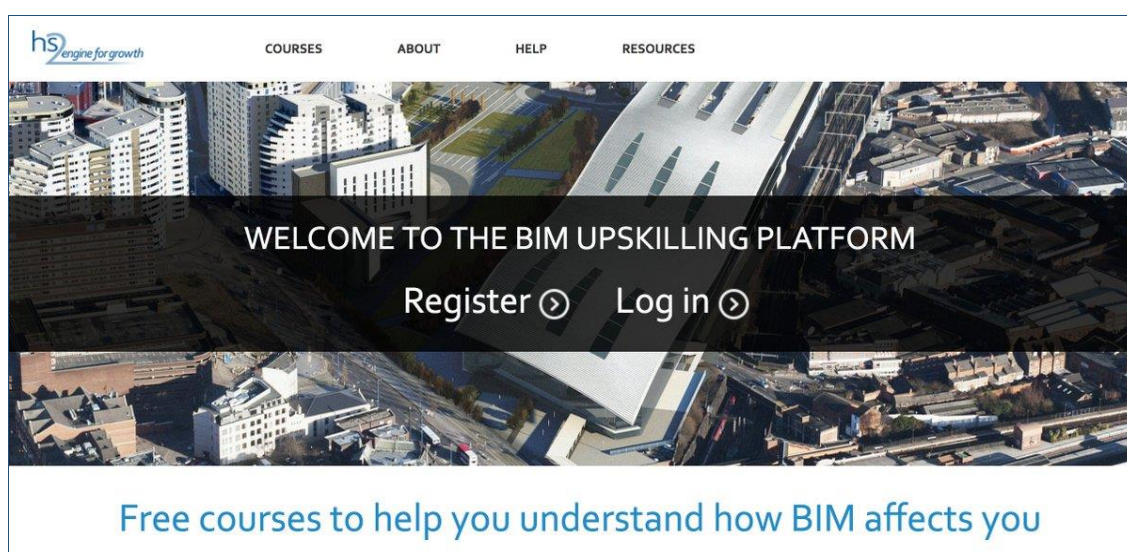


Figure 44 - BIM Upskilling Platform by HS2
(Image retrieved from <https://www.bimupskilling.com/>)


Jon Kerbey (HS2 BIM Director) argued that online resource provides a clear view of HS2 requirements, providing HS2 specific and not only generic information. He also referred that they intend to increase the number of courses to transform that in a rich learning experience for all the construction industry. This web-based environment it is for all interested parties to visit and learn about HS2 guidance, know what HS2 is doing and what are the processes that they will have to meet the requirements of BIM in the project.

4.6. Suggestion for a BIM Execution planning process map

For the package works included in the HS2 project, the potential contractor must acknowledge that should be compliant with BIM Level 2. In the case of the company Barhale that is involved currently in the procurement stage, as mentioned before, the organisation hasn't yet develop BIM processes. Therefore, in this section it is suggested a BIM execution planning process map, that may be of interest for the company.

Prior to a BIM execution plan definition, the BIM goals and uses for the project should be identified according to the project requirements that are defined in the EIRs (see below in Figure 45 an extract of an EIR for HS2 scheme) along with the capabilities of the team members of the organisation (and design consultants, when applicable) that can be involved.

WI1800 Employer Information Requirements
Document no.: 1E001-HS2-PR-ITT-000-000061
Revision: Po2



1 BIM Execution Plan (BEP)

1.1.1 The BEP is a digital asset information delivery plan and provides details of how the Contractor will collaboratively produce, share and manage the Project Information Model (PIM), in accordance with BS1192:2007 and PAS1192-2:2013.

1.1.2 Within the timeframe outlined in the CMP submission schedule but no later than 8 weeks from the starting date, the Contractor shall complete the BEP template provided by the Employer and submit to the Project Manager for acceptance.

1.1.3 A reason for the Project Manager to not accept the BEP includes:

- a. it does not comply with the Works Information
- b. it does not cover all of the requirements and obligations within WI1800.
- c. It is not deemed appropriate to deliver the works.

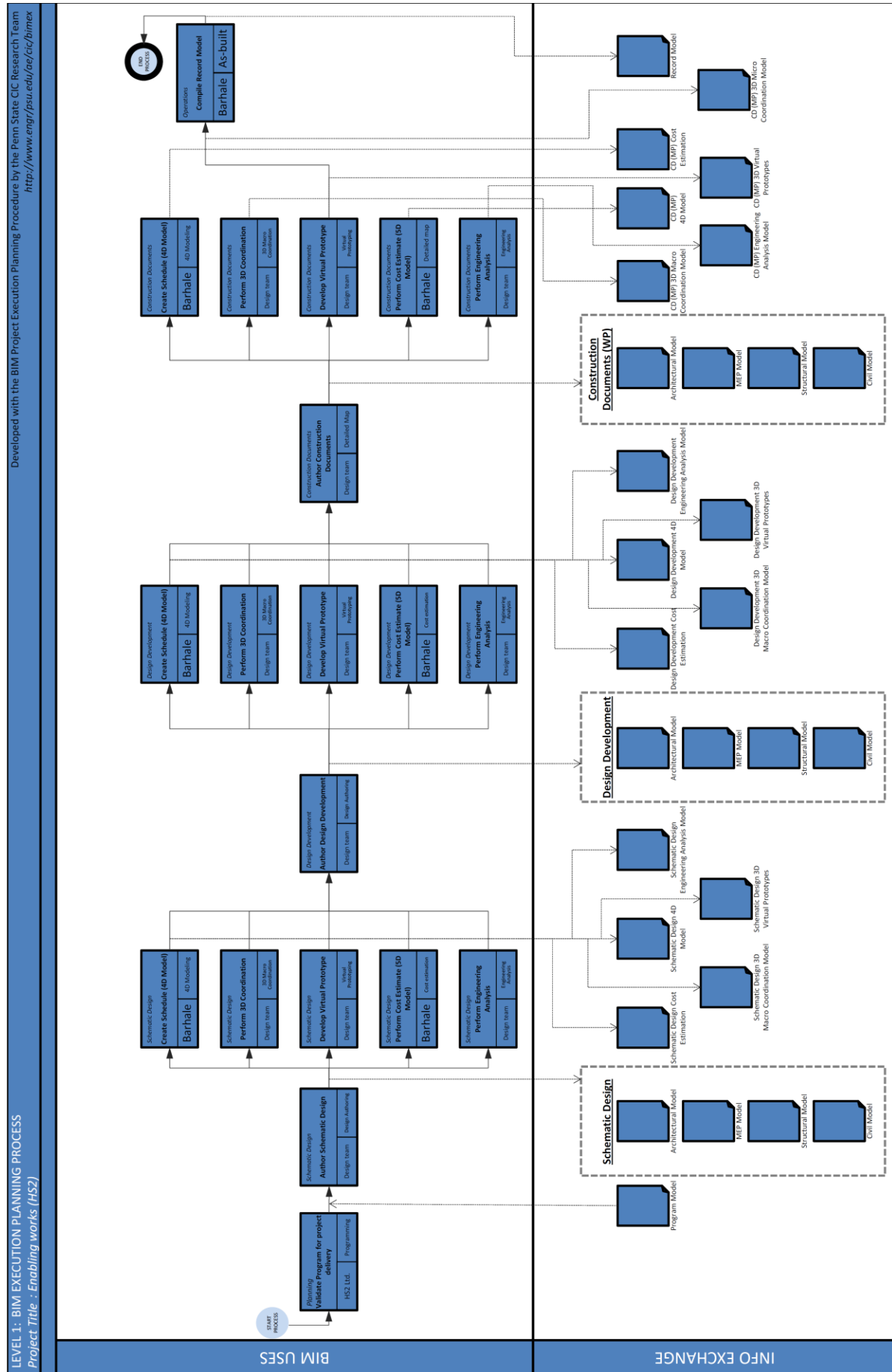
1.1.4 The BEP shall include:

- a. details of the approach for meeting the requirements set out in this part of the Works Information section;
- b. the Contractor's proposals any additions, enhancements or changes to the Standards, methods and procedures detailed in section 4 , and
- c. how the objectives set out in Appendix WI1800/1 will be achieved.

Figure 45 - Extract from HS2 Enabling Works project EIR (Courtesy: Barhale plc)

In order to develop a BIM execution plan, the organisation should have a BIM Execution Planning process map, showing the tasks supported by BIM along with information exchanges. The goal for this procedure is to simulate and direct communication and planning by the project team during the phases of the project. This section provides a suggestion for an overall process map²⁵ for developing a BIM execution plan that could be adopted by Barhale in a project for HS2. It should be pointed out that where it refers 'Design team' that can be internal (Barhale) or external (Consultant), according to the needs. Further processes maps should be developed in a second level, such as 4D modelling, cost estimation, design authoring, design review, etc.

²⁵ Adapted from template by Penn State CIC Research Team (<http://www.engr/psu.edu/ae/cic/bimex>)



Graph 10 - Suggestion for a BIM execution planning map process

Chapter 5 - Conclusions and future works

The goal of this dissertation was assessing the current performance of BIM adoption in the UK and understand how important it is for the construction industry embrace this “industry-wide digital revolution”. Likewise, this study aimed to covers the main drivers and background behind BIM-driven in the UK, referring the key publications, standards and processes available.

The mandate for BIM Level 2, implemented in a ‘top down’ process - a strategic governmental step that addressed the definition of processes on a high level - is been seeing as an example well succeeded and other countries are now scrutinising the steps that UK Government has taken. The government created a BIM task force, which has overseen the production of industry standards and has helped the construction industry to understand what is required, giving guidance on how to deliver the requirements.

Since the UK Government is responsible for a significant portion of total construction, the mandate required for the public sector led to the rest of the industry have interest and discuss BIM and we are seeing strong companies emerging from the private sector requesting their supply chain BIM Level 2 compliance. Clients and companies are thinking differently and embracing organisational change, leaded by first in part by Supply Chain Tier 1 companies, but progressively we are seeing Tier 2/3 and manufacturers adopting the BIM process.

The BIM programme has been a major contributor to the combined record industry savings of £2.2bn between 2013 and 2015, having contributed to meeting the 2011 Government Construction Strategy target of saving 25% on the cost of public sector capital projects.

It is relevant to emphasise that design and construction typically account for only 20% of the total spend on assets, with operation and maintenance accounting for the remaining 80%. This is why the longer-term vision for BIM will extend its influence into those phases of asset management, to ensure reduced whole life costs and enhanced asset performance in service.

We can summarise the following features of the UK strategy that make the government strategy for BIM implementation a case of success and that is driving an entire industry to have BIM adopted as common way of working in a short future (BIM Level 2, 2016):

- ability to help deliver better value for money, higher productivity and improved quality levels on built assets;
- use of public procurement to drive a gradual change in the sector’s performance;
- alignment of customer requirements with supply chain standards in order to propagate existing best practices;

- open and shareable principles of procurement, technology and data, processes and people issues;
- roadmap implementation by steps to enable client and industry development;
- extensive scope and applicability to infrastructures and buildings, to new build and renovations, from small single projects to large scale developments, and to capital delivery and operation phases;
- non-discriminatory and non-proprietary criteria ensuring market competitiveness and encouraging innovation;
- development of a cohesive set of openly available policies, standards, tools and guides that constitute a collaborative and common level of performance for BIM; and
- funding and resources of a management group to implement the strategy with public sector clients, industry and academia.

Related to the awareness of BIM by the industry, considering the NBS report 2017 suggests that BIM usage requires further development as we move past the government mandate, with the findings showing that 62% are using BIM and many organisations are at different stages in their BIM journey. However, we can appreciate that the majority industry has already BIM awareness, still there are some constraints and barriers for BIM implementation in the organisations (mainly in Tier 2 and Tier 3 companies) and continuous efforts must to be done to educate those at each different stage of BIM journey. The expectation is that BIM will soon become the routine process across all the AEC industry and that in 5 years all the industry will be compliant with Level 2.

Step by step the industry is understanding that BIM have equal applicability on all public-sector asset procurement and to private sector building, infrastructure, refurbishment and new-build projects.

A major point to highlight is that significantly there is a growing realisation about the benefits of a “collaborative working”, which involves that each task needs to be carried out in a particular order for the mutual benefit of all those involved, that is the only way BIM can contribute to reduce costs and increase efficiency over the entire construction lifecycle. In a collaborative working environment, all the stakeholders must to have in mind that they need to produce information using standardise processes and agreed standards and methods, to ensure the same form and quality, enabling information to be used and reused without change or interpretation. Effectively this process does not require more work but more discipline, as this information has always been required to be produced, it is just a new approach of true collaborative working where must to be mutual understanding and trust within a team and a deeper level of standardised process.

As it was discussed, adopting BIM requires change and adaption in the people, process and technology: people need to develop new knowledge and new skills, organisations need to

adopt and work in accordance with new processes, there is a need of adopt and use of new technology approaches to information production and management to meet the needs. In some organisations, it will may require investment in hardware, software and training for staff, according to their needs.

This research also leads to the conclusion that it is essential that the organisations should have a BIM strategy in place and that any training required should be addressed to all levels of the organisation, from the top level to the lower ranks of workers, accordingly to the needs. The difficult part of this process level of BIM adoption regarding to education and training needs is the cultural one, BIM adoption requires mindset change.

Looking to the contribution of civil engineers, structural engineers, estimators, planners, contract managers, site managers, etc. all need to understand that BIM processes replaces the traditional way of working by an inter-relationship practice that enables design, costing, programming, management to be brought in a centrally managed BIM model. Working collaboratively with architects, MEP engineers, sub-contractors, specialists, drawn to better understanding of each other's work where all collaborations are well defined and understood.

As we also seen, BIM model is a virtual representation of the real construction, enabling analysis, simulation and testing the asset before the construction is even started, as well as will exist a useful platform for communicating with the clients and other stakeholders. Furthermore, being all stakeholders involved earlier in the whole procurement, clashes and collisions for example, can be spotted and resolved in the design phase, where it is easier to rectify and cheaper to remedy, leading to less problems in the construction stage (delays, variations and counterclaims) and consequently better client' satisfaction. Referring Harty *et al.* (2016) the building information model offers the opportunity also for a new and awesome task: management of sharing, integrating, tracking and maintaining data sets.

For my working field in particular, as a civil engineer dealing with tender stage of the construction process, BIM has the potential to enhance communication with the clients with support of highly visual method, the queries from the clients regarding the construction can be easier and accurately replied. BIM can play a significant role and be used to solve issues in the stages of Pre-award and Pre-construction:

- BIM's common data environment (CDE) ensures that all development information is linked and accessible through one common platform. The information is notated and numbered making it easily accessible as needed.
- Searches and data extraction are easier and faster, like quantity take-offs. With the traditional method, a lot of efforts and time are consumed while doing quantity take-offs, having standard data feature in BIM, the extraction of data and searches can be done straight forward.

- With BIM's accurately indexed metadata specifications, following naming conventions and standard data, it becomes easier to reach information like materials specifications, tolerances for the construction, etc.
- Coordinated BIM models contains information related to the proposed schemes and site constraints enabling clear scope and better information from 3rd party involvement.
- BIM 3D models highlight potential clashes, constructability issues and temporary works requirements.
- BIM provides the site investigation information in a standard format making it easier to interrogate and linking with the 3D model.
- Routine referencing and notations followed in BIM makes it easier to identify risks, related to specific objects.

Particularly, 4D and 5D BIM tools (such as Vico Office) gives estimating and scheduling new importance in the BIM environment, helping not only to visualise better the project and faster quantities take-off, but also costed with indexed pricing and sequenced for optimal construction phasing, and see impacts that will have to the cost and schedule if the designs changes.

BIM processes should be seen as an opportunity for the construction industry to succeeded and should capitalised on and those organisations that will not embrace the digital revolution of the industry could get left behind. The success of BIM now and in the future depends on people, processes and the technology itself.

For future works, it will be interesting develop processes maps in collaboration of the steering group for a practical implementation of BIM in the organisation 'Barhale'. Furthermore, a based study of software for 4D and 5D modelling available in the market and recommend it to the organisation according to the needs and capacities, could be also be conducted. Additionally, a case of study for an infrastructure or specialist civil engineering project of Barhale field (such as tunnels, shafts, etc.) using 4D and 5D modelling could be developed in order to demonstrate full benefits of using the technology BIM on this type of works. Complementary a study could be developed in order to understand how BIM processes and intelligent 3D models could be used to improve health and safety practice to better identify and manage risks throughout the lifecycle of projects.

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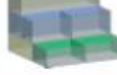









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Appendixes

Appendix 1 - Levels of model definition for building and infrastructure projects (Source: PAS 1192-2, p.35-36)

Stage number	1	2	3	4	5	6	7
Model name	Brief	Concept	Definition	Design	Build and commission	Handover and closeout	Operation
Systems to be covered	N/A	All	All	All	All	All	All
Graphical illustration (building project)							
Graphical illustration (infrastructure project)							
What the model can be relied upon for	Model information communicating the brief, performance requirements, performance benchmarks and site constraints	Models which communicate the initial response to the brief, aesthetic intent and outline performance requirements. The model can be used for early design development, analysis and co-ordination. Model content is not fixed and may be subject to further design development. The model can be used for co-ordination, sequencing and estimating purposes	A dimensionally correct and co-ordinated model which communicates the response to the brief, aesthetic intent and some performance information that can be used for analysis, design development and early contractor engagement. The model can be used for co-ordination, sequencing and estimating purposes including the agreement of a first stage target price	A dimensionally correct and co-ordinated model that can be used to verify compliance with regulatory requirements. The model can be used as the start point for the incorporation of specialist contractor design models and can include information that can be used for fabrication, co-ordination, sequencing and estimating purposes, including the agreement of a target price/guaranteed maximum price	An accurate model of the asset before and during construction incorporating co-ordinated specialist sub-contract design models and associated model attributes. The model can be used for sequencing of installation and capture of as-installed information	An accurate record of the asset as a constructed at handover, including all information required for operation and maintenance	An updated record of the asset at a fixed point in time incorporating any major changes made since handover, including performance and condition data and all information required for operation and maintenance The full content will be available in the yet to be published PAS 1192-3
Stage number	1	2	3	4	5	6	7
Model name	Brief	Concept	Definition	Design	Build and commission	Handover and closeout	Operation
Output	Project brief and procurement strategy	Refined project brief and concept approval	Approval of co-ordinated developed design	Integrated production information	Integrated production information. Complete fabrication and manufacturing details, system and element verification, operation and maintenance information Modify to represent as installed model with all associated data references	As constructed systems, operation and maintenance information Agreed Final Account Building Log Book Information gathered as key elements are completed to feed installation information for the later packages	Agreed final account In use performance compared against Project Brief Project process feedback: risk, procurement, information management, Soft Landings

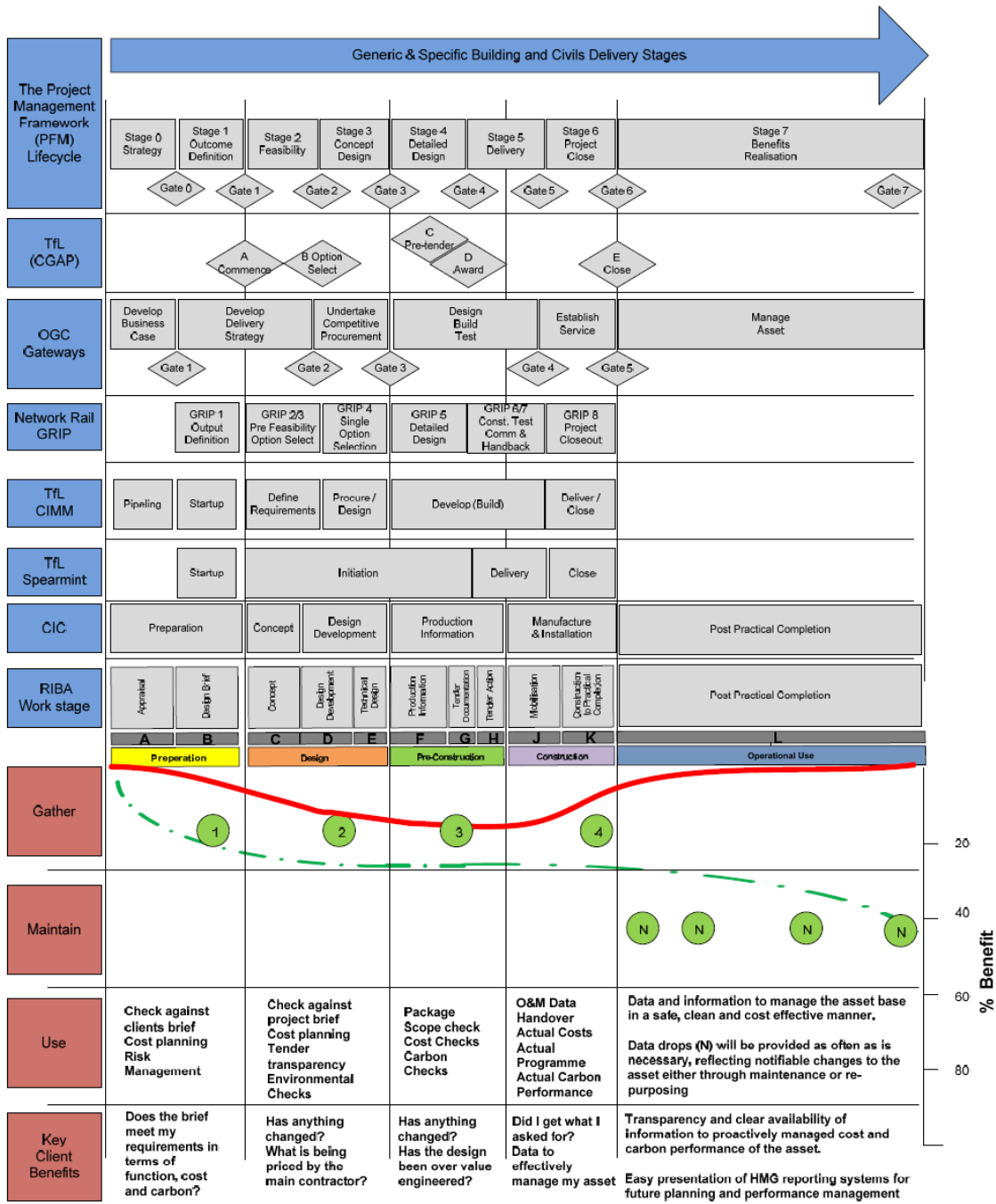
Appendix 2 - RIBA Plan of Work 2013
(Source: <https://www.ribaplanofwork.com/Download.aspx>)

Tasks	0	1	2	3	4	5	6	7
Core Objectives	Strategic Definition	Preparation and Brief	Concept Design	Developed Design	Technical Design	Construction	Handover and Close Out	In Use
Identify client's Business Case and Strategic Brief and other core project requirements.	Develop Project Objectives, including Quality Objectives and Project Outcomes, Sustainability Aspirations, Project Budget, other constraints and preliminary information. Develop Initial Project Brief. Undertake Feasibility Studies and review of Site Information.	Prepare Concept Design, including outline proposals for structural design, building services systems, outline specifications and preliminary information. Undertake relevant Project Strategies in accordance with Design Programme. Agree alterations to brief and issue Final Project Brief.	Prepare Developed Design, including coordinated and updated proposals for structure design, building services systems, outline specifications and preliminary information. Undertake relevant Project Strategies in accordance with Design Programme.	Prepare Technical Design in accordance with Design Responsibility Matrix and Project Strategies to include architectural, structural and building services information, specialist subcontractors, design and specifications, in accordance with Design Programme.	Offsite manufacturing and onsite construction in accordance with Construction Programme and resolution of Design Queries from site as they arise.	Handover of building and conclusion of Building Contract.	Undertake In Use services in accordance with Schedule of Services.	
Initial considerations for assembling the project team.	Prepare Project Roles Table and Contractual Tree and continue assembling the project team.	The procurement strategy does not fundamentally alter the progression of the design or the level of detail prepared at a given stage. However, Information Exchanges will vary depending on the selected procurement route and Building Contract. A bespoke RIBA Plan of Work 2013 will set out the specific tendering and procurement activities that will occur at each stage in relation to the chosen procurement route.	The procurement route may dictate the Project Programme and may result in certain stages overlapping or being undertaken concurrently. A bespoke RIBA Plan of Work 2013 will clarify the stage overlaps. The Project Programme will set out the specific stage dates and detailed programme durations.	Administration of Building Contract, including regular site inspections and review of progress.	Conclude administration of Building Contract.			
Establish Project Programme.	Review Project Programme.	Review Project Programme.	Review Project Programme.	Review Project Programme.	Review Project Programme.			
Pre-application discussions.	Pre-application discussions.	Pre-application discussions.	Pre-application discussions.	Pre-application discussions.	Pre-application discussions.			
Review Feedback from previous projects.	Prepare Handover Strategy and Risk Assessments.	Prepare Sustainability Strategy, Maintenance and Operational Strategy and review Handover Strategy and Risk Assessments.	Prepare Sustainability Strategy, Maintenance and Operational Strategy and review Handover Strategy and Risk Assessments.	Prepare Sustainability Strategy, Maintenance and Operational Strategy and review Handover Strategy and Risk Assessments.	Prepare Sustainability Strategy, Maintenance and Operational Strategy and review Handover Strategy and Risk Assessments.	Review and update Sustainability Strategy and implement Handover Strategy, including agreement of information required for commissioning, training, handover, asset management, future monitoring and maintenance and ongoing compilation of 'As-constructed' Information.	Carry out activities listed in Handover Strategy including Feedback for use during the future life of the building or on future projects.	Conclude activities listed in Handover Strategy including Post-occupancy Evaluation, review of Project Performance, Project Outcomes and Research and Development aspects.
Sustainability Checkpoint - 0	Sustainability Checkpoint - 1	Sustainability Checkpoint - 2	Sustainability Checkpoint - 3	Sustainability Checkpoint - 4	Sustainability Checkpoint - 5	Sustainability Checkpoint - 6	Sustainability Checkpoint - 7	
Strategic Brief.	Initial Project Brief.	Concept Design including outline proposals for structural and building services design associated preliminary Cost Information and Final Project Brief.	Developed Design, including structural and building services design and updated Cost Information.	Completed Technical Design of the project.	'As-constructed' Information.	Updated 'As-constructed' Information.	'As-constructed' Information updated in response to ongoing client Feedback and maintenance or operational developments.	
Not required.	Required.	Required.	Required.	Not required.	Not required.	Required.	As required.	

*Variable task bar - in creating a bespoke project or practice specific RIBA Plan of Work 2013 via www.ribaplanofwork.com a specific bar is selected from a number of options.

Appendix 3 - Alignment of the delivery processes with the various industry plans of works
(BIM Industry Working Group, 2011, p. 64)

**Strategy Paper for the Government Construction Client Group
From the BIM Industry Working Group – March 2011**



BIM Learning Outcomes Framework (1)

1. Understand what BIM is, the contextual requirement for BIM Level 2 and its connection to the Government Construction Strategy and Industrial Strategy 2025; including an understanding of:	
1.01	* Background and the need for collaborative working (removing waste, errors and poor quality/incomplete information)
1.02	* The value of whole life and whole estate approach rather than capital-led and single asset
1.03	* The concept of Soft Landings / Government Soft Landings (GSL)
1.04	* Roles and responsibilities of the supply chain members and clients as part of BIM Level 2 delivery (cultural / behavioural)
1.05	* External context for BIM, global, national, standards and support communities
1.06	* Core and extended suite of standards, documents and deliverables describing BIM Level 2
1.07	* Barriers to successful adoption of BIM Level 2 and how to create the conditions for success
1.08	* The value of high quality data and the principles of data management
1.09	* The key vulnerability issues and nature of controls required to enable the trustworthiness and security of digitally built assets

2. Understand the implications and value proposition of BIM within your organisation; including an understanding of:	
2.01	* Implementation implications for the introduction of BIM Level 2 on your organisation and supply chain (e.g. training, management processes and systems)
2.02	* Organisational change management considerations in context of the introduction of BIM Level 2
2.03	* Assessment of capability of your organisation and your supply chain (e.g. standard methods of assessment PAS91 Table 8)
2.04	* Technical, technology and interoperability requirements of Level 2 BIM (Information Management / CDE, model-based design and analysis)
2.05	* The importance of Level 2 BIM as a driver for business process review and improvement
2.06	* Legal and commercial implementation implications for the introduction of BIM Level 2 on your organisation and supply chain (e.g. commercial stakeholders)
2.07	* The value, benefits and investment associated with BIM Level 2
2.08	* How BIM supports the relationship between Design & Construction and Facilities & Asset Management
2.09	* The potential security threats to built and information assets, and the need for the development of an appropriate and proportionate security risk management approach

Appendix 4 - BIM Learning Outcomes Framework (continuation)
 (Source: <http://www.bimtaskgroup.org/education-and-training/>)

BIM Learning Outcomes Framework (2)

3 . Understand the requirement for the management and exchange of information between supply chain members and clients as described in the 1192 suite of standards and PAS55 / ISO 55000; including an understanding of:	
3.01	* The purposes for information in the capital and asset phase
3.02	* Requirements for the exchange of information between supply chain members in a collaborative manner as described in PAS1192-2: 2013 & PAS1192.3: 2014 and provided in conjunction with BS1192:2007
3.03	* Roles and responsibilities of the supply chain members and clients of BIM Level 2 and the implications on Scopes of Services
3.04	* BIM Plain Language Questions, Employers Information Requirements (EIR), Organisation Information Requirements, Asset Information Requirements and the exchange of information between supply chain and client in a collaborative manner in context of PAS1192.2: 2013 and PAS1192.3:2014
3.05	* BIM Execution Plan (BEP) in context of PAS1192.2:2013 - the related concepts, purpose and implementation principles
3.06	* Digital delivery of information between supply chain members and with clients in context of BS1192-4:2014(COBie), Digital Plan of Work (DPoW) and classification systems
3.07	* The Concept, purpose and implementation principles of Project Information Models (PIM) & Asset Information Models (AIM) and the relationship and interchange between them
3.08	* A Common Data Environment (CDE) as described in the 1192 suite of standards
3.09	* The implications of Level 2 BIM in relation to project team working methods as described in BS1192 :2007
3.10	* The way in which Level 2 BIM can be adopted to benefit decision-making for design management
3.11	* Technologies and methods for creating, using and maintaining structured information
3.12	* Contractual interventions required to support BIM Level 2 and the implications on exiting forms of contract
3.13	* Ownership of information and related issues of IP and copyright, insurances and potential liabilities
3.14	* Requirements for security-minded policies, processes and procedures which address specific security threats or combinations of threats in a consistent and holistic manner

www.bimtaskgroup.org

Birmingham Resilience Project

- ✓ BIM with embedded attribute data

Battersea

Site

- ✓ BIM apps for tablets, 3D point cloud scanning and drones under review

Head Office

- ✓ Drawing Templates, plot styles, 2D libraries
- ✓ L2 BIM project documents u/d
- ✓ 3D Revit libraries u/d
- ✓ Temporary works construction sequencing u/d
- ✓ Navisworks for design clashes

Training

Being assessed for all

Fabrications

- ✓ 3D Solid works
- ✓ 3D Tekla Structures - modelling, estimating, project planning u/r
- ✓ Updating document management system in line with Level 2 BIM.

St. James Market

Peterborough (@one Alliance)

- ✓ 3D BIM Immersive room, virtual headset & smart boards

I.T.

- ✓ AutoCAD Layer generator
- ✓ BIM One-Stop/Dashboard/Portal u/r
- ✓ Trialling multi-discipline collaboration 'in the cloud' with Autodesk BIM360

Watford

- ✓ Navisworks for estimating & project planning

Insurance

- ✓ BIM protocols to be appended to BIM project contracts

Procurement

- ✓ Monitoring Supply Chain BIM capability