Building Information Modelling Case Study

Image 1:Crossrail BIM railway station model

CONTENTS SHEET.

1. The need for BIM

"Between 1996 and 2006 there was a 25% increase in the retail price index cost with construction costs rising by 89%[1]". In a recent 2011 report by McGraw Hill[2], research showed that a quarter of large projects finish late and a fifth over budget by at least 15% with 11% resulting in legal disputes. Of the 35 multi-national firms interviewed 71% of respondents thought BIM (building information modelling) helped to decrease project risk by offering substantial opportunities to increase efficiency.

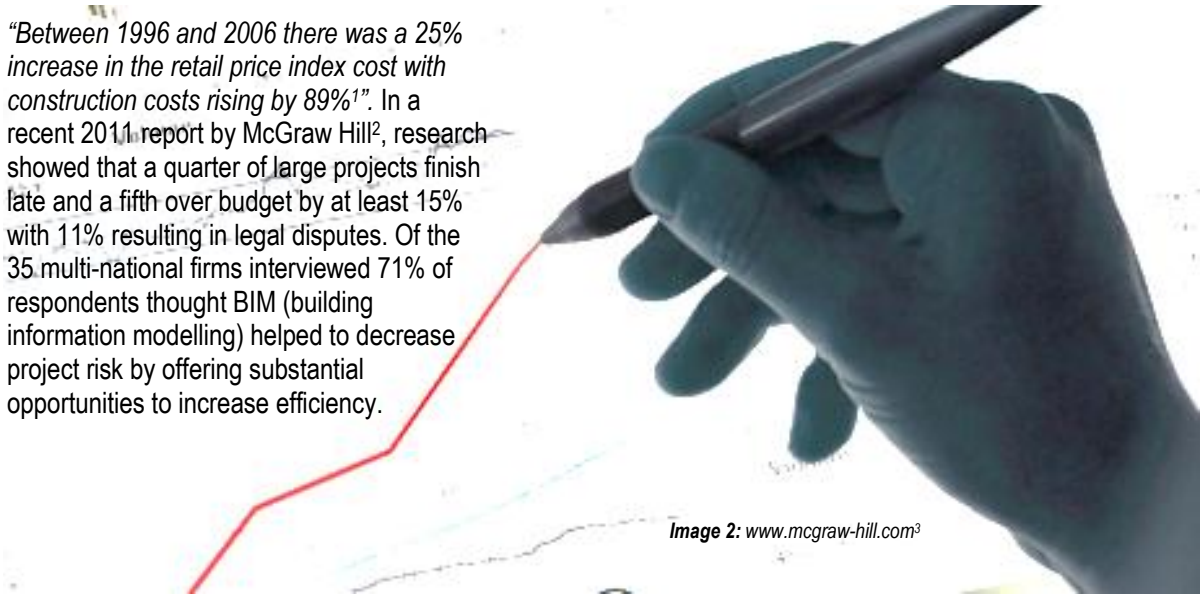

Image 2: *www.mcgraw-hill.com[3]*

In May 2011 the UK government announced a new Construction Strategy[4] with the aim to *"reduce whole-life costs of buildings and infrastructure by 20%, and achieve reductions in CO2 emissions"*[5] *'...Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016'*[6]

This paper focuses on my opinions regarding the challenges of successful implementation of BIM, what applicable software platforms are available and what specific packages I believe are of key relevance to the Crossrail Project to ensure success.

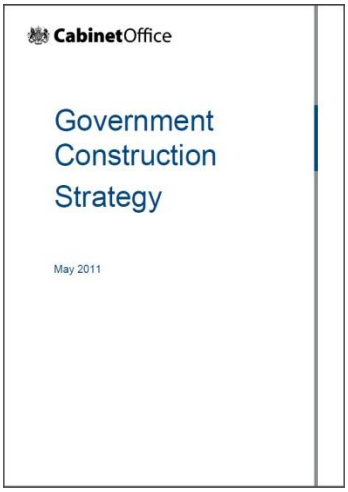

Image 3: *construction strategy 2011*

[1] RICS Construction Journal Feb-March2012- The BIM Edition/page 11
[2] http://www.mcgraw-hill.com/releases/construction/20081202.shtml
[3] Image: http://www.mcgraw-hill.com/site/press-room
[4] http://www.cabinetoffice.gov.uk/resource-library/government-construction-strategy
[5] Quote/Anne McCann (Chairman of the RICS Project Management Professional Group)/RICS Construction Journal Feb-March2012- The BIM Edition
[6] http://www.heacademy.ac.uk/events/detail/2012/09_May_BIM_Education_Salford

2. BIM

BIM is "*a digital representation of the physical and functional characteristics of a facility, serving as a shared knowledge resource for information and forming a reliable basis for decisions during its life-cycle from inception onward*"[7]. A collaborative process of creating an integrated database of information to produce a digital building model from a series of three dimensional objects. Each object is defined once and then placed in the model in multiple locations as required. If the object is then changed, these changes will appear throughout the model. This makes models automatically consistent and reduces errors.

Errors are further reduced as the project team work on one model from the early stages of the project. Therefore BIM is as much about collaborative practices as it is about software.

Objects placed may include geometrical information and information describing its properties, such as its materials, construction process, time-related information (such as delivery times) and operational information. Objects can be defined parametrically, allowing them to be related to other objects.

Drawings and 3D visualisations can be automatically generated from the building model, as can specifications, quantities, ordering and tracking information and information relating to post-occupancy management.

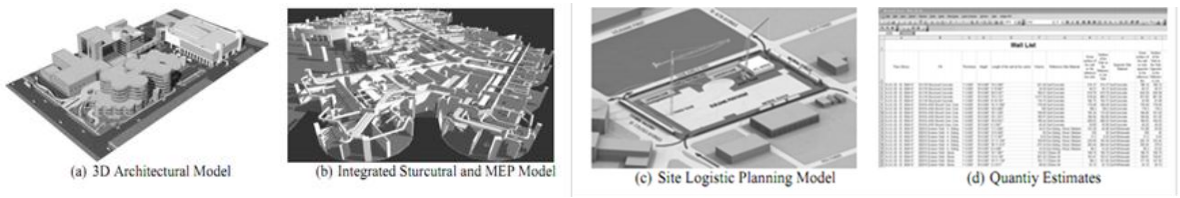

Image 4: Components of a Building Information Model (Azhar et al, 2008)

In short, the successful adoption of BIM ensures clear project evaluation and communication throughout the project team, and can provides optimum efficiency in time, cost quality and risk of a projects delivery and management.

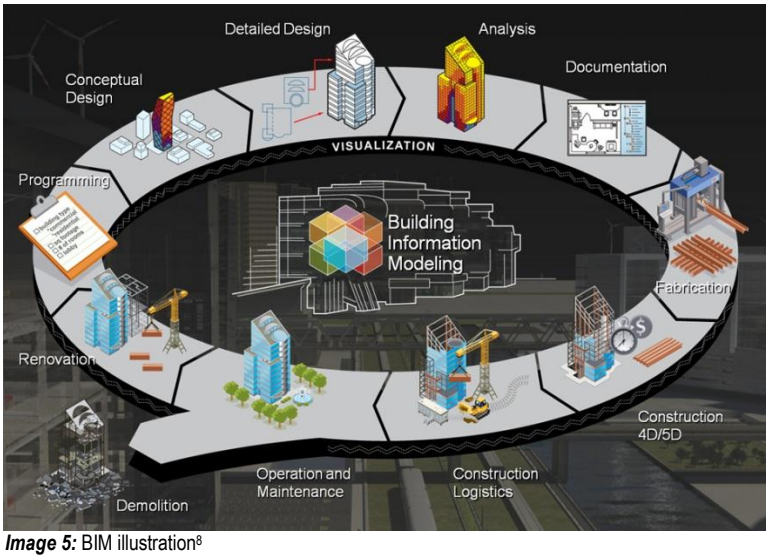

Image 5: BIM illustration[8]

[7] http://www.wbdg.org/bim/bim.php
[8] buildipedia.com

3. Crossrail

Crossrails 2 billion pound construction programme aims to deliver a high frequency, high capacity service to 37 stations connecting Maidenhead in the west, to Shenfield in the east, via 21km of new twin-bore tunnels under central London.

Great Eastern, Great Western and North Kent mainlines will be connected to central London. Reducing journey times and alleviating congestion to London's transport network. This will generate an estimated 1.5 million additional passangers within 45 minutes commuting distance of London's key business districts[9].

Image 6: Typical twin-bore tunnel[10]

Image 7: Regional Map[11]

Image 8: Mock-up of typical station

Increased exit/entrances and platform lengths of 250 meters it is their aim to create a premiere commuter experience.
Diversion of utilities, demolition and other significant enabling works will need to take place before main works can commence **(APPENDIX A).**
Main civil engineering construction works are due to be completed in 2017 with stations Fit-out and testing continuing afterwards. Services are due to commence 2018 followed by a phased introduction of services over several months.

[9] http://www.crossrail.co.uk/railway/timeline
[10] http://www.crossrail.co.uk/news/images/crossrail-construction-progress-image-gallery
[11] http://www.crossrail.co.uk/route/maps/regional-map#content

4. Maturity Levels of BIM

In March 2011 the government published its BIM strategy paper[12]. It details the various levels of BIM, the competence expected, supporting standards and guidance surrounding there application to projects and contracts.

The four levels of maturity and tools associated with their implementation are as follows:

Level	Summary of BIM maturity
Level 0	• Unmanaged CAD
Level 1	• Managed CAD with standard data structures and formats. • Commercial data is managed by stand alone cost management with no integration.
Level 2	• A managed 3D model with attached data. • An *enterprise resource planner* manager is in place • Programme data, cost elements and a feed operational system is used.
Level 3	• Fully open process and data integration • Managed by a collaborative model server.

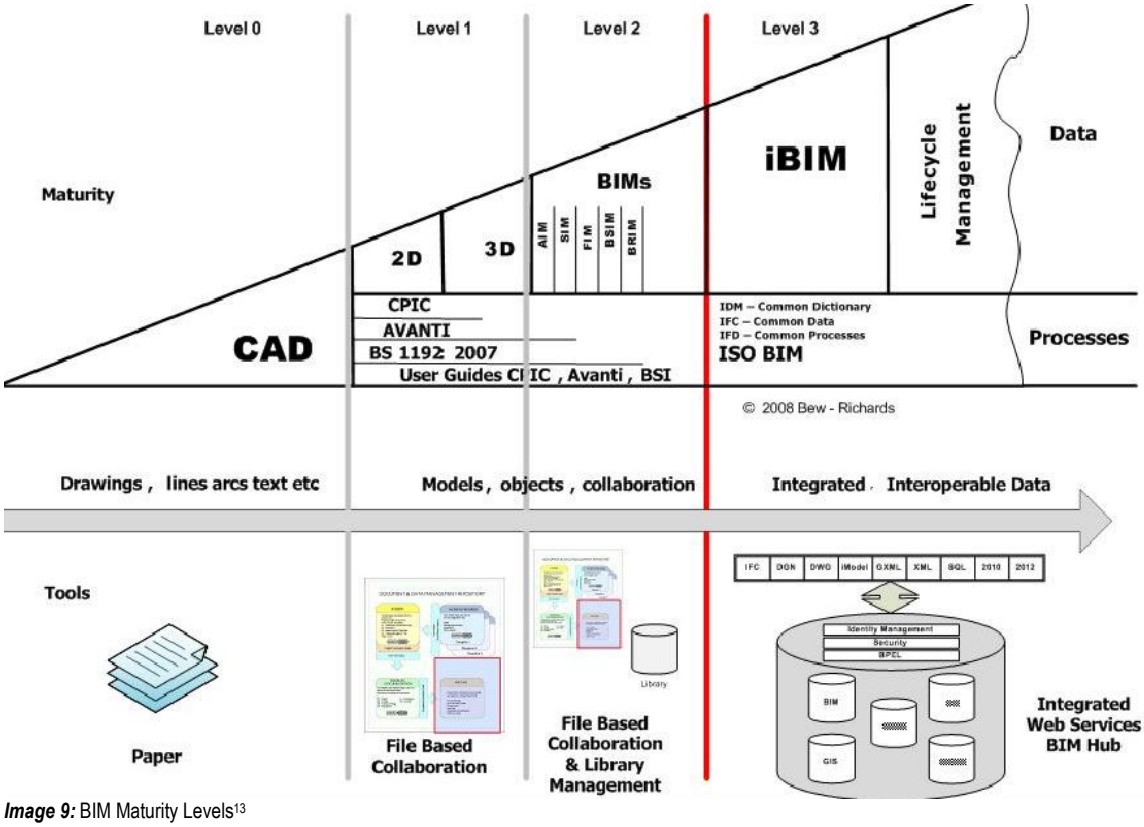

Image 9: BIM Maturity Levels[13]

[12] http://www.constructingexcellence.org.uk/news/article.jsp?id=11787
[13] http://www.bsria.co.uk/news/bim-activities/

By categorising a project level of BIM it means clients can evaluate the technical and collaborative competence of teams and teams themselves can analyse their workings and potentially streamline their communication process.

5. Cost Benefits

In 2007, CIFE evaluated the economic advantages of BIM that was implemented on 10 projects. The research focused on return on investment (ROI) and savings. The findings are illustrated below.

Year	Cost ($M)	Project	BIM Cost ($)	Direct BIM Savings ($)	Net BIM savings	BIM ROI (%)
2005	30	Ashley Overlook	5,000	(135,000)	(130,000)	2600
2006	54	Progressive Data Center	120,000	(395,000)	(232,000)	140
2006	47	Raleigh Marriott	4,288	(500,000)	(495,712)	11560
2006	16	GSU Library	10,000	(74, 120)	(64,120)	640
2006	88	Mansion on Peachtree	1,440	(15,000)	(6,850)	940
2007	47	Aquarium Hilton	90,000	(800,000)	(710,000)	780
2007	58	1515 Wynkoop	3,800	(200,000)	(196,200)	5160
2007	82	HP Data Center	20,000	(67,500)	(47,500)	240
2007	14	Savannah State	5,000	(2,000,000)	(1,995,000)	39900
2007	32	NAU Sciences Lab	1,000	(330,000)	(329,000)	32900

Table 1. BIM Economics (CIFE, 2007)

From the Projects evaluated it can be determined that favourable cost savings through BIM implementation have been made as well as good Rate of interest return to the investor. Over time the cost of implementing BIM will reduce as software will become increasingly competitive and technically advanced and a new generation of consultants will have grown up with it as a normal way of doing things. Currently it is an add-on often operated by a specialist company attracted additional fees. When CAD was first introduced specialist companies provided a service that is now almost universally in-house.

6. Benefits to the project team

The Government strategy requires the whole construction industry to alter its involvement/contribution towards introducing BIM into projects. QSs and PMs roles have been targeted as their involvement thus far has been deemed *"slow to date…but the professionals cannot be outside of the BIM loop.[14]"*

Use of BIM	%	
Not using	39	
Not using, because inappropriate	4	
Not using, but building awareness/monitoring developments	7	
Not using, but aware/have investigated	7	
Using, but early days	6	
Using, infrequently or in limited fashion	23	
Using	**10**	
Other	4	

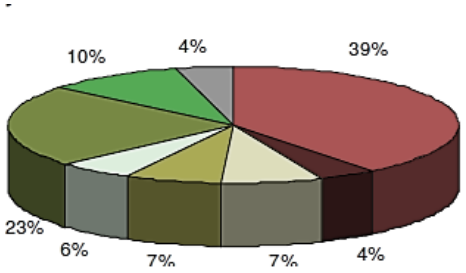

Figure 1. Quantity Surveyors' BIM use

Table 2. BIM use as characterised by 37 Building Surveyors

Use of BIM	%	
Not using	32	
Not using, because inappropriate	14	
Not using, but building awareness/monitoring developments	5	
Not using, but aware/have investigated	3	
Using, but early days	5	
Using, infrequently or in limited fashion	24	
Using	**3**	
Other	14	

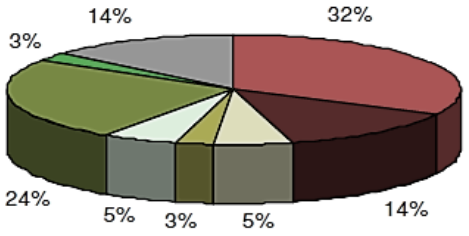

Figure 2. Building Surveyors' BIM use

Table 2: QS & PM BIM implementation[15]

Quantity Surveyors (QS)- BIM provides many opportunities for surveyors which can add value. *"let them go and the profession risks losing out."*

The benefits for the QS are listed below:

- ✓ Clash detection
- Scope gaps when costing and tendering can be more easily identified.
- Detection and improved co-ordination will reduce the number of contract instructions and limit costs and delays and reduce the likelihood of cost risk post contract.
- ✓ Financial reviews
- Prelims, valuations and performance indicators can be measured with more accuracy.
- Real time costing will reduce time delays which will reduce cost escalation.
- Quicker quantity certainty leading to a reduction in cost and programme Carbon estimating software can be linked to the model.

Project Managers (PM)- BIM provides to the PM the "*opportunity to improve the information flows and decision making through integrated working[16]." PM should embrace BIM as is promotes two main areas of PM strength-*

[14] Joe Martin, BCIS Executive Director/RICS Construction Journal Feb-March 2012 (The BIM edition) Pg16
[15] http://www.bcis.co.uk/downloads/RICS_2011_BIM_Survey_Report.pdf

communication and collaboration. PMs may be required to assume the role of BIM model manager and implement a BIM execution plan with the provision for storage back up storage.

The benefits for the PM are listed below:

- ✓ Reduction in risk
- Data managements risk reduction due to dynamic updates
- Increased design coordination.
- Increased accuracy of construction logistics and timeframes.
  - ✓ Improved communication
- Between all stakeholders and third parties.
- Visualization of final product and communicating the requirement of phased works.
  - ✓ Timeframes
- Intergration of programme and and design leading to greater accuracy.
- Depending on the projects BIM maturity, management can be simplified and easily identified and the change impact can be shown in the model.
  - ✓ Performance management
- Design changes can be identified and tracked in the model and scope gaps can be checked for.
- Design team members performance can be reviewed against the programme.
  - ✓ "As built" records
- BIM is continuously updated during the construction process therefore the model becomes a record to support fascilites management which facilitates delivery of the building record documents.

7. Systems currently available

There are a number of BIM design software platforms currently available however there is not a generic template that can be applied to all projects and design team members successfully. I have focused on the BIM tools used by the architects since they have the largest impact on building design. Below I have summarised the key differences and potential limitations of the three main platforms.

[17]**Graphisoft's ArchiCAD** by Nemetschek

Key differences

Available for both Windows and Macintosh

The user interface is relatively intuitive with the 'ArchiCAD STAR(T) Edition' being specifically tailored towards projects of a simple nature.

The models information is managed by a centralized database and supports most import/exporting file types.

It boasts an impressive list of extensions which vary from Carbon analysis programmes to interactive 3D presentation tools and high quality rendering packages that extend the core BIM tool capabilities.

The tool is compatible with a list of external programmes such as Google Earth when exported in its various formats.

Graphisoft has developed the first BIM Server application, specifically

Limitations

ArchiCAD uses an 'in-memory' system, which presents scalability issues for large projects.

Graphisoft lacks a dedicated structural BIM application.

Users have experienced certain parametric modeling limitations in terms of automatic updating between objects

[16] Anne McCann, Chairman of the RICS Project Management Professional Group/RICS Construction Journal Feb-March 2012 (The BIM edition) Pg5

[17] http://www.graphisoft.com/

intended to make large project collaboration easier and faster.

[18]Revit by Autodesk

Key differences	Limitations
Its easy to learn	only available for Windows operating systems
It has an array of Revit programmes that can cater to major building industries	The software can be costly
the software features a high-quality rendering engine.	Revit uses an 'in-memory' system (information must be loaded into the project file to be used in the model), which can make project files very large and performance can suffer as a result – especially when dealing with server-based collaboration.
Autodesk offers a web-based BIM environmental analysis tool, called Green Building Studio Ecotect Analysis) as its comprehensive energy modeling tool.	
Revit uses a central library database structure for storing and linking information.	
It supports importing/exporting various files types	

[19]MicroStation by Bentely

Key differences	Limitations
Can be applied to a wide variety of industries	only available on Windows operating systems.
The software features a powerful rendering engine for the production of high-quality images and animations within the application.	For the best results it is recommended that the entire suite of Bentley products are adopted which means it could be unflexible.
Bentley Architecture features a distributed file structure to help manage large projects, but this type of file organization can be difficult to set up and manage.	The software can be expensive
when deployed in its entirety, potentially offers the most powerful BIM solution to the project.	The user interface is large and non-integrated, which makes it difficult to navigate and learn.
The broad suite of associated applications is well aligned to the key project team professions.	

In summary the BIM platforms listed above have advantages and disadvantages in cost, operational intuitiveness/user development, relevance, and their ability to efficiently convey information to the relevant parties involved in a project.

8. BIM packages & Crossrail

To ensure successful implementation of BIM, collaborative practices are of key importance, as they will need to effectively bring together a large number of diverse disciplines, many of whom will not have worked together before. Due to the scale of the project, emphasis needs to be placed on the co-ordination and integration of highly complex information from an engineering, coordination and operative perspective.

Revit and Bentley are the best known current market leaders with the largest set of asscociated applications which would be relevant to a project of this scale and complexity. Revit/Bentley have signed an Open Design Alliance agreement[20] that stipulates each software can be read by the others. Therefore the decision of implimentation comes down to which software is better for an Architecture/Engineering company that is appointed and the nature of the project.

[18]http://www.autodesk.co.uk/adsk/servlet/pc/index?id=17216803&siteID=452932&src=OMSE&mktvar001=472885&mktvar002=472885

[19] http://www.bentley.com/en-US/Products/Bentley+Architecture/

[20] http://www.bentley.com/en-US/Products/MicroStation/OpenDGN/

BIM Platform- I believe through an Integrated Web Services BIM Hub[21], Autodesk Revit 2013 to be the most appropriate platform to impliment. Due to its wide range of intergrated products such as the architecture, structurer and Revit MEP programmes this would provide a broad synergy across a project to manage the extensive engineering elements. The complexities of signalling and computerised systems with rail stock, point systems and timetable information system with the infrastructure and 37 stations is paramount. Running on both mac and windows will avoid sub contractor compatability issues. Other benefits to sub contractors who may not be as BIM savy are the useful drag over hints for each operattion.

Some of the applications are direct links through Revits open API and others are through IFC or other exchange formats **(APPENDIX B)**[22].

Architecture Package- I would use Bentlys latest V8i Architecture version in place of the Revit package as it is user friendly benefits from a substantial CAD package lying underneath as it's built on top of Microstation. It also allows superior flexibility in exporting/importing formats with DWG, SKP, 3DM, 3DS, RVT, IFC etc. V8i boasts Dynamic visuals through its Sketch Up modelling and Luxology Rendering ability.

Successful implementation of a BIM system is largely dependent on achieving a detailed BIM Project Execution Planning. The stages are detailed below:

In establishing BIM implementation protocols there are 5 specific areas that require consideration:

Scope of works

- Defined for all consultants.
- Consultants responsibilities of design, estimation, and management.

Ownership

- BIM system communicated to the project team

Legal

- Collaborative contractual agreement with effective conflict resolution procedures.
- Project team collaborative working agreements.

Specification

- Compatible selection of software and agreed process and levels of detail for designs and submittals.
- Tolerances and management of infrastructure agreements

Implementation

- Responsibility for model administration and management including version control, design coordination, design management, construction coordination and as-built information.
- Clarity for these areas should be well defined in the scope of works and in the Project Execution Plan.

Table 3: BIM Execution Plan - Davies Street [23]

[21] http://www-03.ibm.com/systems/i/software/iws/index.html
[22] Bim Handbook: A Guide to Building Information Modelling for Owners, Managers/Pg78

9. Successful Implementation

The Crossrail BIM protocols should be agreed as early as possible. This has been set out by BS 1192:2007, Collaborative Production of Architectural, Engineering and Construction Information, Code of Practice)[24]. Here methodology for managing the production, distribution and quality of construction information, including that generated by CAD systems, using a disciplined process for collaboration and a specified naming policy are outlined. BS 1192 is applicable to all parties involved in the preparation and use of information throughout the design, construction, operation and deconstruction throughout the project lifecycle and the supply chain. The principles for information sharing and common modelling are equally applicable to building and civil projects.

10. Implementing problems

There are a number of problems to be overcome with the use of BIM not least agreement on common language and definition, insurance ownership issues and affordability to smaller firms and practices. Investment in CAD/CAM manufacturing equipment in a decade of financial austerity may not happen. It may be government enforced BIM technology and processes alone will not change culture and the hearts and minds of seasoned practitioners and contractors who have learnt their craft and how to survive in the current environment of custom and practice.

11. Legal Issues

The legal and contractual issues will require increasing consideration depending on the BIM maturity level. *"little change is required in the fundamental building blocks of copyright law, contracts or insurance to facilitate working at Level 2 of BIM maturity." However once projects move into Level 3 implementation the following areas will need consideration:*

Terms of Engagement- The UK construction industry is frequently criticised for its fragmented nature. If BIM is to promote a collaborative approach then the traditional contractual frameworks will need to be amended. Currently CIC and several Design and Build contractors are in the process of reviewing the scope of services and terms and conditions of consultants appointments however as yet there are no standard industry terms of appointment for BIM in the UK industry which is of concern.

Ownership- This is likely to be the client however this is not as straight forward as one may assume. Under the JCT Design and Build Contract, the contractor grants the owner a licence to use the 'copyright' in the 'Contractor's Design Documents' for any purpose relating to the works. However in a BIM project the data comes from a number of contributors and is complex in its nature with different laws apply for each of these.

Amendments to standard contracts- Responsibilities and operative information, will need to be outlined from the outset and drafted on a project by project basis, depending on the level of BIM that is adopted. In the 2011 JCT Public Sector Supplement the definition of a contract document has been amended to include 'any agreed Building Information Modelling protocol' so either it is in or not.

[23] BIM Execution Plan - Davies Street
[24] http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030217990

12. Conclusion

In the UK we are currently in the early stage of the BIM maturity and BIM should be considered in the context of the emerging legislation. I believe that simple amendments to traditional contract will prove inadequate and new forms of BIM contracts will emerge.

The requirement to achieve BIM Level 2 by 2016 is a drive towards a more uniformed approach to construction, which considers lifecycle costing, energy performance and carbon 'accounting' in more depth than is currently considered.

This mandatory government requirement will also incentivise IT companies to launch alternative BIM platforms to the market. Additional competition with continuous developments will see packages evolve and teething problems from early versions ironed out. I believe that it's unlikely a sole software will monopolise the industry. Due to the diversity of construction, I believe the future lies with niche packages which have the ability to synchronise seamlessly to other programmes.

Crossrail has an opportunity to benefit from the high value rewards from a fully coordinated and integrating way of working that BIM if implemented correctly can provide.

Total word count, (excluding Contents sheet Table 1, Bibliography & Appendix) = 3,040

13. Bibliography

Journals:	Internet:	Images:	Tables:
RICS Construction Journal Feb-March2012- The BIM Edition BIM Handbook: A Guide to Building Information Modelling for Owners, Managers	www.mcgraw-hill.com www.cabinetoffice.gov.uk www.heacademy.ac.uk www.wbdg.org buildipedia.com www.crossrail.co.uk www.constructingexcellence.org www.bsria.co.uk www.bcis.co.uk shop.bsigroup.com www.ibm.com www.graphisoft.com www.bentley.com www.autodesk.co.uk/bim	Image 1:Crossrail BIM railway station model Image 2: www.mcgraw-hill.com Image 3: construction strategy 2011 Image 4: Components of a Building Information Model (Azhar et al, 2008) Image 5: BIM illustration Image 6: Typical twin-bore tunnel Image 7: Regional Map Image 8: Mock-up of typical station Image 9: BIM Maturity Levels	Table 1. BIM Economics (CIFE, 2007) Table 2: QS & PM BIM implementation Table 3: BIM Execution Plan - Davies Street

14. Appendix

Appendix A: Crossrail Station construction programme

The following table of station start and completion dates reflects the start of construction (main civil contract works) and when enabling works begin.

Where there are separate sites for each station, such as where two ticket halls are being constructed, these are listed below.

Location	Enabling Works Start	Construction Starts	Main Civil works complete
Canary Wharf	Dec 2008	May 2009	Third Quarter 2017
Tottenham Court Road			
Tube station and Crossrail eastern ticket hall at Charing Cross Road	Jan 2009 (Started by London Underground)	Early 2010 (Started by London Underground)	Fourth Quarter 2016
Crossrail western ticket hall at Dean Street	Nov 2009	Third Quarter 2011	First Quarter 2017
Farringdon			
Thameslink and Crossrail western ticket hall at Cowcross Street	July 2009	Third Quarter 2011	First Quarter 2018
Crossrail eastern ticket hall at Barbican	March 2010	Second Quarter 2011	First Quarter 2018
Paddington			

New Hammersmith & City and Circle Line station	Feb. 2009	Aug. 2010	First Quarter 2012
Crossrail station at Eastbourne Terrace	May 2010	Sep. 2011	Second Quarter 2018
Whitechapel	Apr. 2010	Feb. 2011	Third Quarter 2018
Woolwich	Apr. 2011	First Quarter 2012	Third Quarter 2013
Bond Street			
Crossrail western ticket hall at Davies Street	April 2010	Fourth Quarter 2012	Third Quarter 2015
Tube station	Aug. 2010	Late 2010	2016
Crossrail eastern ticket hall at Hanover Square	April 2010	Second Quarter 2013	Second Quarter 2015
Liverpool Street			
Crossrail and Tube integrated ticket hall on Moorgate	June 2010	Third Quarter 2011	Fourth Quarter 2017
Crossrail eastern ticket hall at Liverpool Street station	May 2010	Aug. 2011	Fourth Quarter 2017
Finsbury Circus temporary shaft	March 2010	May 2011	Fourth Quarter 2017
Custom House	First Quarter 2012	Third Quarter 2012	Third Quarter 2014

*correct as at April 2011

Tunnel Portals and Shafts

The following table of start and completion dates for the tunnel portals and shafts reflects the start of construction (main civil contract works) and when enabling works begin.

Location	Enabling Works Start	Construction Starts	Works Complete
Westbourne Park / Royal Oak Portal	Feb. 2010	May 2010	2014
Pudding Mill Lane Portal	July 2009	April 2010	2015
Victoria Dock Portal	July 2010	Third Quarter 2012	2016
Plumstead Portal	Oct. 2010	First Quarter 2011	2016
North Woolwich Portal	Aug. 2010	First Quarter 2012	2015
Fisher Street shaft and crossovers	Sept. 2009	Second Quarter 2011	2015
Stepney Green shaft	April 2010	Dec. 2010	2016
Mile End shaft	Oct. 2012	Third Quarter 2013	2016
Eleanor Street shaft	April 2012	Third Quarter 2013	2016
Limmo Peninsula shaft	May 2010	Dec. 2010	2016

*correct as at April 2011

Tunnelling Works- The current and 3 month prediction of the progress of the tunnel boring machines will be able to be tracked on the Crossrail website in due course.

The completion dates shown in the following table refer to the completion of the tunnel. Fit out will take place beyond these dates.

Location of Tunnel Drive	TBM Launch	Tunnel Drive Complete
Royal Oak to Farringdon (Drive X)	Second Quarter 2012	Third Quarter 2013
Limmo to Farringdon (Drive Y)	Third Quarter 2012	Third Quarter 2014
Stepney Green to Pudding Mill Lane (Drive Z)	Fourth Quarter 2013	Third Quarter 2014
Limmo to Victoria Dock Portal (Drive G)	Second Quarter 2014	Third Quarter 2014
Plumstead to North Woolwich (Drive H)	Fourth Quarter 2012	Second Quarter 2014

(APPENDIX B).

- *Structural (with Revit Structure):* Revit Structure (Dir), ROBOT (Dir), and RISA structural analyses (IFC), BIM ME S.A.R.L. ETABS Link, SismiCAD for FEA analysis, Graitec's Advance and ARCHE, Fastrak Building Designer, StruSoft FEM-Design, SOFTEK S-Frame, STAAD-PRO via SIXchange, SOFiSTiK
- *Mechanical (with Revit MEP):* Revit MEP (Dir), HydraCAD (fire sprinklers), MagiCAD (mechanical design), QuantaCAD (mechanical laser scanning for as-builts), TOKMO (COBie facility operators handover—see Chapter 3)
- *Energy and environmental:* Ecotect, EnergyPlus, IES all indirect, Green Building Studio via gbXML