London South Bank University

Faculty of Engineering, Science and the Built Environment

Department of Built Environment

BUILDING INFORMATION MODELLING AND ITS EFFECT ON COMPUTER AIDED MANUFACTURE IN THE UK CONSTRUCTION INDUSTRY

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For

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1. ABSTRACT

1.1 Aim

To predict outcomes of current Government strategy in regard to the UK Construction industry. BIM has the potential to radically change the way the industry works by forcing integration and collaborative practices in an industry that is fragmented and founded on Victorian concepts, in terms of separation of professions and trades set out in traditional construction contracts.

1.2 Objectives

Objective1:	To determine whether or not the cost savings and uptake aspirations of BIM will materialise.
Objective 2:	To highlight the potential of increasing CAM in the event of the role out of BIM.
Objective 3:	To explore what flexibility is offered to designers in the event of the expansion of BIM/CAM.
Objective 4:	To examine changes in methods of design procurement following the widespread implementation of BIM & CAM.
Objective 5:	To establish the criteria necessary for the successful implementation of BIM & CAM.

1.3 Assumptions

I. That the announcement by the Cabinet office of The Government Construction Strategy report on 31 May 2011 which stated that, *"collaborative 3D BIM with all project and asset information, documentation and data"* being electronic (level 2), will be imposed on all Government projects by 2016.

II. Major clients involved in development in the private sector will follow the public sector and impose level 2 BIM.

III. Technological advancements in BIM & CAM software and scale of production in hardware and robotics, will lead to affordability and flexible within systems which are not currently available.

IV. CAM will be intrinsically linked to BIM.

V. The Internet will continue to provide a platform for the dissemination of innovation and research.

1.4 Author's declaration

I declare that this dissertation is my own unaided work except where specifically referenced to the work of others:

Signed by the author Stephen Trench…….

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4. ACKNOWLEDGEMENTS

Over the past three years I have received support and encouragement from a great number of individuals. I would like to thank my father David Trench CBE who has provided encouragement, enthusiasm and invaluable insights into the industry. My employer JLL for their sympathetic understanding of my Masters study commitments. In particular my line manager and colleague Ed Gregg MRICS who offered guidance over the past 3 years as I juggled my Masters with my day to day work responsibilities. I owe my thanks to my dissertation tutor Steve Pittard, the Academic Lead for the London South Bank University BIM Centre, who has provided patience, vision and on-going guidance as my dissertation moved from an idea to a completed study. I would also like to thank all those who took the time to complete my questionnaire and those who gave up their time for individual interviews.

5. INTRODUCTION

The purpose of the Dissertation is to explore a comparatively new phenomenon whereby the UK Government has directly intervened to impose its will on the Construction Industry. It is forcing radical change to both industry culture and the methodology applied to the entire business of designing, constructing and operating Government built projects undertaken from 2016 onwards by imposing the mandatory application of level 2 BIM on Government procured constructions.
The aims and objectives of this dissertation are set out in the aforementioned Abstract. The research to support the text has derived from:

- Extensive reading of trade and institution journals.
- Internet desktop research.
- Project managing the implementation of level 2 BIM on a major project for an international plc.
- Visiting manufacturing facilities using computer aided technology.
- Market research using questionnaires.
- Meetings with practitioners in the industry.

The main issues that will be addressed are what effects this will have on the private sector and whether the perceived advantages will materialise in the public sector. It will also determine whether the supply industries will respond by investing time and finance into adapting their tooling in such a way that it is synchronised with the BIM modelling produced by designers. The explanation in my conclusion addresses the 5 objectives listed in the Abstract following comprehensive research and a Questionnaire that has been circulated and analysed.

6. THE CONSTRUCTION INDUSTRY

There have been 28 well publicised reports on the Construction Industry since the Second World War. The most widely recognised are:

1944. Simon- Placing and Management of Building Contracts
1962. Emmerson- Survey of Problems Before the Construction Industries.
1964. Banwell- The Placing & Management of Contracts for Building & Civil Engineering Work.
1994. The Latham- Constructing the Team.
1998. The Egan- Rethinking Construction.
2009. Wolstenholme- Never Waste a Good Crisis.
2013. Department for Business, Innovation & Skills- Construction 2025: strategy.

The notable aspect of the reports above is that, with exception to Wostenholme, they were all written by outsiders to the industry. Furthermore, whilst Contractors have acknowledged these reports, in reality the UK Construction and Property industries have not universally implemented the recommendations proposed. During the seven decades of these reports the main improvements to productivity have been influenced by the demise of large national contractors directly employing thousands of tradesmen to a specialist sub-contractor market of smaller trade contractors. In addition to freeing the industry from the grip of militant trade unions, the focus on specialism has resulted in huge technological advances both in mechanised plant and computing.

The UK Construction Industry currently represents 7.5% of GDP with revenues of around 90 billion however, since the Second World War, the industry has shrunk in terms of output, labour force and the number of large international companies. In the rebuilding boom from War destruction, the share of construction workers in the UK workforce rose to circa 12% in 1960 which has shrunk to 4.14% today, *"This is the lowest level since July of 1946" (*Kolko, J. 2012).

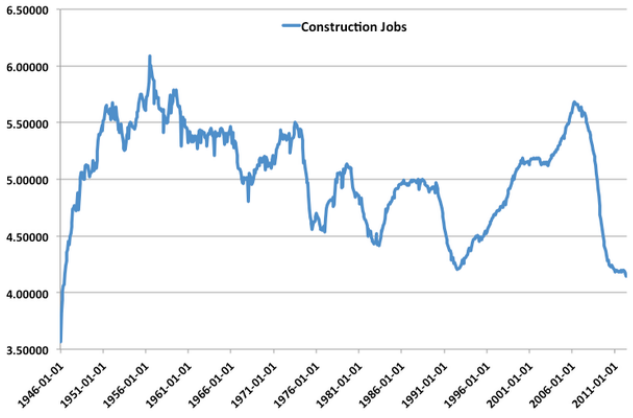


Table 1: Construction workers in the UK workforce.
Source: (*www.theatlantic.com. 2012)*

Successive governments have used the construction industry as an economic regulator in times of boom or bust. The current coalition have announced commissioning strategies such as the Cross Rail and HS2 projects and mortgage guarantees to lead the UK out of recession. These economic swings have played havoc in an industry dependant on market forces causing uncertainty and rapid expansion and contraction of labour, material and

plant resources. It has discouraged long term investment, forward planning and above all apprenticeships and training.

6.1 Management and procurement

85% of construction projects in the 1960's used traditional fixed price tenders as a method of procuring construction contracts. Reports such as Survey of Problems Before the Construction Industries (Emmerson, H. 1962) and The Placing and Management of Contracts for Building and Civil Engineering (Banham, H. 1964) capture criticism of traditional contracting identifying client dissatisfaction with the industry.

In the 1970's - 1980's we saw an increase in Management contracting and Construction management procurement systems whereby large elements of general contracting risk is transferred to, or shared with, the client. It is argued that developers working on 25% margins are better placed to shoulder risk than general contractors working on 5% margins. Adoption of shared risk procurement systems led to less adversarial behaviour and fewer disputes on the larger projects than traditional fixed price tendering. It encouraged collaboration between client, designers and contractors and savings in construction time and cost. The Rosehaugh/Stanhope development of Broadgate responding to de-regulation of the financial sector led the way in this type of thinking.

Sir Egan's report, published in 1998 which is regarded by many as the last major report, focused on ways to improve efficiency/quality in areas such as low profitability, low investment in R&D and inadequate training. Stating that "*the UK construction industry at its best is excellent"* however he also voices concern that "*the industry as a whole is underachieving" (Egan. J, 1998)*.

Now, and for the first time, the Government has stepped in to imposed tangible improvement to the way buildings are designed, built and operated. It differs insomuch that it is mandatory as opposed to publishing reports which recommend optional improvements/guidance. There two principle aspects to this initiative:

- Fully collaborative 3D BIM by 2016
- A single, national, overarching Knowledge Transfer Network for the Modern Built Environment (MBE KTM)

6.2 **The catalyst for BIM-** McGraw research & Government intervention

Research has indicated that a 25% of large projects finished late and a fifth over budget by at least 15% with 11% resulting in legal disputes (McGraw Hill, 2011). Between 1996 and 2006 there was a 25% increase in the retail price index cost. Construction costs rose by 89% **(**RICS Construction Journal, 2012). Of the 35 multi-national firms interviewed, 71% of the respondents believed that BIM would help to decrease project risk by offering substantial opportunities to reduce cost.

The state of the UK public finances led to the coalition Government of 2010 setting up a cabinet office Efficiency and Reform Group (ERG) under the minister Francis Maude MP. One of the first elements of public costs to be scrutinised was future Government capital projects. Consequently in 2011 the major project office was established. The Office announced a new Construction Strategy with the aim to *"reduce whole-life costs of buildings and infrastructure by 20%, and achieve reductions in CO2 emissions*...[the] *Government will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016"(Cabinet Office, 2011).* It is believed that the financial efficiency's forecasted as a result of BIM will stimulate an increase in Construction. Consequently the construction workers in the UK workforce figures captured on page 5 will increase.

7. **BIM-** What is it?

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*" (National BIM Standard, 2014).

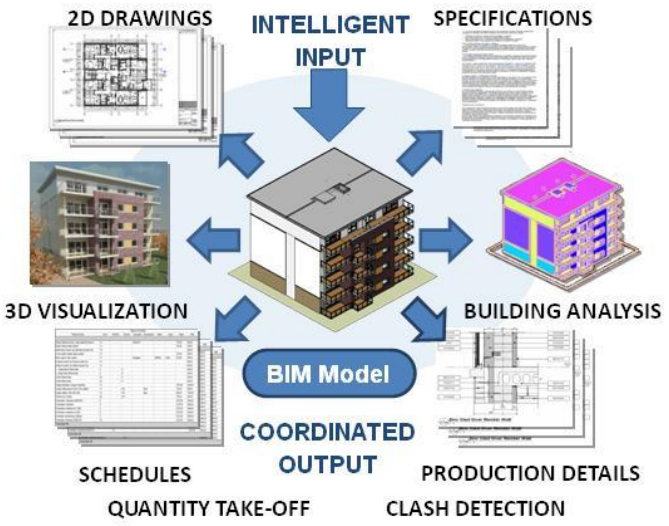


Figure 1: The BIM model.
Source: (www.surveyorsblog.com. 2013).

It is a collaborative process of creating an integrated database of information to produce a digital building model from a series of three dimensional objects. Every object is specified once and then inserted into the model. If the

object is then amended, the changes will appear simultaneously throughout the model where that object is repeated. This results in automatic consistency within the model which reduces errors.
Collaborative practices between design disciplines is thereby encouraged and 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.
The Objects information can be specified parametrically which allowing multiple objects to be linked.

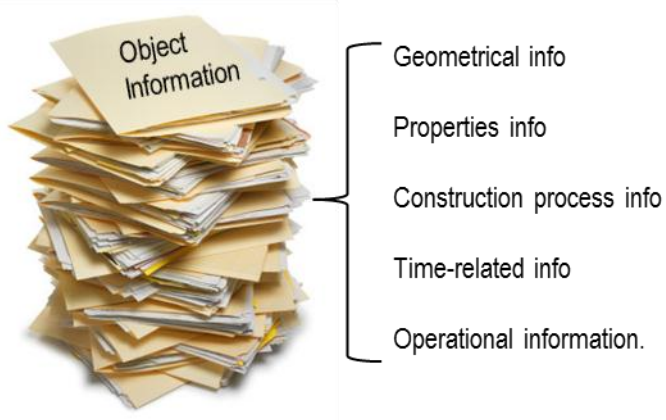


Figure 2: BIM model object information
Source: (Trench, S. 2014)

Plans, sections, elevations etc. as well as 3D renders can be automatically generated from the building model by simply specifying the geo-location of the screen view. In addition specifications, quantities, ordering and tracking information and information relating to post-occupancy management can also be generated from the model.
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 contribute to the mitigation of many risks associated with construction projects.

7.1 Maturity Levels

In March 2011 the government published its BIM strategy paper. It details the levels of BIM maturity, supporting standards and guidance in the context of projects and contracts. The four levels of maturity and tools associated with their implementation are captured in the diagram below:

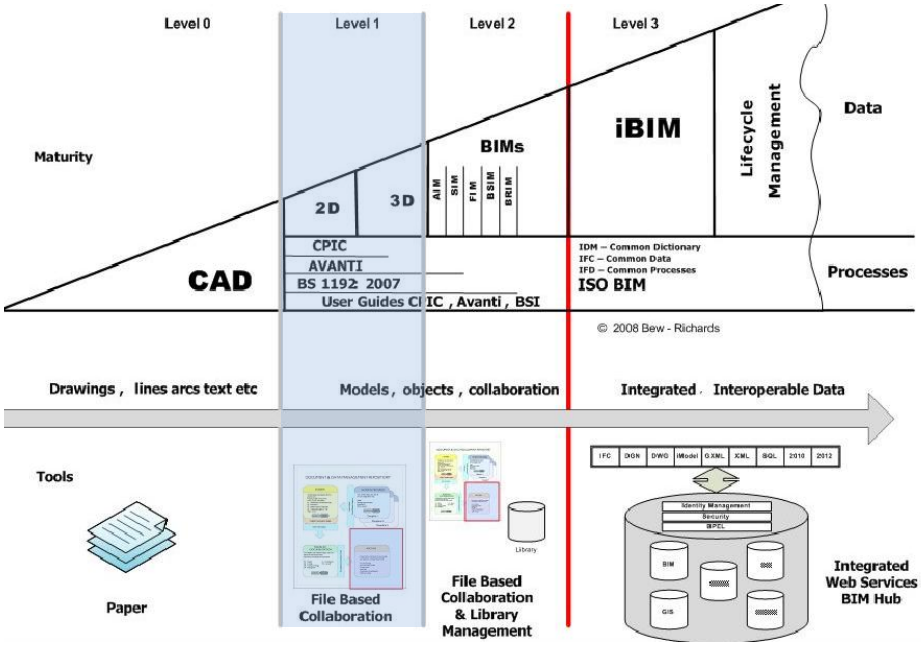


Figure 3: BIM Maturity Levels.

Source: (www.bimtaskgroup.org. 2014)

The range of levels and summary within the modelling are categorised as follows:

Level	Summary of BIM maturity
Level 0	Unmanaged CAD in 2D, with paper (or electronic paper) data exchange.
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 (4D), cost elements (5D) and a feed operational system is used.
Level 3	Fully open process and data integration enabled by 'web services' and compliant with emerging Industry Foundation Class (IFC) standards. This level of BIM will utilise 4D construction sequencing, 5D cost information and 6D project lifecycle management information. Managed by a collaborative model server.

Table 2: Summary of BIM maturity levels

Source: (www.bimtaskgroup.org. 2012).

7.2 **Level 2 Maturity-** Mandatory by 2016

Level 2 requires the project design team and wider stakeholder team to provide specified outputs by a BIM which will be managed as a number of self-contained models using proprietary information exchanges between systems. In order to achieve this, the minimum data standards of Construction Operations Building Information Exchange (COBie) will be maintained during the first phase of the strategy.

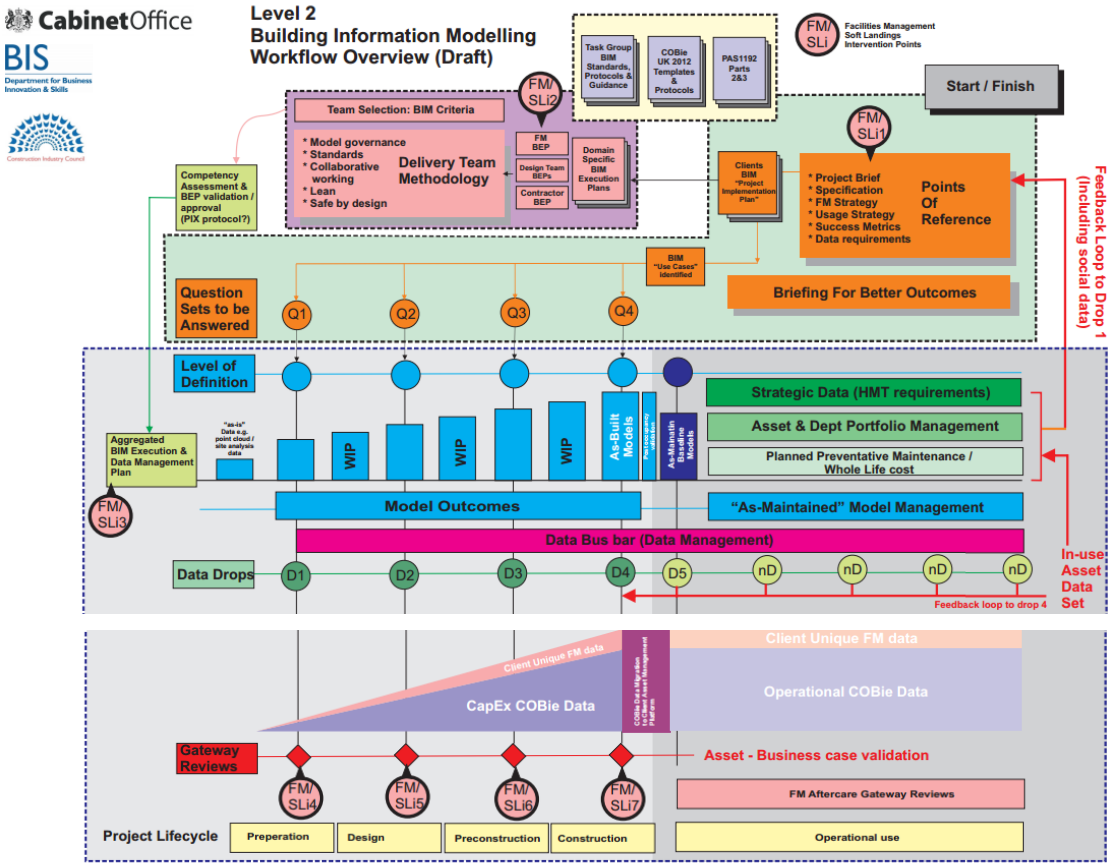


Figure 4: Level 2 BIM Workflow overview

Source: (www.bimtaskgroup.org. 2012).

The maturity model also recognises that some supply chains may want to achieve greater levels of integration in line with the Government Strategy.

The Government's long term ambition to achieve deeper integration within the construction industry is identified and set out within Level 3. This is captured in greater detail within the Infrastructure UK report.

7.3 Construction Operations Building Information Exchange (COBie)

Traditionally the handover of Operation and Management folders (O&Ms) following the completion of a construction Project has been issued in paper form, from the contractor to the client.

The COBie approach is to enter the data information when it is created during the design, construction, and commissioning stages rather than upon completion in an interactive soft copy. The majority of this data origionates directly from the product manufacturers who are also able to participate in COBie which means of sharing structured information which will prove far more accurate and useful for the Facilities Management Team during the buildings operational stage. A single, national, overarching Knowledge Transfer Network for the Modern Built Environment (MBE KTM).

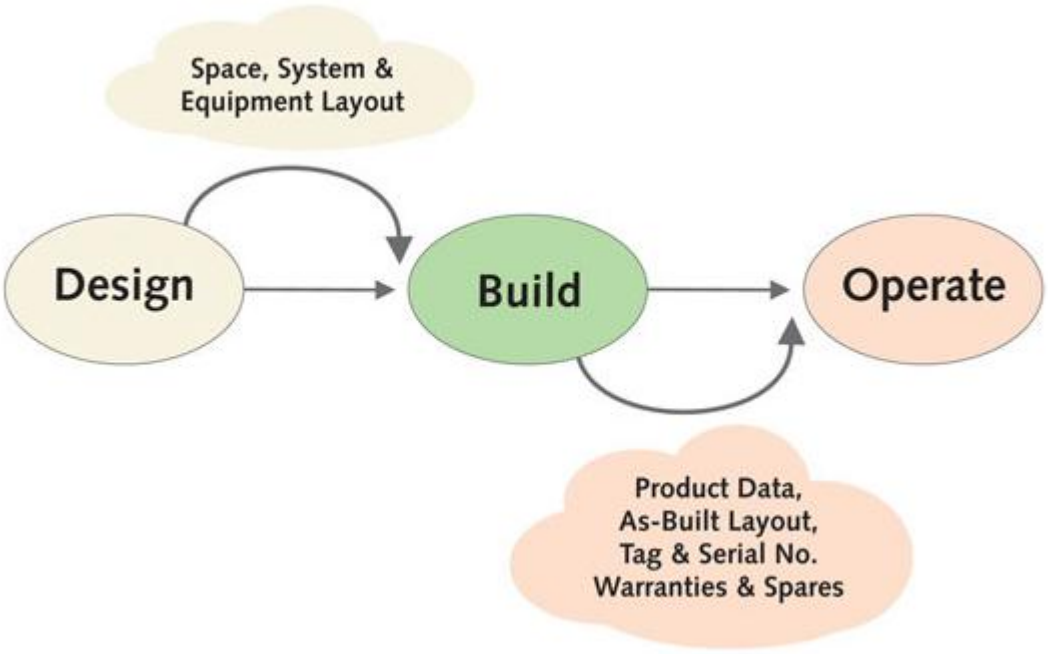


Figure 5: The COBie data information
Source: (USACE ERDC. 2012)

The Owner	The Designers and Contractors
An owner may need the delivery of COBie from the design team or contractor to support the timely delivery of information to support the management of the Facility. A complete COBie is required at the time of handover (Practical/Section Completion), however earlier interim deliveries can be used to evaluate the clients business case for the facility and to help plan for taking ownership. The information can either be delivered and stored within a standard database or uploaded directly into existing FMs operating applications. It is important that the owner clearly defines the purpose for which the information is needed and regarding the timing and content of any interim deliveries.	COBie allows the team to document their knowledge about a Facility into spatial and physical aspects. Spaces can be captured and their grouping into floors/sectors and into other zones. Physically it captures the components and their product types groupings and other systems. The information needed to complete the COBie deliverable typically available already within the BIM model or in reports and schedules and in other material prepared for handover in the Operation and Maintenance Manuals (O&Ms).

7.4 PAS1192:2 (Publicly Available Specifications)

(PAS) are fast-track standards, specifications, codes of practice or guidelines developed by sponsoring organisations to meet an immediate market need following guidelines set out by BSI (British Standards Institution). PAS1192 and BS1192:2007 are the framework for collaborative working on BIM enabled projects, and provides specific guidance for the information management requirements (BSI Group, PAS 1192-2. 2013). The purpose of these specifications is to support the strategic objective to achieve the Governments mandate of Level 2 BIM by 2016 as a single, national, overarching Knowledge Transfer Network for the Modern Built Environment (MBE KTM). They are currently the only government endorsed and funded standards, that support the Construction BIM Strategy.

The assumption within PAS is to build on the existing collaborative production of design and construction information, which is specified within the code of practice. It captures specific details of the standards, processes and procedures that should be implemented to achieve "*consistent, structured, efficient and accurate information exchange" (BIM Task Group. 2014*).

PAS 1192-2 focuses specifically data and the documents that are accumulated from design through to the construction activities. Only the information exchanges specific to BIM such as structured data are listed in this PAS such as:

- Taxonomy of terms
- References to other relevant BSI standards, CPI guidance and other documents
- Definitions for Process and Data needs
- Roles and Responsibilities (BIM Task Group. 2014)

The intended audience for this PAS are the Organizations and individuals responsible for the entire lifecycle of the buildings/infrastructure assets.

A forthcoming document, PAS 1192-3 is currently being developed. It is the intention that this will offer guidance on the operation and maintenance of the asset information model (AIM) to help support the planned preventative maintenance programme and the portfolio management activity for the life of the asset.

8. IMPLEMENTING BIM

An assessment of the project specific objectives should be undertaken to determine how BIM will be most beneficial and this will indicate what level of BIM is required. A 'schedule of deliverables' for each work stage is clearly specified from the outset and needs to be captured in tender protocol documents as well as the level of

the BIM model expected. *"If the appropriate information is not included at the outset, or if standard formats are not adopted, later integration with other disciplines, processes or software packages can become extremely difficult'* *(Trench, S. 2014- Designing Buildings Wiki).*

Best value is achieved when the whole project team and the relevant stakeholder groups adopt the model. This is especially relevant in respect to the facility's proposed operating management who must be capable not only of understanding the model throughout the life cycle of the building but also updating it as indicated in the diagrams in the preceding chapter.

To avoid abortive work under a BIM regime it will be necessary to obtain contributing information to the emerging 3D model from parties in the supply chain prior to them being contracted to supply material or labour to the project. This raises the problem of committing to using companies without full definition of scope and price . There will be an element of loss in respect to competitive bidding that may cut across the government objectives of reducing construction costs by 20% through the introduction of BIM.

8.1 Implementation issues –(Construction Manager Magazine. 2014)

In a survey carried out by Construction Manager magazine in January 2014 it became apparent that contractors' shared the same opinion. They thought that the cost and practicalities of implementation would be intrinsically linked to the size of their practice. These findings are captured in the graph below:

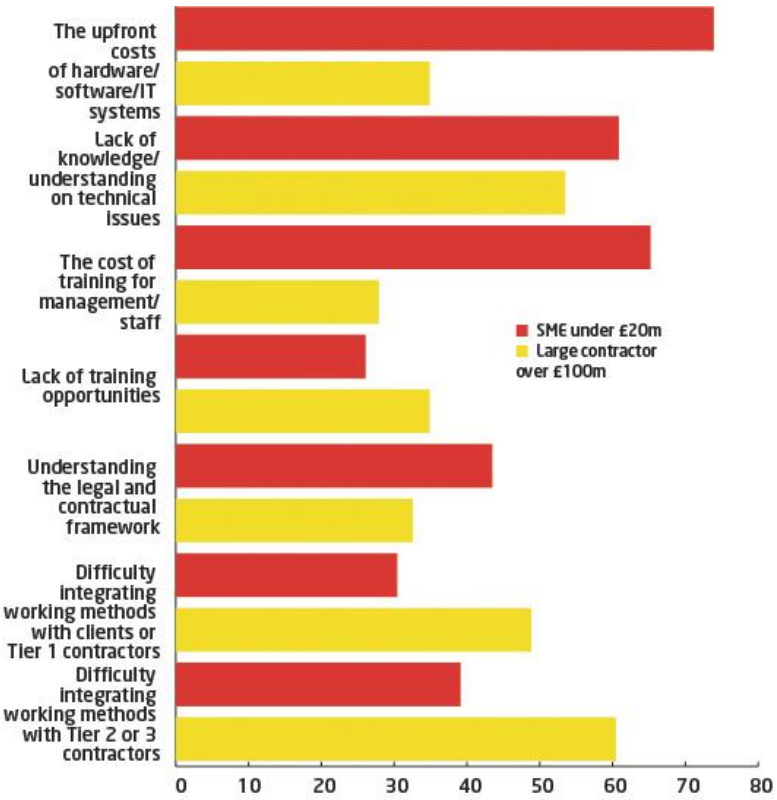


Figure 6: BIM implementation issues.
Source: (www.construction-manager.co.uk. 2014).

The survey found that 78% of public sector clients lack technical awareness of implementation issues when compared to private sector clients. This lack of knowledge has been specifically highlighted in the Facilities and Maintenance (FM) when looking at the operational perspective of buildings post completion of construction. In 2014 Louise Roberts, the studio director for Capita who have a £60m BIM portfolio stated that *"A number of clients are interested in BIM but not committing to any requirement for COBie There would need to be a parallel step change in their own FM to maximise the benefits. They are delighted by what BIM offers in terms of 3D modelling, understanding the building at the front end and integration of services etc, but Level 2 asset management appears only relevant to large institutional [public sector] clients at the moment."*
Peter Trebilcock, the Construction Services BIM director for Balfour Beatty, has voiced his concerns, stating that *"On the government side at high level, clients know exactly what they want. But at the level of local NHS trusts or MOD bases, clients will need help in defining what is required and how to request it." He adds, "We already deliver lots of data to the client in the spirit of Level 2, but lots of clients are just not interested in COBie – they're not going to train their FM teams to use it".*

The Government strategy requires the whole construction industry to alter its involvement/contribution towards introducing BIM into projects. Quantity Surveyors and Project Managers have been slower than designers to invest in BIM. Their involvement has been criticised as *"slow to date…but the non-design professionals cannot be outside of the BIM loop."* (BIM strategy Report. 2012). One of the major obstacles to progress, especially in a recession, is the high cost of software and training, estimated at £10,000 per desktop.

Figure 7: 2014 RICS BIM conference:- Implementation of BIM in a business
Source: (Trench,S. 2014).

This issue is also highlighted in the survey which found that the single most common barrier was the high capital expenditure for IT systems. Medium-sized contractors (£20m-£100m) displayed particular concern regarding cost with 70.6% indicating training costs and IT costs are the largest barriers to the implementation of BIM.

The different levels of skill and general understanding of what BIM is a major handicap to the successful implementation of BIM throughout the industry. As part of the BIM project planning stage the skill level and how individual stakeholders will be required to use the BIM will need to be assessed. Once the skill level strengths and weaknesses have been identified, the client and the design team will need to work with each stakeholder to ensure they are trained to the skill level required. For example the design team will need to know how to build

the BIM where as a quantity surveyor will need to know how to extract quantities for either and individual element (eg number of doors) or a whole system (eg pipe lengths).

8.2 BIM Execution Plan

A BIM Execution Plan (BEP) is prepared by the suppliers of services (such as a bidding project team) prior to the award of consultancy contracts. This illustrates their proposed approach to achieve the Employer's Requirements. Upon being awarded the contract, the successful team then submits a Master Information Delivery Plan (MIDP).This document will list what project information details are needed, by whom, and by what processes and/or procedures. It will also specify the nature and timing of any expansion to the team as suppliers further down the chain are enlisted to contribute their expertise to the project such as acousticians, lighting consultants, interior designers and specialist trade contractors.
The MDP is then further broken down when each task team manager is required to prepare a Task Information Delivery Plan (TIDP) which captures the responsibility for delivery for each member of the team allocated to the task.

Also within the BEP is the BIM Employer's Information Requirements (EIR) which needs to be defined as part of the Employer's Requirements. This document defines at what level the 3D model needs to be developed to each project stage by listing the level of detail required. These models are important deliverables in the 'data drops' that contribute to efficient decision making at the key stages of the project.
EIR covers are categorized as follows:

Technical	Management	Commercial
• Software Platforms • Data Exchange Format • Co-ordinates • Level of Detail (general) • Level of Detail (components) • Training	• Standards • Stakeholder Roles and Responsibilities • Planning the Work and Data Segregation • Security • Coordination and Clash Detection Process • Collaboration Process • Model review meetings • Health and Safety and Construction Design Management • System Performance Constraints • Compliance Plan • Delivery Strategy for Asset Information	• Timing of data drops • Clients Strategic Purpose • Defined BIM/Project Deliverables • BIM-specific competence assessment

Table 3: EIR categorize
Source: (www.bimtaskgroup.org. 2014).

9. THE ASPIRATIONS OF BIM- Objective1

9.1 A record of cost benefits- Stanford Universities findings (Hartmann, T & Fischer, M. 2007)

It is widely considered that the USA is several years ahead of the UK in development and adoption of BIM. This is predominantly due to the substantial funds available to research and development to establishments. Stanford University's Centre for Integrated Facility Engineering, an academic research centre for Virtual Design and Construction of Architecture - Engineering - Construction (AEC) industry projects evaluated the economic advantages of BIM that has been implemented on 10 projects in the USA during the design and construction stage in 2007. The research focused on return on investment (ROI) and savings. The data is provided by Holder Construction Company, Atlanta, Georgia and the findings are illustrated below:

Year	Cost	Project	BIM Cost	Direct BIM	Net BIM	BIM ROI
		($M)		($)		Savings ($)
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 4: BIM Economics

Source: (CIFE, 2007)

From the Projects evaluated it was claimed that favourable cost savings which will continue into the operational phase of these buildings lifecycle. The (ROI) varies from **140% to 39900%** for different projects and therefore it is hard to conclude a specific range for BIM ROI as each projects will have a varying scope of BIM. It is worth making note that none of the cost figures listed above account for indirect, design, construction or owner administrative or other cost savings. Therefore the BIM ROI may well be more substantial to what is reported above.

9.2 Case Study from Stanford Universities findings- (Hilton Aquarium Hilton, CIFE. 2007)

The purpose of Aquarium Hilton case study is to illustrate the cost and time savings realized by implementing a building information model on a construction project. In the survey, the participants were unanimous that the implementation of BIM resulted in these savings. The projects details are listed below:

Project name:	Hilton Aquarium, Atlanta, Georgia
Project scope:	$46M, 484,000 SF hotel and parking structure
Delivery method:	Construction manager at risk
Contract type:	Guaranteed maximum price
Design assist:	GC and subcontractors on board at design definition phase
BIM scope:	Design coordination, clash detection, and work sequencing
File sharing:	Navisworks used as common platform
BIM cost to project:	$90,000 - 0.2% of project budget ($40,000 paid by owner)
Cost benefit:	$600,000 attributed to elimination of clashes
Schedule benefit:	1143 hours saved

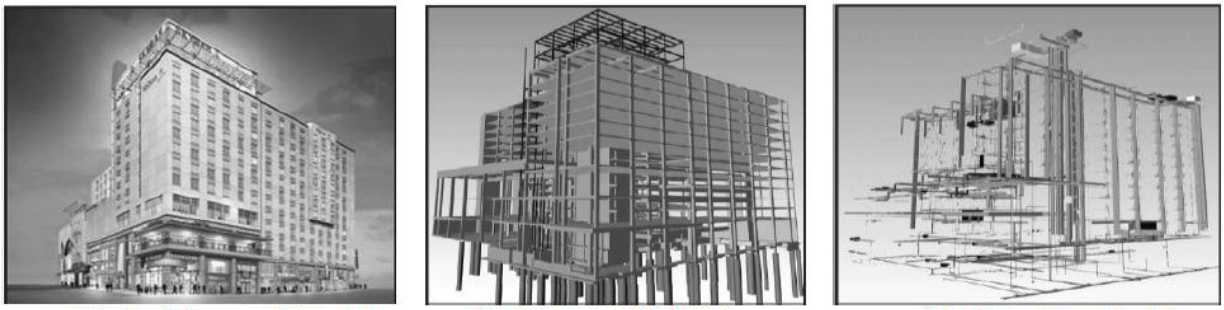


Figure 8: Building Information Modelling for Hilton Aquarium, Atlanta, GA

Source: (Holder Construction, 2010)

The project team was able to identify and resolve system conflicts through frequent 3D coordination sessions which resulted in an estimated cost saving of $600,000 and negated substantial programme delays. A documented list of these clash detections is captured below:

Collision Phase	Collisions	Estimated Cost Avoided	Estimated Crew Hours		Coordination Date
100% Design Development Conflicts	55	$124,500	NIC		*June 30, 2006*
Construction (MEP Collisions)					
Basement	41	$21,211	50	hrs	*March 28, 2007*
Level 1	51	$34,714	79	hrs	*April 3, 2007*
Level 2	49	$23,250	57	hrs	*April 3, 2007*
Level 3	72	$40,187	86	hrs	*April12, 2007*
Level 4	28	$35,276	68	hrs	*May 14, 2007*
Level 5	42	$43,351	88	hrs	*May 29, 2007*
Level 6	70	$57,735	112	hrs	*June 19, 2007*
Level 7	83	$78,898	162	hrs	*April 12, 2007*
Level 8	29	$37,397	74	hrs	*July 3, 2007*
Level 9	30	$37,397	74	hrs	*July 3, 2007*
Level 10	31	$33,546	67	hrs	*July 5, 2007*
Level 11	30	$45,144	75	hrs	*July 5, 2007*
Level 12	28	$36,589	72	hrs	*July 5, 2007*
Level 13	34	$38,557	77	hrs	*July 13, 2007*
Level 14	1	$484	1	hrs	*July 13, 2007*
Level 15	1	$484	1	hrs	*July 13, 2007*
Subtotal Construction Labor	590	$564,220	1143	hrs	
20% MEP Material Value		$112,844			
Subtotal Cost Avoidance		**$801,565**			
Deduct 75% assumed resolved via conventional methods		($601,173)			
Net Adjusted Direct Cost Avoidance		**$200,392**			

Table 5: An Illustration of Cost and Time Savings via BIM in Hilton Aquarium Project

Source: (Holder Construction. 2010)

During the construction process, stakeholders who were not BIM proficient where able to access the visualization models through the Navisworks free viewer. The collaborative 3D viewing sessions enabled quicker decision making at an earlier stage in the design process resulted in improved communications between all the stakeholders groups. The owner, Legacy Pavilion, LLC, were provided with a digital 3D model of the building and its various systems to help aid O&M procedures down the road (CIFE, 2007).

9.3 Current uptake and Survey analysis- (National BIM Report. 2012).

In the 2012 NBS BIM survey, it was found that *'31% of respondents were using BIM however 30% of those surveyed had only used 2D (CAD) rather than 3D and 35% had not use CAD at all'.* The survey, carried out annually, targets some 1000 practitioners across the Construction industry. In 2013 NBS BIM survey revealed that BIM uptake in the UK had increased from 9% to 39% which has further increased to 54% in the recent 2014 survey, with a prediction of a 93% take up by 2016.

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	

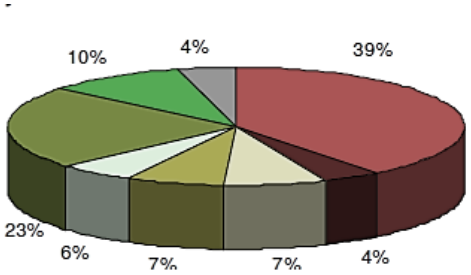


Figure 1. Quantity Surveyors' BIM use

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	

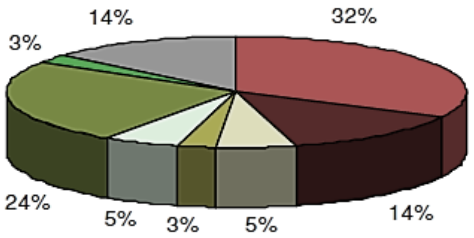


Figure 2. Building Surveyors' BIM use

Table 6 QS & PM BIM implementation

Source: (www.aps.org. 2013)

In a separate survey carried out by Construction Manager magazine in January 2014, it was found that 18.7% of the respondents were unaware of the scope of the government's 2016 BIM mandate. The Survey questionnaire was completed by 246 active practitioners who represent the contracting, consultancy and client communities. The survey indicated some unexpected results that showed that forecasting the trajectory up to 2016 was far more challenging than previously anticipated.

In terms of the implementing the 2016 BIM mandate, the survey found that over half of the participants had some experience with BIM, with 36% indicating they had worked on a project that met the Level 2 criteria, and 77 having worked on a project with at least a BIM philosophy.

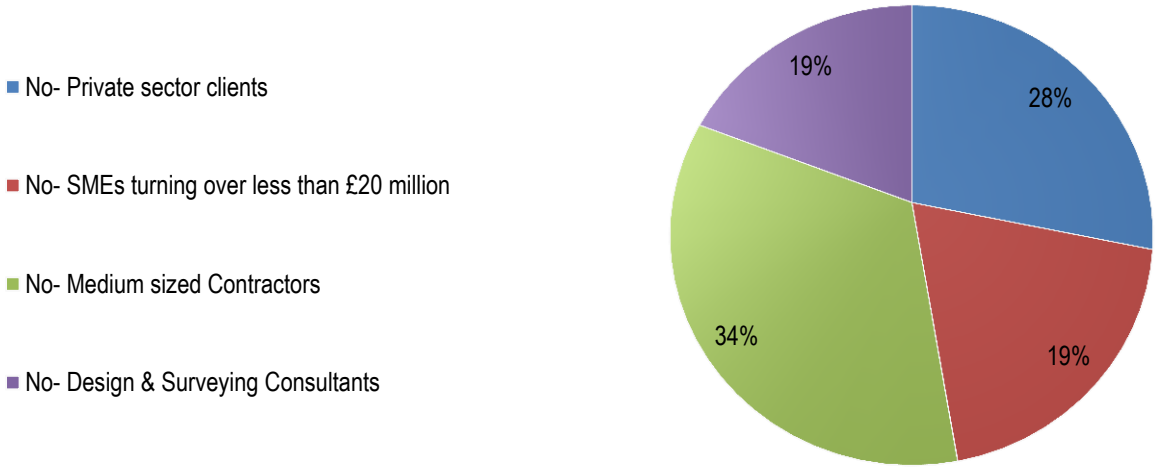


Figure 9: Representation of Stakeholders groups who haven't worked with BIM
Source: (Trench, S. 2014)

In comparison, 36% said they had no "live BIM" experience. The vast majority of small and medium enterprises (SMEs) fell into the not-yet-a-BIM-beginner category, while large £20m-£100m contractors clustered in the middle category. It was found that 50% of the 18 public sector clients that responded had no experience of BIM. Other findings are listed below:

- 47% claim a poor knowledge of PAS 1192:2 (versus 53.5% of all respondents)
- 52.6% say they know little of EIRs (68.8%)
- COBie is a hazy concept to 52.6% (55.7%)

When asked how to best describe the participants understanding of level 2 BIM as it applies to their organisations compared to whole Industry, the results were as follows:

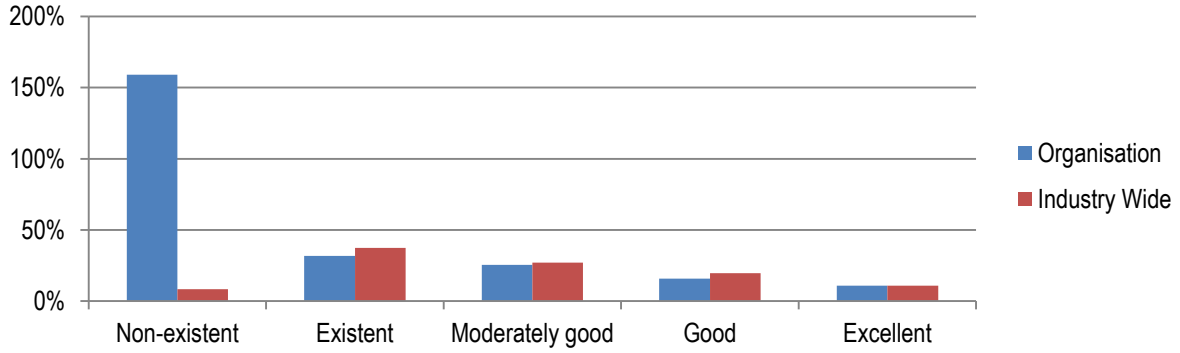


Figure 10: Compiled from Construction Manager 2014 survey findings
Source: (Trench, S. 2014)

Organisational:	Industry wide:
116 respondents answering moderately good, good or excellent which was marginally more than the 106 who answered non-existent or existent. However when you analyse the separate employment categories the figures are make interesting reading: • Private sector clients (7 versus 11) • SMEs (11 versus 16) • Large contractors over £100m (29 versus 19) • Consultants (33 versus 22)	It's apparent that respondents had a better understanding of Level 2 BIM and its application to the industry, however private sector clients showed great disparity with 12 saying their knowledge of BIM overall was non-existent or sketchy, versus 4 who considered themselves to be in the good or excellent category.

9.4 Forecasted growth in the UK -(Construction Magazine. 2014).

Construction Manager magazine survey showed that the respondents were cautious when asked to *"rate their theoretical preparedness to implement Level 2 BIM on a scale of 1 to 10" (1 being underprepared and 10 being ready).* The results are captured in the graphic below:

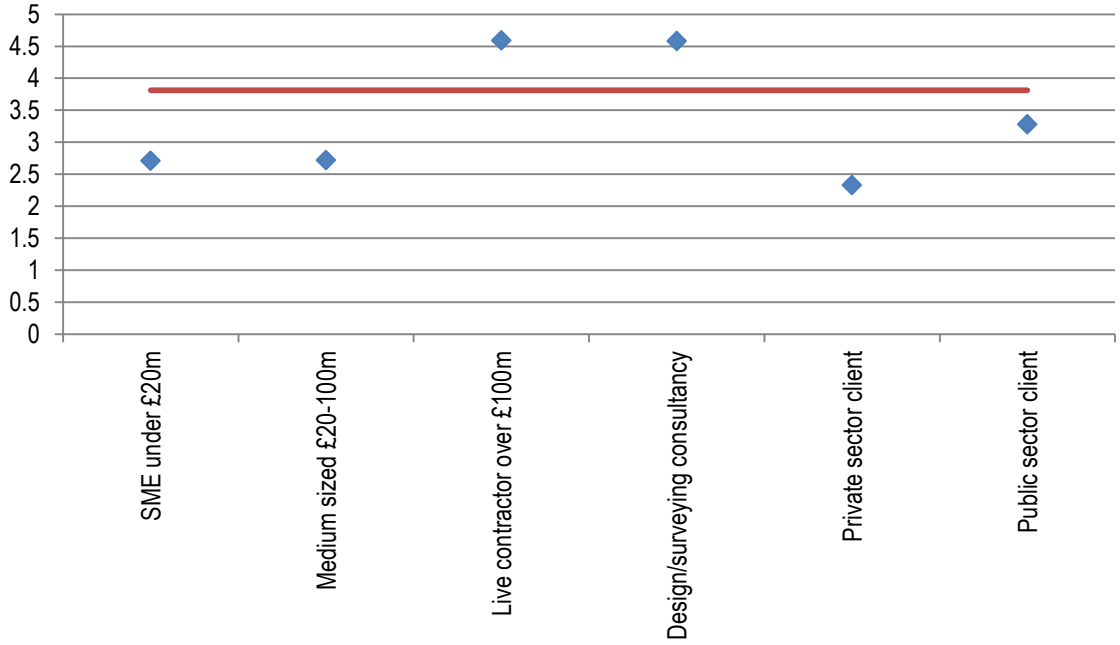


Table 7: Theoretical preparedness to implement Level 2 BIM
Source: (Trench, S. 2014)

The overall average (solid red line) was disappointing at 3.81 of the Private sector clients were found to be the most under-prepared with 60% rating themselves at 1. Public sector clients on the other hand where more informed with 33%. This compares to 44% of all the SME and 26% of large contractors. Consultants responses range from 22.9% at just 1 to 14.6% at 10.

The interface between Tier 1 and Tier 2/3s contractors is a key area for successful BIM which is detailed in with COBie requirements. Balfour Beatty's Trebilcock warns that COBie compliance will add an extra layer of work and complication. It's a step change for the industry to manage and capture all that data. It will need specialist training and the injection of some specialist people to make sure we meet our contractual requirements. It's certainly true that a large part of the team is not ready to provide data in COBie. (Trebilock. 2013)

"We have identified Tier 1 supply chain partners, starting with M&E subcontractors, and have been visiting them to talk through our vision and requirements, saying we'd like them to be able to view the BIM data and to offer them training. There are some very good traditional subcontractors we don't want to lose the services of because they're not technically capable, so it's up to us to provide support and training."-(Speller, A. 2013)

9.5 Forecasted growth globally -(Pikes Research LLC. 2012)

In a 2012 report by BOULDER - Pike Research LLC, a Boulder-based clean-tech market intelligence and research firm IN America, concluded BIM software sales are anticipated to triple over the next seven years with annual worldwide revenue anticipated at circa $1.8 billion at the end of 2013 and reaching $6.5 billion by 2020. Pike's report, entitled "Building Information Modelling," covers the market landscape of BIM, market drivers, technology issues, key industry players, regional forecasts, and other areas (Pike Research, 2012). A worldwide growth of 17.3% in BIM-related services and software revenue products and services is forecasted over the next seven-year period is described as "nascent" but "evolving rapidly". This figure may well increase due to energy conservation issues becoming increasingly prioritised on a global level thus, construction efficient use of scarce resources will become essential, leading to greater use of virtual reality modelling prior to sourcing construction materials.

The research forecasts continued growth in Western Europe, America and a significant growth in the Asia Pacific region due to a large building stock as well as a significant amount of building and construction taking place. It is the belief that as the benefits of BIM run projects are seen its adoption will slowly gather momentum and become standard practice in those regions such as Eastern Europe, Latin America, Africa and the Middle East. *"Building information modelling represents one of the most important paradigm shifts in the last 10-20 years in the way construction services are delivered. The construction industry is notoriously slow-moving, so the rapid development of BIM solutions in recent years has been remarkable."* - (Bloom, E. 2103. Pike Senior Analyst).

10. **BIM SOFTWARE-** Platforms currently available

There are a number of software packages currently available that have the capacity to convert 2D design data into a 3-D model however at this point in time there is not a generic template that can be applied to all projects and design team members. This issue is currently being addressed by the Government who are using its clout to ensure that all proprietary BIM software packages operate with the same icons, toolkits and language. This will allow compatibility across all systems.

BIM software's are not design analysis software's and are not intended to evaluate the structural integrity of the design, but are there to analyse potential omissions and conflicts within the various design elements. The industry leading software's are as follows: Graphisoft ®. By Nemetschek, Revit ® by Autodesk and Bentley ® Systems. The sales claims of these three leading BIM software providers are compared and contrasted below:

Graphisoft's ArchiCAD by Nemetschek

ArchiCAD was the first 2D / 3D CAD product designed to be used on a personal computer.

Key features

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.

Limitations

The programme uses an 'in-memory' system, which can sometimes lead to problems on large projects due to the amount of storage required.

Graphisoft lacks a dedicated structural BIM application.

Users have experienced certain parametric modelling limitations with regards to automatic updating between objects.

Graphisoft developed the first BIM Server application which is intended to optimise project collaboration by making it easier and faster.	

Revit by Autodesk

According to their sale claims, Revit is designed to work the way you think, so you can *'create naturally, design freely'.* As it is purpose-built for BIM, the changes are automatically coordinated which allows the design and documentation to stay coordinated, consistent, and complete throughout the project. Revit offers three compatible modules:

- Revit Architecture
- Revit MEP
- Revit Structure

Key features	Limitations
Easy to learn. The programme uses a central library database structure for the storing and linking of information. It has an array of Revit programmes that can cater to major building industries. The software features a high-quality rendering engine. Autodesk has its own web-based environmental analysis tool, called Green Building Studio Ecotect Analysis).	Only available for Windows operating systems. The software is comparatively expensive. Revit uses an 'in-memory' system similar to Graphisofts programme which can result in performance issues on large projects, especially when dealing with server-based collaboration.

MicroStation by Bentley

The Bentley system has certain capabilities that Revit is not able to perform which is as of a result of being based upon the Microsoft Station technologies. The programme is considered more robust than its Revit competitor however it does require more upfront programming and developmental which results in higher costs for implementation.

Key features	Limitations
Can be applied to a wide variety of industries.	Only available on Windows operating systems.

high-quality images and animations can be created as the software features a powerful rendering engine. It has a distributed file structure to aid in managing large projects. When deployed in its entirety, potentially offers the most powerful BIM solution to the project. The broad suite of associated applications is well aligned to the key project team professions.	For the best results it is recommended that the entire suite of Bentley product are adopted which means it could be inflexible. The software can be expensive. The user interface is substantial and non-integrated, which makes it non intuitive and requires advanced knowledge to navigate.

"We were interested to find such a broad industry for BIM that goes well beyond Autodesk and Bentley, the two main software players in the market. Many small engineering and construction firms consider themselves 'BIM-based' at this point, so there's a true shift happening within the construction industry."–(Bloom E. 2013- Pike Senior Analyst).

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 parties involved in a project. It is worth noting that architects lean towards Autocad while engineers seem to prefer Bentley as a provider.

11. BIM: BUILDING CONTRACTS & CONDITIONS OF ENGAGEMENT

11.1 CIC Protocol

Currently the Construction Industry recognises the CIC BIM Protocol as the leading document it terms of drafting BIM compliant contracts. The Protocol is a supplementary legal agreement that creates additional obligations and rights for the contracted party and the employer but doesn't create additional rights or liabilities between different suppliers. It is incorporated into the professional services appointments and the construction contracts by inserting a relatively simple amendment. In essence "the protocol provides standard terms and procedures in preparing BIM to implement the UK government BIM strategy" -(Barnes, P. 2013).

The BIM protocol should be set out as early as possible as it sets out the legal status and management of the model which in turn will be incorporated into all contracts having a design element for the project. The current standard forms of contracts in use, do not properly deal with this issue. The protocols need to be included within

the appointment and tender documentation and therefore need to be agreed as early as possible. A BIM protocol should cover the following aspects of BIM:

- Definition of responsibilities.
- Level of detail for 'data drops' at defined stages during the development of a project.
- Information management standards that will be adopted.
- Collaborative working practices.
- Copyright and licensing issues.

The standard protocols available are as follows:

- AEC BIM protocol (Architectural, Engineering and Construction UK).
- Construction Industry Council (CIC) BIM protocol. Published in February 2013.

It is worth noting that the CIC warns that any future move to Level 3 BIM may raise additional issues of responsibility, copyright and liability that will require the development of new protocols.

11.2 Contract -(Pinsent Masons. 2014)

In a report by the law firm Pinsent Masons, It was revealed that according to a survey which canvasses the views of experts from 70 organisations across the infrastructure industry, 2/3 of respondents did not believe that the industry was able to achieve the government's 2016 BIM target on all centrally-procured contracts. A breakdown of the results is captured in the figure below:

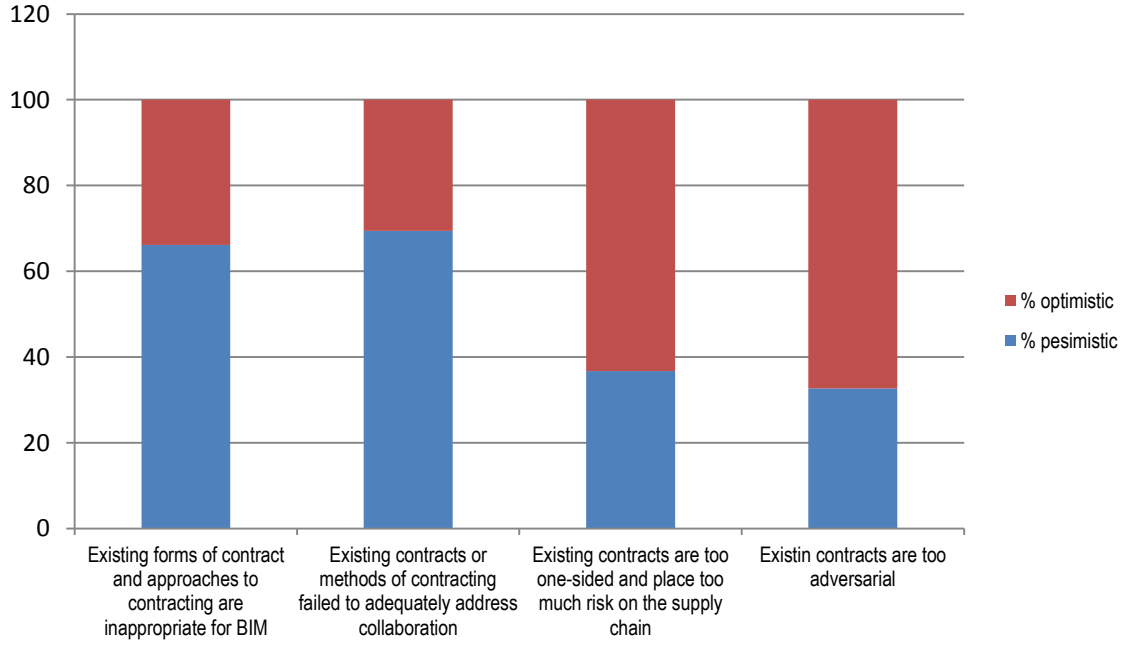


Table 8: Achieve the government's 2016 BIM target
Source: (Trench, S. 2014).

94% of the respondents believe a more collaborative approach between the client and construction team is required to achieve BIM with 1/4 noting that the absence of collaboration is the most significant barrier to achieving Level 2 BIM capability in their organisation. The problem is that the majority of construction contracts are not very collaborative. Risk tends to be allocated in a binary manner, with each party incentivised to look after its own interests – rather than the wider interests of a project. Because the parties' interests are rarely aligned, this tends not to create an environment where true collaboration is possible – at least not if things go wrong. BIM, however, by its very nature requires a more collaborative environment.
69% believe that "existing construction contracts will fail to adequately address the means by which collaborative contracting can be achieved".
*"This may not make pleasant reading for the publishers of standard form contracts, particularly the NEC and PPC2000 forms, which are generally considered to be at the more collaborative end of the spectrum. We believe this is evidence of an industry crying out for a different approach and for contractual arrangements that work in a collaborative environment."- (*Hallam, C. 2013, partner in Pinsent Masons' projects, construction and engineering team.)

In 2013, barrister Tony Bingham raised separate concerns that BIM presents a platform where Tier 1 contractors are able to practice the "black art of risk shift", or ensuring their margins on fixed price projects by leaning heavily on their supply chain.
Between introduction of BIM and new integrated project delivery models such as alliances and partnerships into the construction industry there have been much discussion and confusion with how BIM should be managed contractually, which has led to the development of many BIM specific contracts.
It is important to understand that BIM is essentially an integrated design document and database which facilitates the use of integrated project models. As such, as with any design document and project specific intellectual property final ownership would be with Shell. All project contractual agreements should be determined by the project model, as BIM may be used in any project model from construction only through to alliances, and project documentation, including the BIM, should be managed accordingly.

11.3 BIM & NEC3 contracts –(Barnes CBE. 2013)

The NEC is a family of standard commercial contracts that have been endorsed by the Cabinet Office. Peter Hansford, The UK Governments Chief Construction Adviser, has been closely engaged with to ensure these contracts offer the legal framework required to achieve the Government construction strategy. There are four contracts proposed for use during the creation of the model:

- NEC3 Engineering and Construction Contract (ECC),

- NEC3 Engineering and Construction Subcontract (ECS),
- NEC3 Professional Services Contract (PSC),
- NEC3 Term Service Contract (TSC).

It is worth noting that the short versions of these contracts will not be suitable for those responsible for creating the model. Where short forms are used, the participants may be required to provide digital information by the design team and contractors so they can be added into the model. The parts that set out the technical requirements should be inserted into the works information or the scope for each of the three contracts listed previously under the Z clauses. These clauses can be a way of referencing the relevant parts of the protocol. The Facilities Management (FM), when it is an external appointment, will be appointed under the NEC3 TSC, and will be unlikely to be involved with the preparation of the model. However it is encouraged that this engagement should occur as early as possible to ensure a seamless asset management post completion. Operational aspects of a building may drive the selection for the plant which will be specified at the design stage therefore FM early engagement is desirable.

11.4 NEC3 & the CIC Protocol

Suggested additional clauses are provided under Option Z of the respective contracts for each of the main NEC3 contract forms,. Short forms are not appropriate for appointing Consultants or Contractors to prepare parts of the model, however in exceptional cases such as appointment of an artisan by a letter of appointment similar provisions would need to be included in the agreement terms.
The Protocol includes terms that modify the NEC3 contracts conditions, and include other provisions which form part of the Works Information or Scope. These can be amended through clause 2 so that the amendments can be instructed as compensation events.

The Works Information/Scope needs to include the completed forms which are appended to the Protocol for the Model Production, Delivery Table, the Information Requirements and any other information that the Employer wishes to specify to be used in preparation of the Models. Clause 2.1 lists what the terms of the Protocol take priority over any other document.
Compensation events have been created through sub clause 3 of the additional clause. These are split into the first and second clauses which are listed below:

The first- This is to address how the Consultant or Contractor is unable to comply with the requirements for providing a model, as provided for in clause 4.1.2 of the Protocol. A subjective test is applied as to whether or not the compensation event has occurred by considering whether the Consultant or Contractor is entitled to any additional cost and time required to complete their work as a result.

The second- This is to deal with the issues that would arise if the Employer was obliged to revoke the sub-licence provided to the Consultant or Contractor to use information provided by others in their models.

The respective liabilities of the parties for the work they carry out is captured within Clauses 5 and 7. These create additional 'Employer's risks' under the ECC, and reduce the circumstances covered by the indemnity provided by the Consultant under the PSC.

ECC additional clause

CIC BIM Protocol

1	In this clause, the Protocol is the CIC Building Information Modelling Protocol, first edition 2013. Terms used in this clause are those defined in the Protocol.
2	Clauses 1, 2, 5, 6. 7 of the Protocol are *additional conditions of contract*. Clauses 3 and 4 and Appendices 1 and 2 of the Protocol are Works Information.
3	The following are compensation events. • The *Contractor* encounters an event which is outside his reasonable control and which prevents him from carrying out the work specified in clause 4.1.2 of the Protocol. • The *Employer* revokes a licence granted under clause 6.6 of the Protocol.

ECS additional clause

CIC BIM Protocol

1	In this clause, the Protocol is the CIC Building Information Modelling Protocol, first edition 2013. Terms used in this clause are those defined in the Protocol.
2	Clauses 1, 2, 5, 6. 7 of the Protocol are *additional conditions of subcontract*. Clauses 3 and 4 and Appendices 1 and 2 of the Protocol are Subcontract

	Works Information.
3	The following are compensation events. • The *Subcontractor* encounters an event which is outside his reasonable control and which prevents him from carrying out the work specified in clause 4.1.2 of the Protocol. • The *Contractor* revokes a licence granted under clause 6.6 of the Protocol.

PSC additional clause

CIC BIM Protocol

1	In this clause, the Protocol is the CIC Building Information Modelling Protocol, first edition 2013. Terms used in this clause are those defined in the Protocol.
2	Clauses 1, 2, 5, 6. 7 of the Protocol are *additional conditions of contract*. Clauses 3 and 4 and Appendices 1 and 2 of the Protocol are Scope.
3	The following are compensation events. • The *Consultant* encounters an event which is outside his reasonable control and which prevents him from carrying out the work specified in clause 4.1.2 of the Protocol. • The *Employer* revokes a licence granted under clause 6.6 of the Protocol.

Table 9: How to use BIM with NEC3 contracts

Source: (Barnes, M. 2014- Pg14)

12. BIM: CHANGES IN PROCUREMENT- Objective 4

At first observation it appears that the Government will be the main driver of change as there is a mandatory requirement to use BIM on all its sites in the near future. However in a competitive market every supplier to the construction industry, in order to get ahead of other competitors, will be keen to supply all the information required for BIM to the national BIM library controlled by the NBS. No more so, will be those manufacturers whose machinery is controlled by computers that can be linked to BIM data. In the case of work in the public sector, only suppliers that produce this information will be eligible to be the contributors to the BIM model. Thus for the first time change will be driven both top down and bottom up in the supply chain whereas in the past attempts have been solely to introduce change at the top of the supply chain via consultants and general contractors.

12.1 New Models of Procurement

In 2012, the Government with the support of industry, established a programme to trial three new models of procurement proposed by industry -(Cabinet Office. 2014). These are fully consistent with the objectives of the Government Construction Strategy (May 2011) and the ambitions of the Industrial Strategy for Construction,

Construction 2025 (July 2013). It is anticipated that the adoption of these methods will contribute considerably to the reductions in the cost of construction to both Government and industry. All models encompass the principles of early supplier engagement, transparency of cost, integrated team working and collaborative practice which are as follows:

- Cost Led
- Integrated Project Insurance
- Two Stage Open Book

These documents which are being trialled on a number of public sector projects, represent the next step in the journey to achieving transformation and embedding best practice in conjunction with the implementation of the UK's Infrastructure Routemap and Building Information Modelling Level 2. These models are based upon delivery by integrated project teams working collaboratively. As well as reducing costs, the models are expected to: *"contribute to improved programme certainty, reduce risk, encourage greater innovation, and improve relationships across clients and the supply chain to deliver the most cost effective and value for money outcome" -(Hansford, P. 2014)*

12.2 Cost Led

'The client selects one or more integrated supply chain teams from a framework based on their ability to work in a collaborative fashion to deliver a quality outcome for below the cost ceiling on the first project, and achieve cost reductions on subsequent projects'. -(Cabinet Office. 2014).

In competition at the beginning of the project, a handful of integrated framework supply teams are then given the opportunity to develop their bids with the client team. This is to allow the experience to innovate and drive cost reductions at an earlier stage. The supply team will be selected based on the commercial and physical proposals, the quality of the team members, and provision of at least one scheme that can beat the cost ceiling Should none of the teams be able to deliver the work within budget, the project is offered to suppliers outside the framework. If the price of the scheme cannot be matched or bettered, it should not proceed and the client may need to reconsider the budget or specification. Therefore it is key that the client selects a realistically challenging price, and work to enable its achievement by the industry supply chain. The pre-appointment costs, funded by three teams, will be expensive particularly for the unsuccessful teams who will not have the opportunity to recoup costs from the design and construction phases. The implementation is likely to meet with resistance by the industry or collusion to ensure even distribution of work.

12.3 **Integrated Project Insurance** (IPT)

The client holds a competition based on:

- competence,
- proven track record,
- fee declaration,
- capability,
- maturity of behaviours and,
- proposals for removing waste and inefficiency,

to appoint the members of an IPT who will be responsible for delivering of the project.

Once appointed, team then works up a preferred solution that will deliver savings against existing cost benchmarks for the project. This differs to existing procurement models through the adoption of a single (third party assured) insurance policy to cover risks associated with delivery of the project under one construction-related insurances package. This will be held by the client and supply chain members. Any claim on the insurance policy will need to demonstrate loss and damage. This method is potentially high in risks as any uninsured cost overruns on the project are split between client and the contracted parties (including any key members of the supply chain). This shared accountability removes the potential for a blame culture within the team. Payment of claims is based on the demonstration of loss not the assignment of blame. Yet in order to secure the insurance in the first place, the team will need to present a credible proposal which will need to be validated by the independent expert assurer. This is to ensure that the insurer is comfortable that the proposal can be delivered and that the commercial tension is maintained. Over a period of time insurance companies will police the industry by charging high premiums or refusing to insure consultants or contractors whose track record consistently leads to claims on policies. It is not clear what sort of premiums and conditions will be set by the insurance industry for this type of cover or whether the policy is taken out by the client giving the insurer subrogation rights or whether it is a policy taken out by the co-insured supply team. A project trialling this method of procurement has yet to be undertaken.

12.4 **Two Stage Open Book**

With this model, the client invites prospective team members to bid for a project based on an outline brief and cost benchmark.

1st stage- A number of contractors and consultant teams compete for the contract with bidders being selected based on their:

- capability,

- fee,
- experience,
- stability,
- capacity and
- strength of their supply chain.

During this first stage the model has deadlines for their design and risk contributions and the selected team develops a scheme that has an agreed fixed price and clear risk profile before the client authorises the construction stage.

2nd stage- The successful contractor and consultant team are appointed on a fixed price on the basis of the open book build-up of cost that meets the client's stated outcomes and cost benchmark.

This differs from Cost Led Procurement as it enables faster mobilisation and also provides the opportunity for clients to work earlier with a single integrated team testing design, cost and risk issues ahead of start on site.

12.5 Supply Chain Collaboration

In conjunction with Two Stage Open Book a framework/project team can use a (Tier 2) supply chain intervention. The bidding (Tier 1) contractors propose their preferred supply chains. Once appointed the contractor works with the client and team members to re-engineer that supply chain to ensure best value. It is stipulated that this is not Tier 2 nomination by clients; it is the use of the preconstruction phase for a systematic joint review process. This process ensures earlier involvement and better understanding by Tier 2 supply chain members, and potential sharing of supply chain members among more than one Tier 1 contractor on more favourable common terms. In both cases it is predicted to achieve substantial cost savings.

BIM has been identified as a tool that many assist with management and standardisation of the procurement chain. For example in the UK the NBS has launched a free to use library of BIM elements called Nation BIM. The intent is that the library will become the main source of information for the whole UK construction supply chain, enabling significant savings to the industry. The UK government intends to work in parallel with library as it develops a suite of guides and protocols for its implementation program which as due for full industry integration by 2016.
On a project level the client can use the BIM to strengthen various aspects of the procurement chain. This includes:

- More accurate cost estimates when determining package budget allowances and assessing tender submissions

- More accurate design for contractors to price, reducing provisions sums and “rough guesses” due to lack of visibility
- Having a visual representation of the building will enable contractors to complete more thorough risk assessments, identify project challenges and “pinch points” and develop more accurate project schedules during the tender stage.
- Fabricators can use the model to take accurate measurements enabling elements such as pipes and ducts to be cut off site, producing between quality assurance, significantly reducing project waste and installation times.

12.6 Model selection

A useful tool in the pre-procurement planning process is the Infrastructure UK Routemap3 which will be re-launched later this year. A client will need to determine which procurement model best fits the:

- Project
- Programme
- Capabilities of the client
- Capabilities of the supply chain

This will be based on the client’s required resource commitment, the benefits and the client's requirements and objectives.

13. CHANGES TO MANAGEMENT HIERARCHY IN DESIGN- Objective 5

BIM will bring back a system by which key trade contracts are awarded in advance of the main building contract because of the necessity of specialist input into the development of the 3D model. This was once the case when prime cost sums were inserted as a sum of money in the main contractor’s tender to be awarded as nominated subcontracts by means of an architect’s instruction during the construction stage. The practice went out of favour when the courts ruled that when nominated subcontractors were imposed on the main contractor, the client took on the risk of the nominated subcontractor’s performance.

One might conclude that if the client is unable to place the performance risk of key trade contractors with the main contractor, they may as well employ the main contractor as a construction manager acting as an agent and not a principal in the contractual chain of liability. In other words the trade contracts are directly with the client co-ordinated and managed by a construction manager whose liability is a duty of care as a construction management consultant.

The result is that trade contractors will need to become stronger both in financial and management terms, than they are currently. Alternatively main contractors who currently dominate the industry will buy up key specialist contractors seeking the larger margins of profit that go with risk rather than rely on competitive fee income for providing a management service. So we will see a shift in how the contracting industry presents itself particularly if small high quality project management companies proliferate who can provide a rapid and boutique response to challenge the less flexible large organisations and public companies currently acting as general contractors. There will be a new independent consultancy role for a BIM manager. There are already signs that quantity surveyors and project managers are gearing up to challenge the architectural profession for this role. It has the long term attraction of the possibility of retaining fee income for the entire life of a building rather than the short life of the construction stage. Clients who regularly carry out development work and landlords who invest in real estate may decide to employ individuals in-house to take on this role. The BIM manager will have a key co-ordinating role and will indirectly be a vital cog in the control of the design progress, measurement, specification and cost. Like project management it will require experience and an all-round knowledge of both design and construction disciplines.

14. **CAM-** What is it?

The world leading product manufacturer Siemens state that Computer-aided manufacturing (CAM) *"commonly refers to the use of numerical control (NC) computer software applications to create detailed instructions (G-code) that drive computer numerical control (CNC) machine tools for manufacturing parts."* In other words CAM is a highly automated factory computerised system that allows real time control over robotic tools such as lathes, milling machines, welding tools and cutting tools to give a high degree of precision and consistency. This allows the manufacturing process to be repeated constantly whilst ensuring high quality and uniformity of parts and goods.

Some CAM systems will provide additional information automating the ordering processes from suppliers and the delivery processing to customers.

15. CAM: ADVANTAGES AND DISADVANNTAGES TO THE INDUSTRY

The perceived advantages and disadvantages of CAM are listed below:

Perceived advantages	Perceived disadvantages
• Consistency of quality in large scale production. • High accuracy.	• Expensive capitol cost in the setup of hardware, software and tooling. • Can be slower than standard traditional on

• Speed of production (even on low volume products). • Quicker turnaround on trial and error and on modifications. • Ability to transfer production to other manufacturing facilities. • Reduction in labour and human error. • Reduction in waste. • Health and Safety improvements. • Ease of customization by computerized adjustments to machining tools. • Rapid variation in design requirements due to the above.	one off products. • Considerable investment in operative training.

Successful implementation of CAM improves efficiencies in manufacturing time, cost and quality, and reduces risk of human error. It is a common fear amongst factory workers and Unions that the increased use of robotic tools will eliminate manual labour jobs in the manufacturing industry. Although there is an element of truth in this assumption machines will still require human workers however the nature of manual operation has changed. Repetitive task have now been delegated to the machines whereas the human workers are now responsible for setting up the machines, ensure quality control and undertake machine maintenance.

When an order is entered, the CAM systems aid plant operatives to schedule the flow of materials and resources in coordination with other orders in the factory, notify suppliers when materials or components must be delivered and provide cutting, hatching or assembly instructions for automated equipment. In addition, CAM could be used to help monitor operations and make necessary adjustments. This "factory-of-the-future" is already operating to varying degrees in other industries, notably the transport sector. (Building Product Marketing. 2011). What we are seeing is mechanical plant and equipment increasingly being manipulated and controlled by sensors and electronics linked to computers. You only have to take the automobile industry as an example. Three decades ago the owner with a very basic knowledge of a car engine could make adjustments and replacements to parts under the bonnet. Today only well trained mechanics with skills in electronics and associated circuitry can service and repair engines. While we bemoan the fact that the average driver no longer understands what is under the bonnet we cannot argue that engines are much more efficient and reliable coupled with a host of safety features and warning systems.

16. THE CATALYST FOR CAM- Objective 2

BIM-CAM is the logical linkage between the BIM system used in the design of a building component and the CAM system used in its production. BIM-CAM allows design data to be used directly in the manufacturing process so the same dimensions inputted for a product can be used to drive a numerically controlled machine tool. In addition, BIM-CAM can make it easier for a designer to incorporate manufacturing considerations into design decisions.
The premise is that such advanced technology will become more wide spread in the Construction Industry due to the mandatory requirement of BIM in the Government sector by 2016.

17. THE INFLUENCES OF BIM/CAM ON DESIGN CREATIVITY- Objective 3

As BIM/CAM develops it will lead to the design freedom of not having to standardise everything in order to capitalise on production line savings associated with receptivity. Currently much of manufacturing cost and time is incurred in the manual setting up and alteration of machinery. However when machinery can change its characteristics more or less instantly through computer commands the costs of bespoke components will be little more than standard products, The removal of current standardisation cost shackles will offer designers the opportunity to be more creative with new found flexibility. Suppliers who install these facilities will gain advantage over their competitors and can get themselves appointed at the early stages of BIM 3D modelling development. The ongoing result of this will be a substantial improvement in the aesthetics and quality of design departing from the cost constraints that say blight the current residential box type developments.

18. CAM & CONSTRUCTION

There is an assumption that construction is different from manufacturing as the management techniques differ. This however in some instances is not the case. As the dawn of the Industrial Revolution, Joseph Paxton successfully implemented basic manufacturing techniques such as standardisation and assembly lines to the design and construction of the Crystal Palace in 1851.
In recent years manufacturing just-in-time critical path scheduling delivery has moved from the shop floor (offsite) to the job site (onsite). The time has come to appraise manufacturing experience with CAM to apply its benefits to construction and BIM provides the opportunity for this integration to develop.
The following is a list of some products used in the Construction Industry that lend themselves to CAM. This involves cutting, drilling, shaping of components:

- Reinforcement steel bar.
- Prefabricated mono concrete manholes, frames and covers.

- Underground services pipework- Polyethylene, pitch fibre, cast iron etc.
- Victaulic couplings for pipe connections avoiding hot trades.
- Tanks- Bolted sections.
- Structural steel.
- Cladding- glazing, extruded aluminium, curtain wall panels etc.
- Insulation.
- Metal work- balustrades, stairwells, handrails, iron monger, metal flooring etc.
- HVAC-ductwork, hangers, access panels, fire dampers, fans, controls etc.
- Fabric material such as PTFE used on the Millennium Dome.
- Doors and frames
- Residential roof trusses
- Windows and frames
- Suspended ceilings
- Raised access flooring
- Prefabricated plant rooms
- Prefabricated toilets
- Brick and stonework

18.1 Robotics

A state-of-the-art robot which uses a camera based vision system and vacuum suckers has been developed by Boston based company, Rethink Robotics. Their creation, named Baxter, is able to carry out a number of advanced repetitive tasks simultaneously. The cameras which are located on each arm are able to locate and detect multiple objects. This was displayed at the Bristol Robotics Laboratory in March 2014 where apples where sorted into differing containers based on colour and size.

Figure 11: Baxter the robot

Source: (www.robaid.com. 2014)

Microprocessors that control individual pieces of machinery have been addressed in the previous chapter however the more complex machinery in the form of robotic arms are better known as robots.
According to the CRC handbook of mechanical engineering, Lewis (2014) states that robotics was first used in the mass production in the automotive industry in the 1920's. These robots had been developed in a structured and predictable environment of a factory however in recent years there have been breakthroughs in non-structured environments in military use such as bomb disposal robots and automated drone aircraft.
There are two disciplines of manipulation (mechanical movement) and integration (microprocessor controls) form the basis of robotic design. This is generally achieved with kinetic machines resembling articulated arms with 6 axes (degree of freedom) operated by a proprietary controller. The first three axes control special positioning with the other three controlling rotation and drive. The design also incorporates the characteristics in accomplishing:

- Reach
- Dexterity
- Payload (weight)
- Speed
- Precision (measured by repeatability)

The controlling processors are programmed to provide motion generation and process and information integration and Human intervention/integration.
Today we see varying dependencies on micro processing control as illustrated below:

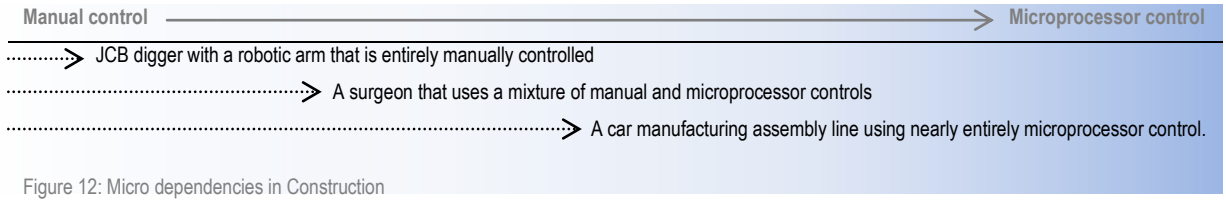


Figure 12: Micro dependencies in Construction
Source: (Trench, S. 2014)

It is not beyond the imagination to envisage a JCB digging a trench without manual control providing that every facet had been accounted for. This is where the move to BIM producing predictability and precision and its transference of data to CAM might allow a greater use of robotics firstly for offsite factory fabrication and possibly in time its use in predictable site activity such as the building of block walls, the erection of scaffolding and the use of surveying equipment when setting out.

19. CONSTRAINTS TO THE DEVELOPMENT OF CAM IN THE UK CONSTRUCTION INDUSTRY.

There is a fundamental difference in the structure of construction and manufacturing which presents the first hurdle for CAM. In a manufacturing environment, marketing design, engineering, purchasing, and production all take place within one structure which differs to construction where separate entities - developers, architects, suppliers, general contractors, subcontractors, etc. are each responsible and represent different facets of the process.

Whereas the location for fabrication in other industries can be confined to a warehouse or factory, this differs in the Construction Industry as the finished product is the site of assembly. The characteristics of each site will vary on a project by project basis as will the location.
It follows that any investment specifically for a project is therefore short term which will prove difficult to justify in terms of value for money.
Road transportation issues restrict the maximum width of materials to 3.5 meters on UK roads without a police escort and heights are restricted by overhead bridges and/or tunnels. Furthermore additional temporary bracing support is often required to combat lateral load stability incurred during transportation.
There is a cost associated with volume in respect of transport. Specifically shipping. The point being that it is not economic to be shipping large volumes of space such as porter cabins and therefore this encourages a flat pack "IKEA" approach. Japanese car exporters fill their boot space with electrical goods.
Other constraints to development include:

- Access/egress to final locations such as size of door openings and entry means to basements.
- Weight of components or assemblies are restricted with regard to site crane capacities and other lifting equipment.
- The bespoke nature of buildings is an impediment to large scale mass production except for those components that are common throughout a building.
- Whereas a factory is in a permanent location which generates a local skilled labour force. A construction site is temporary and requires third party resources to be brought in who may not have worked together.
- Manual assembly requires generous tolerances at interfaces. Engineering tolerances involved with CAM are infinitely less which effects consistency and quality.
- The UK is an island and its manufacturing market is not as large as say the USA and continent and therefore mass production does not have an internal market with the same economies of scale.

20. CURRENT USAGE OF CAM

20.1 Hotchkiss ltd site visit and Interview- 10th February 2014 Eastbourne UK.

Hotchkiss is one of the UK's leading air conditioning ductwork contractor. Their draftsman operates two screens that run drafting software and clash detection software simultaneously. This allows real-time clash detection with the other trades as they work. Approved 3D drawings are downloaded directly into the CAM equipment to assure that the product fits together precisely and clash-free at the construction site.

"The 40,000sqft fabrication shop is equipped with advanced machinery and a highly-skilled manufacturing team.. ….the company is fit to handle any size project quickly, safely and efficiently"- (Daines, P. 2014- Contracts Director for Hotchkiss)

The CAM in the workshop uses completely automated fabrication equipment which enables the production of the most complicated ductwork. This is done quickly and accurately by using:

- Plasma cutting tables,

- Coil Line former with duct lining capability


- Pressure water jet cutter for closed cell insulation


20.2 Current use of CAM outside the UK construction Industry -(University of Illinois. 2007).

The Beckman Institute for Advanced Science and Technology at the University of Illinois at Urbana-Champaign designed by Smith, Hinchmann & Grylls is a prime example of BIM-CAM communication between a building designer and builder. The building is clad in highly detailed coloured bricks which vary sizes and shape. The architect's CAD drawings specified layouts for individual bricks to create a pattern. To draw this brick detail traditionally would have been unfeasible as it would be expensive and slow however CAM gave the designer better control over the building's appearance and provided the contractor with easy- to- follow installation requirements and more accurate information about quantities and dimensions.

Similarly the new grandstand at Ascot Racecourse has a complex cantilevered roof that curves in plan. Every tubular steel truss was different and therefore set to different co-ordinates so complicated to calculate that the setting out drawings contained very little dimensional information. Instead the 3D modelling was transferred to the factory and converted into CAM cutting and assembly criteria from which it was manufactured and transported to site where the roof structure was assembled without a hitch.

The Ascot example is just one area of CAM innovation where the design team and building product manufacturers have shared information. There are new developments in computerised tools that build on this

design, manufacturing collaboration to allow the design vision to be feed directly to the producer's manufacturing operations.

Instead of manufacturing large amounts of uniform products in bulk, producers may now find it more economical to manufacture on order thus switching to more flexible manufacturing systems (just in time production). This could result in shorter lead times on items. Lead time will be further reduced project administration will become simplified. For example, it is standard practice for a manufacturer to have shop drawings to demonstrate their understanding of the designers construction documents. However if the construction documents were created using software supplied by the manufacturer themselves then there would be no need for shop drawings. Therefore the electronic data exchange will result in simplified order-entry procedures and quicker quantity surveys and bidding. This unified database of information will expedite construction.

20.3 The Immediate future

- There are design programs that produce electronic bills of material for direct order entry which assigns each component with a project ID number. When these components arrive on the job site, they are bar coded to assist the contractor with assembly and the owner with inventory control.

- New techniques that are being developed for desk-top manufacturing enable 3D prototypes to be created directly from computer data. In these systems, a laser "draws" scores an object onto a photosensitive or heat-fusible polymer. The laser causes a thin film of the polymer to harden, and the three dimensional shape is gradually built up layer by layer. While the initial applications for this equipment will most likely be complex machine tool parts, costs will likely come down to a point where architects can use it to design and manufacture custom ornaments or building accoutrement like door knobs or plumbing trim.

20.4 The future- (UKCES. 2014).

According to the UK Commission to Employment and Skills, the lines drawn between IT and manufacturing will become increasingly more blurred as the industry heads towards 2030. The report published in February 2014 lists 13 trends which include such areas as converging technologies and cross-disciplinary skills to the digitalisation of production. The report also lists 10 scenarios or “disruptions” that although not supported by evidence may be plausible, such as the development of artificial intelligence (AI) and robotics. These are listed below:

- Reverse migration
- Employees' changing values

- Zero-hour contracts become the norm
- Anywhere, anytime skills delivery
- Artificial intelligence and robots
- De-globalisation
- Geographically alternative centres of excellence
- Disrupted internet developments
- Resource conflicts or climate disasters threaten supply
- Partial fragmentation of the EU

Peter Glover, the senior research manager stated that "smart systems will be employed to assist in the management construction workers and processes." The findings from the report indicate that construction professionals will require a more in depth skillset as they will need to interact with other professionals in external industries such as IT, data analysis and manufacturing. An example of this has been shown with offsite manufacture such as 3D printing where the automatic links between logistics and manufacture have reduced the need for human intervention.

A separate report by the University of Oxford titled, 'The Future of Employment- How susceptible are jobs to computerisation?' also highlighted an impact of AI and robotics following its research across 702 job sectors including the construction sector. The findings have indicated that manual jobs such as painting, carpentry and plant operations may well be replaced in part by factory production lines and automated onsite vehicles. However management positions may remain relatively unchanged by automated procedures in comparison.

21. BIM/CAM

Currently the process from an architect and consulting engineers drawings to a manufactured good is a very long and fragmented one. For example a services consulting engineer will produce linear drawings of pipework, ductwork and electrical to be included in a ceiling void. A contractor will then produce individual drawings for ductwork, drainage, pipework and electrical services all coordinated both within each other and within the structure and the ceiling grid. These drawings will include access arrangements to each individual service. These individual drawings are in turn passed on to manufacturers and they in turn will produce individual component drawings that suit their own standardised components and if necessary produce individual details for variables often bespoke. The machinists will create the mathematical formulae to feed into the computers to control the machining. This process can be particularly time consuming since each recipient of information has to send his output back up the chain to the previous donor to check that it is compliant and it is coordinated with the other relevant information and specialisms.

Current design information	Info flow	Checking & approving	BIM design information	Info flow	Checking & approving
Architect & consulting engineers drawings Specialist Subcontractor drawings Manufacturers drawings Machinists data input	↓	↓	Architect & consulting engineers drawings ~~Specialist Subcontractor drawings~~ ~~Manufacturers drawings~~ Machinists data input	↓	Not needed
	↓	↓	End product	↓	

Figure 13: BIM/CAM information flow

Source: (Trench, S. 2014)

The introduction of building design 3D modelling will bring in the specialist's contribution as and when it is needed so that at the onset co-ordination is ensured and not left as something that has to be integrated into a design that was developed independently. The diagram above illustrates how it will knock out two stages of development that will not be necessary saving time, resources and subsequent cost.

22. THE CRITERIA FOR SUCCESSFUL IMPLEMENTATION OF BIM & CAM- Objective 6

As the government is leading the charge on the implementation of BIMs, it needs to ensure the following:

- That all providers of software standardise their products at the interfaces of systems so they can be compatible with each other since teams of designers with different software packages can contribute to one building model.
- That nomenclature is standardised and embraced so that training can be applied across the board.
- That BIM protocols, conditions of engagement and insurance liability is also regularised across the industry.
- That entry level in purchasing BIMS software becomes much more affordable than is currently the case estimated to be in the order of £10,000 per desk. This is keeping medium and small practices out. The government needs to set up some sort of financial incentive for small firms to invest in BIMS and CAM technology either by:

    - Offering loans in much the same way as they have for first time buyers of housing.
    - Or offering full tax relief for those practices prepared to invest.
    - Or collude with the major suppliers of software by subsiding sale prices.

The BIM Task Groups have identified that there is an essential need to have better controls and definitions of data classification and data deliveries. Manually defining data requirements and checking it using traditional techniques proved inefficient and added little to the overall task of improving design deliveries. Consequently, they launched a competition in 2014 called the 'Functional Specification A digitsl tool for building information modelling' (The BIM Task Groups) to the public for a digital Plan of Work (dPoW) and

Classification. The programme will also include a digital tool to distribute the dPoW and Classifications to make use of these resources as open and simple as possible.

23. KEY RESEARCH

23.1 Introduction and approach

I decided to use a questionnaire as a way to establish the industry's attitude towards BIM and CAM as a way of clarifying consensus in regard to the specific objectives set out in the abstract of this Dissertation which are as follows:

Objective1:	To determine whether or not the cost savings and uptake aspirations of BIM will materialise.
Objective 2:	To highlight the potential to increasing CAM in the event of the role out of BIM.
Objective 3:	To explore what flexibilities is offered to designers in the expansion of BIM/CAM.
Objective 4:	To examine the changes in methods of design procurement following the widespread implementation of BIM & CAM.
Objective 5:	To establish the criteria necessary for the successful implementation of BIM & CAM.

In an effort to achieve diversity I selected a broad range of individuals within varying fields of activity. The questionnaire was canvassed to 162 recipients to which I received 41 responses which equates to a 25% success rate return.

The questionnaire consisted of 7 questions which addressed the objectives listed above and the questions and answers provided were listed in a way that was not unfairly weighted. This was achieved by offering a balanced response matrix (Likert scale). I chose a combination of closed and open-ended questions as I believe it provided the respondents with the space to develop their own ideas whilst achieving quantitative data that can be numerically compared and analysed. The questions that where formatted as statements, for example: 'BIM will result in earlier specialist input in the pre-construction stage.' With the non-biased responses available:

Strongly disagree	Disagree	Neither agree nor disagree	Disagree	Strongly Disagree

24. QUESTIONNAIRE ANALYSIS AND DISSERTATION CONCLUSIONS

The questions, rationale and conclusions reached following the analysis are captured below:

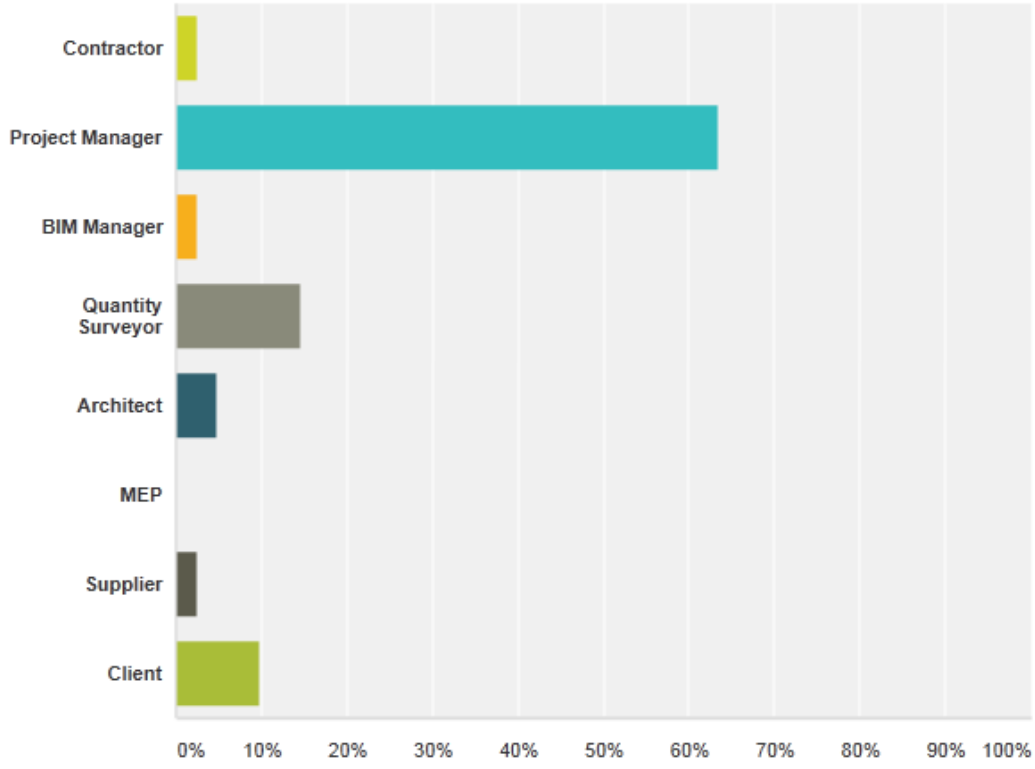
Dissertation question 1

What is your job description?

Rational for question

- To establish the allocation of questionnaire engagement across key sectors and to identify spikes and troughs in participation.
- To establish the perspective for the remaining responses.

Results:



Answer Choices	Comments	
Contractor	2.44%	1
Project Manager	63,41%	26
BIM Manager	2.44%	1
Quantity Surveyor	14.63%	6
Architect	4.88%	2
MEP	0.00%	0
Supplier	2.44%	1
Client	9.76%	4
Total		41

Analysis & Conclusion

From the 41 respondents, over half were Project Managers possibly because of the impact it will have specifically on their day to day activities. This indicates that this field of employment has been more receptive to survey participation. This is encouraging as they will be a key player in the implementation of BIM. It is worth acknowledging that although the questionnaire was distributed to a broad spectrum of practitioners, the project management fields enthusiastic participation may have occurred out of comradary as I am a Corporate Real Estate Project Manager myself.

MEP involvement was non-existent which is disappointing as they are a key member in the evolution of BIM. This being said they will not be the driving force with the implementation which may explain the lack of engagement on my survey. This mentality may result in "riding the coat tails" of other members of the design team with a reactive approach rather than a proactive one and create design bottlenecks with slow MEP design input.

1 in 6 of respondents where Quantity Surveyors which is an encouraging indication of participation and that areas acknowledgment of the Governments mandatory requirements and the cost related impacts.

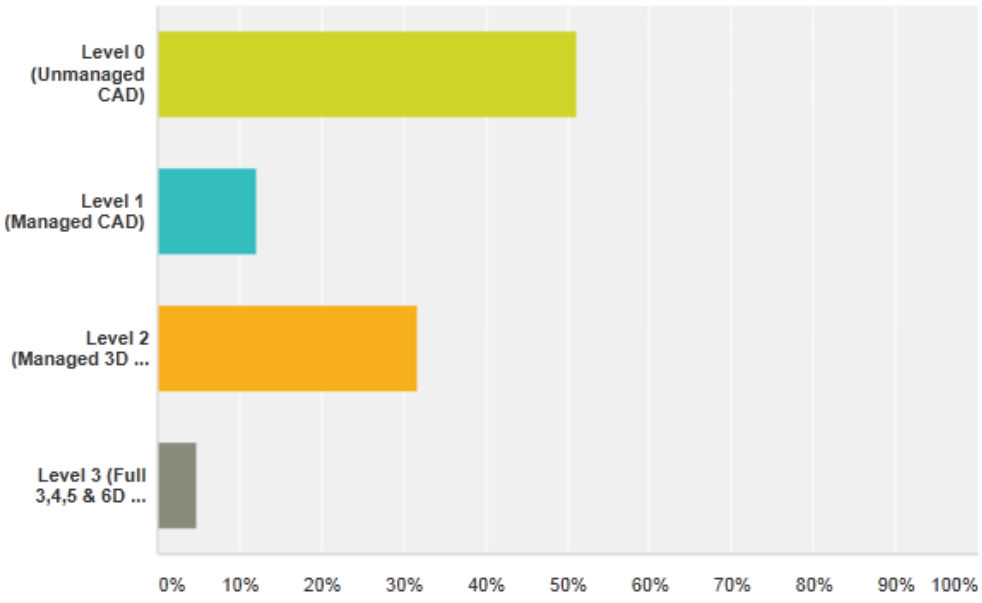
Dissertation question 2

What is your project experience using BIM?

Rational for question

- To determine whether or not the cost savings and uptake aspirations of BIM will materialise. **(Objective 1)**
- To establish the varying levels of BIM currently being used.
- To determine what common trains of thought there are amongst practitioners or contradictions in comparison to the NBS survey.
- To determine what common trains of thought there are amongst practitioners or contradictions in comparison to the Pikes Report.

Results:



Answer Choices	Comments	
Level 0 (Unmanaged CAD)	51.22%	21
Level 1 (Managed CAD)	12.20%	5
Level 2 (Managed 3D model)	31.71%	13
Level 3 (Full 3,4,5 & 6D integration)	4.88%	2
Total		41

Analysis & Conclusion

Half of the respondents have indicated that the projects with which they have been involved with have not been undertaken with managed CAD. This figure is in keeping with the 54% uptake figures that were recorded from the 2014 NBS survey listed in chapter 9.3 and therefore I consider this to be an accurate account of uptake in the marketplace. Unmanaged CAD can often lead to ambiguity over design interpretation especially with a traditional procurement run project. This in turn results in inefficiencies with project delivery in terms of time, cost , quality and may result in disputes and as the majority of the survey participants are PMs (over half) this indicates a worrying trend in terms of project administration.

32% of respondents have been involved with level 2 projects which is in keeping with the 36% figure for level 2 experience which was found following the 2014 survey carried out by Construction Manager magazine discussed in chapter 9.3. It is however hard to determine the number of level 2 projects as this may have been a one off project and whether the individuals possess a comprehensive understanding of the intricacies of level 2 BIM. I am somewhat sceptical that programme data (4D), cost elements (5D) and a feed operation system as well as the information exchanges between systems via COBie has been done on all these projects. Referring back to the BIM maturity level summary discussed within chapters 7.2 and 7.3 of the dissertation.

The results found in chapter 9.3 indicates that Public sector clients are slightly ahead of private sector clients, with an overall confidence level that is higher however worryingly, public sector clients seem to be no more

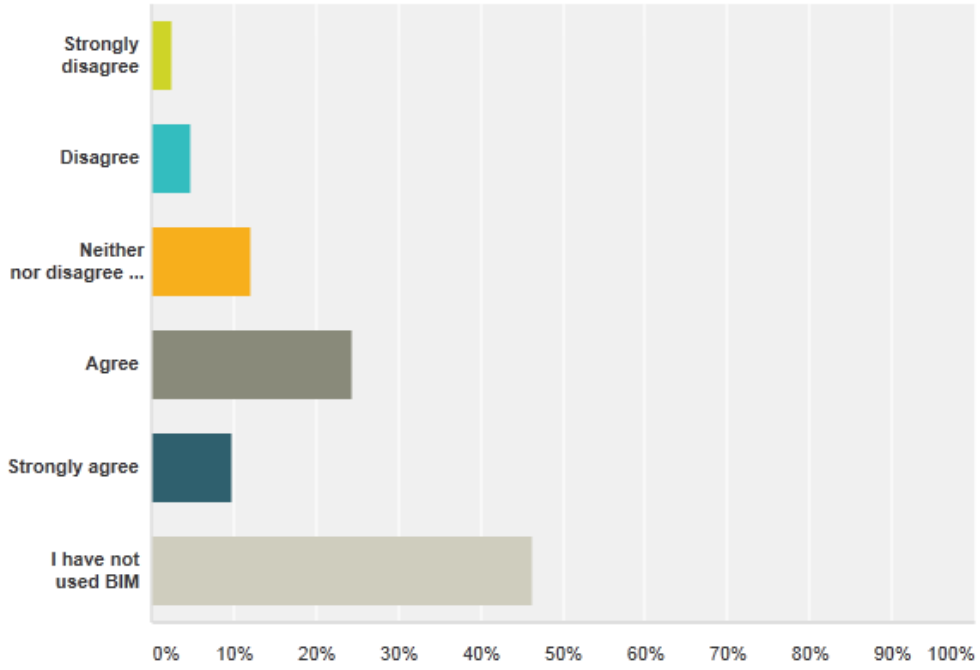
clued-up on the technical requirements than most in the industry which could lead to potential pitfals within the public sector.

Dissertation question 3

BIM has added value to the projects i have worked on?

Rational for question

- To determine whether or not the cost savings and uptake aspirations of BIM will materialise- (Objective 1).
- To establish the perception of added value to a project by the marketplace.



Answer Choices	Comments	
Strongly disagree	2.44%	1
Disagree	4.88%	2
Neither agree nor disagree	12.20%	5
Agree	24,39%	10
Strongly agree	9.76%	4
I have not used BIM	46,34%	19
Total		41

Analysis & Conclusion

Of those who have used BIM, 50% have confirmed that they believe that the implementation of BIM has added value to the project with a 25% neither agreeing or disagreeing. As noted in chapters 8 (implementation issues) “best value is achieved when the whole project team and relevant stakeholder groups adopt the model”. Perhaps the remaining quarter who do not believe it has added value have been involved with projects where complete buy into the model has occurred which may have resulted in a disjointed project.

This information indicates that the general consensus is that value has been added however it does not reveal

whether the responses relate to time, cost quality, lines of communication etc. In order to determine the perceived benefits without subjective interpretation, I held interviews with individuals who took part in the questionnaire who represented the various stakeholder groups (Architect, Client, QS etc) that made up the questionnaire response pool. My findings from these interviews are captured in chapter 23.1 (BIM: Perceived benefits to the client and the project team).

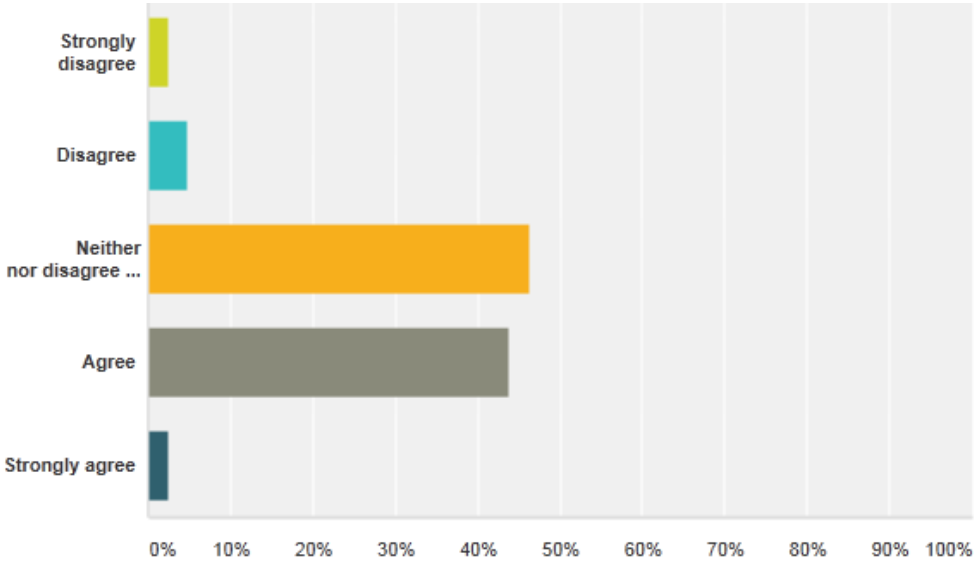
In general, the industry has struggled to show how to accurately show direct savings achieved through the implementation of BIM. Thus is due to many of the savings achieved being "soft savings" through improved collaboration and communication between stakeholders and improved quality and visualisation of the design.

Dissertation question 4

BIM will increase the use of CAM?

Rational for question

- To highlight the potential to increasing CAM in the event of the role out of BIM (Objective 2).



Answer Choices	Comments	
Strongly disagree	2.44%	1
Disagree	4.88%	2
Neither agree nor disagree	46,34%	19
Agree	43.90%	18
Strongly agree	2.44%	1
Total		41

Analysis & Conclusion

As discussed in chapter 16 (the catalyst for CAM) there is a logical linkage between a BIM system used in the design of a building component and a CAM system for the production and it is encouraging to see that 44% of the participants acknowledge this synergy. This percentage will only increase as the industry gets to grip with the standardisation of BIM platforms and therefore the boundaries of its development are stretched from the design capabilities into the manufacturing areas.

This being said 46% remain uncertain of the intrinsic link between the two areas.
BIM-CAM is the ultimate integration between computer programs. With the construction industry is entering unexplored territory with mandated BIM which sees traditional methods and relationships being re-examined this area will only become feasible as BIM implementation becomes more standardised. From my research I believe BIM-CAM is likely to result in new levels of design and construction productivity and promote the architectural imagination to venture into areas of design that are currently dismissed.

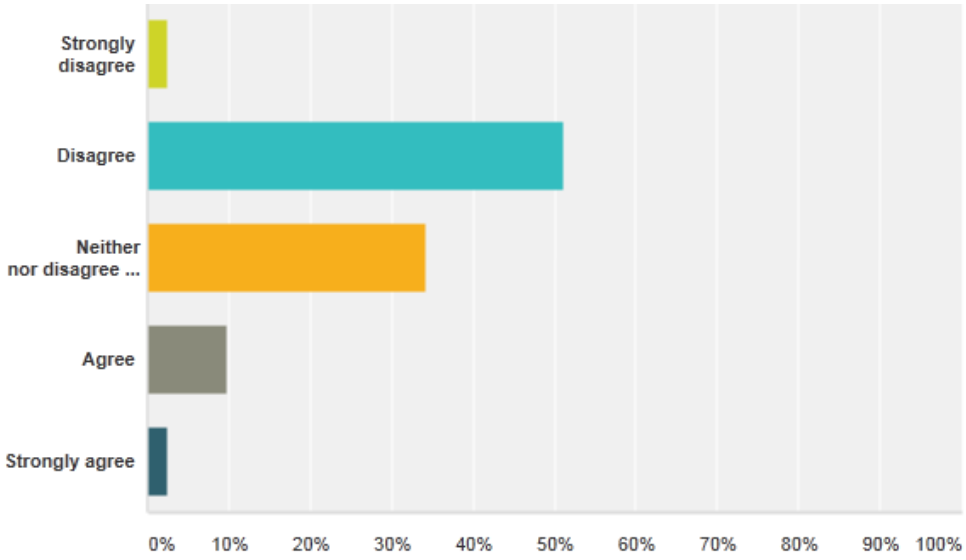
The building industry is entering unexplored territory in which traditional methods and relationships will be re-examined and BIM-CAM provides the ultimate integration between computer programs to unify the design, construct and operate processes. While slow to take off, the Governments intervention inevitable act as a catalyst in speeding up the design and construction productivity and provide new outlets for architectural imagination.

Dissertation question 5

BIM stifles design creativity

Rational for question

- To examine the changes in methods of design procurement following the widespread implementation of BIM & CAM **(Objective 3).**



Answer Choices	Comments	
Strongly disagree	2.44%	1
Disagree	51.22%	21
Neither agree nor disagree	34.15%	14
Agree	9.76%	4
Strongly agree	2.44%	1
Total		41

Analysis & Conclusion

The majority believe that BIM will allow design creativity to flow which is a surprising response as previous research has indicated otherwise. This is especially interesting when you consider that on 4 out of the 41 respondents are designers so this opinion belong predominately to the other team members.

Traditional Contracts are procured in such a way that design has to be taken to a stage where a main contractor can produce a tender. After the Contractors appointment they are in a position to appoint specialist subcontractors who produce their working drawings under the management of the Principle Contractor for approval by the design consultants. With the advent of BIM the specialists need to be brought aboard at a relatively early stage of design, in order to contribute input into the 3D modelling. The Principle Contractor may not necessarily be appointed at this stage. To persuade clients that value for money is being obtained on specialist work, it is likely that two stage competitive tendering on specialist work will become the preferred choice.

Two stage tendering is a system by which contractors competitively bid on a notional set of criteria setting out rates , preliminaries, overhead and profit in the form of prices that will be used at a second stage when the design has been properly established. The idea being that the second stage is a mathematical calculation and not a negotiation. Whereby the consultants may manage the first stage tender and the Principle Contractor may manage the second stage of the Tender. BIM will ensure there is early specialist design proportion carried out

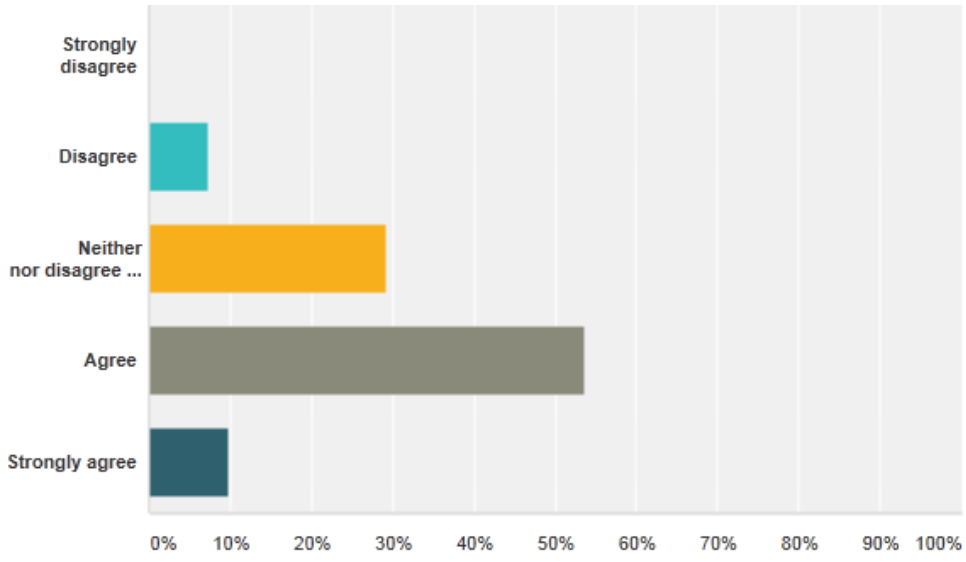
which will promote more creative design as the form of the Construction is driven from an artistic perspective from the outset.

Dissertation question 6

BIM will result in earlier specialist input in the pre-construction stage.

Rational for question

- To establish the criteria necessary for the successful implementation of BIM & CAM (Objective 4).



Answer Choices	Comments	
Strongly disagree	0.00%	0
Disagree	7.32%	3
Neither agree nor disagree	29.27%	12
Agree	53,66%	22
Strongly agree	9.76%	4
Total		41

Analysis & Conclusion

The results indicate that the early input from specialist designers is required. This is positive acknowledgment that the way in which design is procured will need to change from the traditional linear exchanges of information which is in keeping with the three Government procurement routes that have been discussed.

Many developers will be difficult to persuade that best value for money can be judged in a construction market that steps away from competitive tendering on a full pack of information. All BIM procurement trials advocate loosing negotiating leverage by promoting a system of selecting teams before the scope and price is established.

BIM adoption on a wide scale is likely to lead to professional and contracting coalitions being formed as well as mergers and acquisitions that will promote themselves as single uniformed teams with their joint track record. One might envisage major contractors buying smaller specialist subcontractor and supply companies to give

themselves an edge.

The contractors with financial clout are already leading the charge in the purchasing of BIM technology. The government is primarily interested in cost and procedures. If BIM becomes a management tool by project managers driving down costs design creativity and innovation will become the first casualty.

Many manufacturers retain their prominence by good design and secrets of the trade that they might not wish to give away in the early stages of design prior to being awarded work only for their competitors to benefit. Such reticence would prove an obstacle to two stage appointments.

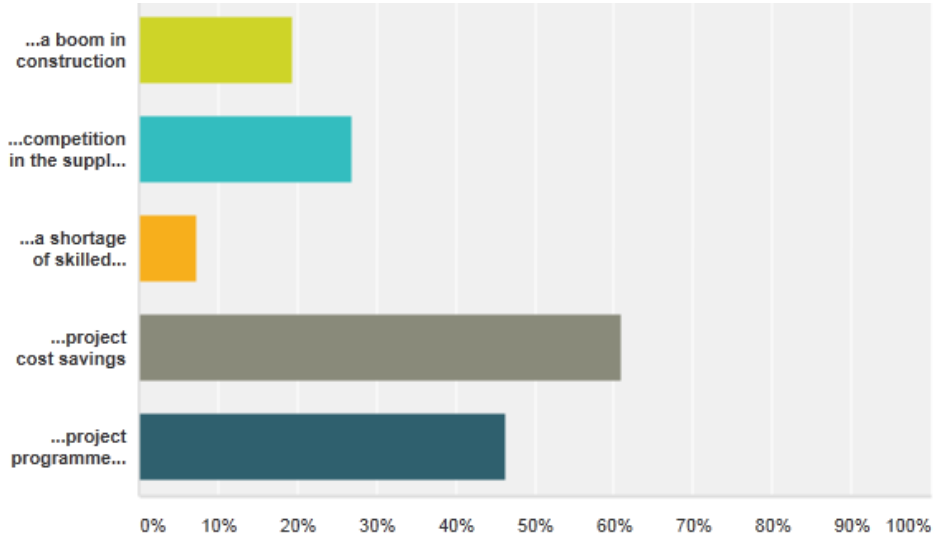
Dissertation question 7

Irrespective of Government insistence on the use of BIM. Investment in BIM/CAM will increase due to...

Rational for question

To establish the criteria necessary for the successful implementation of BIM & CAM (Objective 5).

Results:



Answer Choices	Comments	
A boom in construction ...	19.51%	8
Competition in the supply chain ...	26.83%	11
A shortage of skilled labor ...	7.32%	3
Project cost savings ...	60,98%	25
Project acceleration program ...	46,34%	19
Total number of respondents: 41		

Analysis & Conclusion

It is clear to see that the survey participants share the same opinion of the Government in acknowledging the cost savings that can be generated from its implementation. It is interesting to see that the perceived programme savings are listed as the second most beneficial aspect from implementation.

In terms of successful implementation, BIM creates a complex design liability scenario contractually. It needs to

overarch the contractual structure of design obligation in order to be truly collaborative and fully effective. If this is avoided then we are likely to see a number of complex liability issues, such as:

- different duties of reasonable
- skill care and fitness for purpose
- software glitches
- breach of the duty to warn
- conflicts over insurance cover
- claims under the Contract (Right of Third Parties) Act 1999 or contribution disputes under the Civil Liability (Contribution) Act 1978.

25. FURTHER INVESTIGATIONS: Perceived benefits

In addition to the information from the respondents data from the questionnaire, I decided to follow up with a number of interviews with individuals who represent different stakeholder groups to determine their perception of the benefits of BIM that may not have been captured within the confines of the questionnaire. This was to specifically address objective1 (To determine whether or not the cost savings and uptake aspirations of BIM will materialise. My findings are listed below:

Role:	**The Client**- Head of Project Delivery for Shell International, London
Name:	Andy Sillitoe
Date of Interview:	6th January 2014
Advantages:	• The client s can no longer be kept in the dark in respect to what is happening on their projects providing they have access to the BIM platform. • By having accurate computerised design information there is the potential opportunity to transfer this information to computers that are able to manufacture components leading cost reduction and quality improvement and consistency.
Additional Comments:	The BIM Task Group suggest that *'...if successfully implemented, (BIM) will help organisations strip the waste from their processes which in many cases could be in the bandwidth of 20-30%'*.

Role:	**The Quantity Surveyor**– Senior Quantity Surveyor at JLL
Name:	Leon Clark
Date of Interview:	7th January 2014
	• Detection of clashes between services and structure and improved co-ordination will

reduce the number of contract variations, saving additional costs and delays in the construction phase.

- Scope gaps when costing and tendering can be more easily identified.
- Computer tracking of the BIM model will be more accurate than visual subjective judgements. This will result in improved accuracies in valuation.
- Greater transparency and speed in estimating and agreeing variation costs with the Contractor leading to improved Project Evaluation to the Client.
- Carbon estimating software can be linked to the model.
- Alternative options "what if scenarios", can be developed further and evaluated instantly at the design stage and at less cost in respect of resources.

Additional comments: The opportunity for surveyors which can add value. *"let them go and the profession risks losing out."*

Role: **The Project Manager**- Senior Project Manager at Mace

Name: Chris Mole

Date of Interview: 8th January 2014

Advantages:

- A regular updated data management system, shared between the project participants replaces the post box delay syndrome, historically associated with projects.
- Guaranteed and simplified design coordination.
- Performance and progress against Contract Programme can be measured with more accuracy.
- Improved communication between all participants of the Project, including stakeholders and third parties.
- Visualization of final product and communicating any need for phasing works.
- Design changes can be identified and tracked in the model and scope gaps can be checked.
- Operational Manuals and asset management systems are continuously updated during the construction and commissioning processes. Therefore the model becomes a record to aid the FM team.

Additional comments: The "*opportunity to improve the information flows and decision making through integrated working",* which should be embraced as is promotes two main areas of PM strength- communication and collaboration. PMs may be required to assume the role of BIM model manager and implement a BIM execution plan.

Role: **The Architect-** Senior Architect at Pringle Brandon Perkins & Will

Name:	Simon Bone
Date of Interview:	9th January 2014
Advantages:	• Reduced work load in co-ordinating design at all stages in regard to other Consultants input and specialist input. • Some of the advantages listed above are of benefit to the Architect. • Provided that the Architect adopts the role of "BIM Manager" he/she ensures that they are in a prime position to be appointed for future works which require the coordination of this information. • More information will be available at an earlier stage of design due to the specialist designers earlier involvement. • It is easier to determine the full impacts from variations to design.
Additional comments:	There is a temporary advantage to all participants that are able to offer BIM compliancy to the Client. Entry cost for software and training presents a prohibitive barrier to entry to smaller design consultants, thus offering the larger consultancies a distinct advantage.

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27. APPENDICES

27.1 Appendix 1: Questionnaire

*

1. What is your job description?

- What is your job description? Project Manager
- Architect
- Client
- BIM Manager
- MEP
- Quantity Surveyor
- Supplier

Other (please specify)

*

2. What is your project experience using BIM?

- What is your project experience using BIM? Level 0 (Unmanaged CAD)
- Level 1 (Managed CAD)
- Level 2 (Managed 3D model)
- Level 3 (Full 3,4,5 & 6D integration)

Additional comments:

*

3. BIM has added value to the projects i have worked on

- BIM has added value to the projects i have worked on Strongly disagree
- Disagree
- Neither disagree nor agree
- Agree
- Strongly agree
- I have not used BIM

Optional comments:

*

4. BIM will increase the use of CAM

- BIM will increase the use of CAM Strongly disagree
- Disagree

Neither disagree nor agree

Agree

Strongly agree

Additional comments:

*

5. BIM stifles design creativity

BIM stifles design creativity Strongly disagree

Disagree

Neither disagree nor agree

Agree

Strongly agree

Additional comments:

*

6. BIM will radically change the way design is procured

BIM will radically change the way design is procured Strongly disagree

Disagree

Neither disagree nor agree

Agree

Strongly agree

Additional comments:

*

7. The expansion of BIM & CAM is most dependent on

The expansion of BIM & CAM is most dependent on A boom in construction

Competition in the supply chain

Shortage of skilled labour

Government intervention

Cost savings

Programme acceleration

Other (please specify)

8. As part of my research I may wish to contact you directly. If you wish to stay anonymous please leave fields empty. No details will be published as part of my dissertation and will be deleted once used. As part of my research I may wish to contact you directly. If you wish to stay anonymous please leave fields empty. No details will be published as part of my dissertation and will be deleted once used.

Name:

Contact number:

Total word count: 17,056