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The Dynamics of BIM Adoption: A Mixed Methods Study of BIM as an Innovation within the United Kingdom Construction Industry

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Copyright Statement

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Dedication and Acknowledgements

This thesis is dedicated to:

- My creator, may we all be touched again by his Noodly Appendage.

- My late father for the gift of life and his inspiration since my birth.

I would also like to thank the following individuals:

- My wife Karen and daughter Lucy without whose patience and understanding, this research would not have been possible.

- Annie Yeadon-Lee, Steve Lawson, Leigh Morland and my DBA cohorts for their support and encouragement.

- To Pat Condell for so many laughs when I needed them most.

Abstract

Building Information Modelling is an approach that fully integrates people, systems, business structures and practices into a collaborative and highly automated process, applicable to the design, construction and operation of buildings. With the United Kingdom Construction Industry (UKCI), the UK Government, as the industry's largest client, has mandated the use of BIM on all public sector projects by 2016. By considering BIM as an innovation, a total of 104 potential dynamics of BIM adoption were identified from literature along with potential variations by company type and size. Through the application of equal status mixed methods and robust stratified random sampling of 335 respondents, to match the profile of the UKCI, the key findings of the study are:

Overall 62% of respondents have adopted BIM, with adoption highest among Consultants and Main Contractors, and lowest among Sub-contractors, with a substantial increase in adoption following the Government Mandate. Although there is scope for the increased utilisation of BIM for those who have adopted it, 10% of respondents have no plans to adopt BIM.

23 significant dynamics of BIM adoption were identified, with 15 of these inhibiting adoption and 8 supporting adoption. For large companies the government mandate and advantages of BIM as a collaboration tool were the more significant supporting dynamics, while for smaller companies the cost of BIM was the more significant inhibiting dynamic. For Main Contractors, the robustness of existing practices and for Sub-Contactors the cost and complexity of BIM, along with company survival were the most significant inhibiting dynamics. The results suggest that under Rogers's diffusion of innovation model, while relative advantage is an important supporting characteristic of BIM, compatibility with existing practices Is an equally important but inhibiting characteristic, while observability is not relevant.

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Glossary of Key Terms and Abbreviations

In order to provide a quick reference for the reader unfamiliar with the subject of this research, Table 0.1 provides a list of key terms and abbreviations, as well as enhancing the accuracy of interpretation and readability of the thesis.

Abbreviation / Key Term	Meaning
BIM	Building Information Modelling.
CAD	Computer Aided Design.
Client	The company or individual responsible for commissioning a construction project or building.
Consultant	A company or individual who provides construction related professional advice and services e.g. Architect, Structural Engineer, Acoustician.
Design and Build	Design and Build: A form of contracting used where design and construction of the project are the responsibility of a single company, usually a Main Contractor. Hence design and construction can be better integrated.
Innovation	Innovation is the application or introduction of something which is either new or significantly different, from the perspective of the user.
Main Contractor	Usually the leading company responsible for the delivery of a construction project on site, including management of day to day activities on site including sub-contractors. Often the party ultimately responsible from a contractual basis for delivery of the project.
SSI	Semi structured Interview.
Sub-Contractor	A more specialist contracting organisation, responsible for the delivery of a particular part of the works on site, usually under contract to the main contractor.
Traditional contracting	A form of contracting used where design is completed by a consultant team before the project is tendered and a Main Contractor selected to deliver the project. Hence design and construction are separate processes.
UKCI	The United Kingdom Construction Industry.

Table 0.1 – Key Terms and Abbreviations

Chapter 1 - Introduction

This chapter provides the reader with an introductory overview of this thesis and in doing so aims to equip the reader with a framework to support their understanding. It includes the background and context of the study, the rationale for the study, the aims and objectives as well as limitations / exclusions of the study. This chapter concludes with a roadmap of thesis, including details of the literature review and methodology chapters.

1.1 Background and Context to the Research

The United Kingdom Construction Industry (UKCI) can be considered an important part of the UK economy (Kollewe, 2011), contributing approximately 8% of UK GDP and employing some 1.5M people (Office of National Statistics, 2012).

There is evidence of the extensive adoption of ICT within the UKCI, with the widespread use of e-mail on site (Chan and Kamara, 2008) and CAD (McGraw Hill, 2010). However, the Government as its largest client, has expressed concern that the UKCI "… under-performs in terms of its capacity to deliver value" and has not taken sufficient advantage of the "… full potential offered by digital technology" (Cabinet Office, 2011, p.5 & p.13). In seeking to obtain better value as a client and also address this wider performance issue, the Government as part of a wider construction strategy, has mandated the use of Building Information Modelling (BIM) on public sector projects by 2016 (Cabinet Office, 2011).

In addition to this, the researcher has worked in the UKCI for the past 27 years and has hands on experience of the challenges faced by the adoption of CAD within a public sector Architects Department in the 1990s and the early adoption of BIM in large private sector main contractor in the mid 2000's. Full details of the researcher's career can be found at Appendix 1 – About the Researcher.

1.2 Rationale for Study

There is a view that the UKCI has remained inhibited by long term performance issues reflected in a plethora of Government reviews, with Jones & Saad (2003) highlighting a total of twelve between 1944 and 2002, (Egan, 1998, p.4) noting that “Too many of the industry’s clients are dissatisfied with its overall performance” and Manseau & Shields (2005, p.43) commenting that “Productivity levels are still relatively low in comparison to other sectors”.

Building on this issue , the drivers for this study emerged from combination of the researchers own professional interest and experience, combined with the fact that the Government has, somewhat unusually, felt compelled to mandate the use of BIM on its projects from 2016 (Cabinet Office, 2011), rather than allowing the UKCI to implement this at its own pace under market forces.

Given the apparent dissatisfaction with the UKCI, combined with the potential of BIM to deliver benefits (Autodesk, 2006, Yan and Damian, 2008, Succar, 2009, Cabinet Office, 2011)and the Government’s intervention, this study seeks to build on previous literature to understand both the status of and issues relating to the dynamics of BIM adoption. While the literature review below suggests what appears to be a relatively comprehensive range of issues in previous studies, this study aims to build on these while addressing a number of perceived issues.

Reflecting the potential for impact on practice resulting from this being a management (DBA) rather than a traditional doctorate (PhD), the study also aims to influence the application of BIM within the researcher’s own professional practice, their sponsor employer and the wider industry. The researcher’s post research reflections on the opportunities for this to take place, can be found in the accompanying Personal Impact Statement. In support of these desired outcomes, the intended audience of this study includes both academics and practitioners with an interest in the adoption of BIM.

1.3 Aims and Objectives

1.3.1 Research Aims

Building upon the rationale above, the two primary aims of this research are to establish:

1. The state of play of BIM adoption in the UKCI.
2. The perceived dynamics which support and inhibit the adoption of BIM and, in a sector characterised by companies of many different sizes and types, any variations in these across different types and sizes of companies.

A key term, introduced within the second aim, is dynamics. Originating from the Greek word for force, this was selected by the researcher as a term to identify characteristics, circumstances, topics, issues or factors relevant to BIM which impact on its adoption by companies within the UKCI. This etymological origin, also reflects the application of field theory (Lewin, 1951) within this study as an organising framework, with Cartwright describing group dynamics, within the context of field theory as:

> the forces operating in groups ….. a study of these forces: what gives rise to them, what conditions modify them (Cartwright, 1951, p.382).

Finally, contemporary definitions of the term dynamics, reflect this origin by reference to the forces or properties which stimulate among other things, change or motion within a process or system, in this case the adoption of BIM.

1.3.2 Research Objectives

A critical decision in support of these aims was consideration of BIM as an innovation, thus providing innovation theory as a theoretical lens, through which the study was undertaken. In particular, this enabled the application of diffusion of innovation theory based around the seminal work of Rogers (2003), as an organising framework and focus.

The consideration of BIM as an innovation was supported by a number of factors including, the relevance of innovation literature to the UKCI, which despite having well noted performance issues, has according to many authors including Egan (1998), a poor track record of innovation. In addition, the networks between companies within the UKCI are arguably different than other industries. When combined with identification of social structure as key factor in the diffusion of innovations (Rogers, 2003), this has the potential to provide key insights to the adoption of BIM. Innovation theory is also suited to the study of technological innovations (Rogers, 2003), such as BIM, provides a systematic and well defined organising framework (Panuwatwanich and Peansupap, 2013) and have been successfully applied to consider inter-organisational systems (Ibrahim, 2003), one of the many characteristics of BIM. Finally, reflecting the potential for this study to influence practice, Dearing and Rogers (1996) describe how the application of innovation theory can practically inform programmes to accelerate the diffusion of an innovation, in this case increasing the adoption of BIM within the UKCI.

The four research objectives, summarised below as RO1 – RO4, are introduced as a Venn diagram, shown at Figure 1.1, which combines the three key elements.

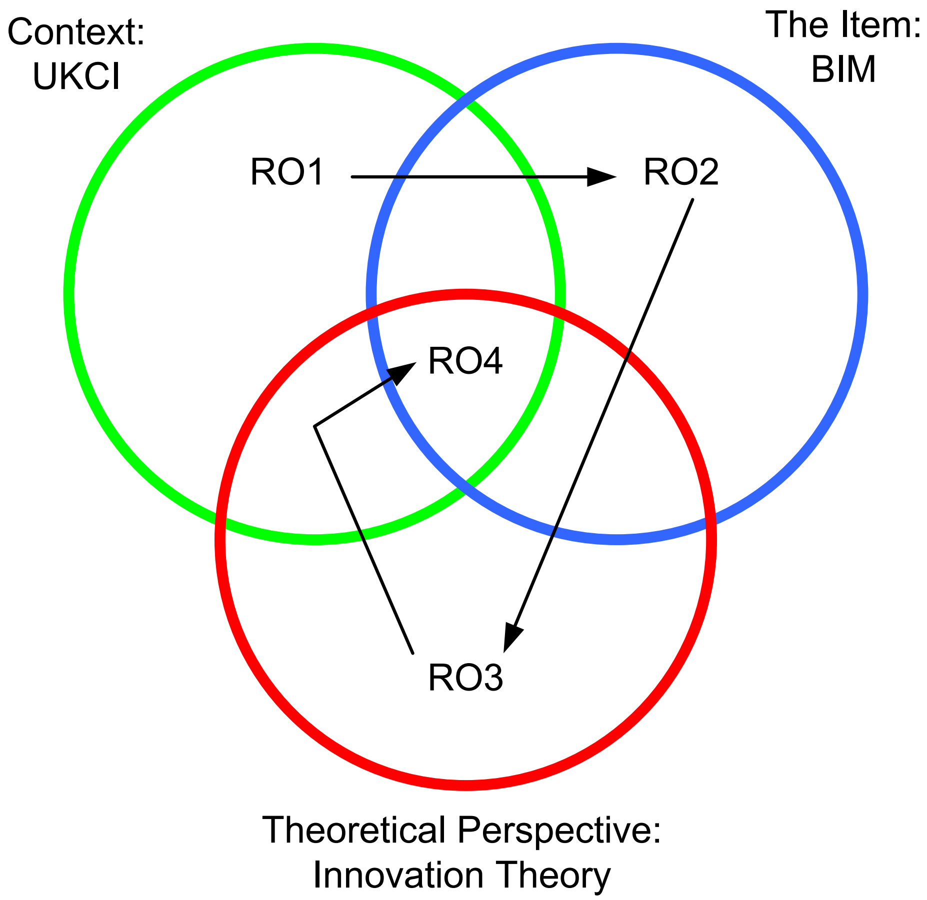

Figure 1.1 – Meeting The Research Objectives

The first objective (RO1) explores the context of the research, namely the UKCI, while the second (R02) focuses on BIM as the item under scrutiny and the third (R03) explores innovation as the selected theoretical underpinning. Within the fourth objective (R04), these are synthesised to support completion of the primary research from literature, i.e. to predict the patterns and dynamics of BIM adoption. These objectives can be summarised as questions below:

R01: What is the UKCI and what are its market and structural characteristics?

RO2: What is BIM and what are its characteristics, benefits, drivers for and issues with adoption?

R03: What is innovation and what innovation theories are relevant to this research?
R04: What are the patterns and dynamics of BIM adoption across different company types and sizes?

Through the application of a hypothetico-deductive approach, these patterns and dynamics are then tested through the robust capture and analysis of data, during the secondary research described in the methodology, analysis and results chapters.

1.3.3 Intended Contribution to Knowledge

While a number of authors have already explored the adoption of BIM, a review of literature in early 2012 highlighted the opportunity to build on previous literature while addressing issues perceived by the researcher and setting this study apart in a number of ways.

To give a balanced rather than pro-BIM perspective, this study includes the identification of a wide range of both supporting and inhibiting dynamics of BIM adoption. To address a perceived lack of validity and reliability in much of the literature reviewed[1], this study aimed to achieve high level of robustness in terms of its validity and reliability, through the application of a number of methodological techniques. Described in full detail in the methodology chapter, these included the use of mixed methods and methodological triangulation to overcome the weaknesses inherent with any single research method and provide methodologically robust results. Stratified random sampling and large sample sizes were also applied to ensure results were statistically robust and representative of the UKCI. Finally, sampling also included an appropriate range

[1] For example, while one of the largest UK specific surveys (NBS, 2011b) achieved 800 responses, in the absence of detail on the sampling method applied, this appears to have been carried out on a convenience basis.

of company types and sizes to enable variations in adoption and dynamics to be explored in detail.

In doing so, this study aims to make a contribution to knowledge which addresses perceived gaps in previous research.

1.3.4 Intended Contribution to Practice

As a professional doctorate, this study provides a number of opportunities to influence professional practice within the UKCI, through the provision of a representative current state of play of BIM adoption. In addition, it identifies both supporting and inhibiting dynamics, including those most relevant to different company types and sizes, suggests ways in which the adoption of BIM can be better supported and also discusses the potential impact of BIM on the UKCI and Government Policy.

Following completion, the researcher aims to facilitate application to practice through a range of channels, including making results and the thesis widely available, the publication of articles in both academic and trade journals and presenting at BIM conferences and working parties. In addition, practice can also be informed through the researchers own professional activities and by their employer, strengthened by this DBA research.

1.4 Significant Exclusions and Limitations

The time constraints of this DBA mean that this study is cross sectional, covering the UKCI at a single point in time. In doing so, it provides a snapshot at a point in time, rather than detail of any trends or changes that would be enabled by longitudinal research. This study reflects the current focus within the UKCI on the application of BIM during the design and construction phase of a project, although some note is made of the potential benefits of BIM to the much longer and expensive operational phase.

Although mixed methods are applied, the perspective of this study is generally positivist to support the stated UKCI wide perspective as well as the aims of the study. This limits the opportunity for more detailed exploration and understanding of the individual concepts identified. While stratified random sampling and a high sample size will be sought, there is no guarantee that this will be achieved or the results will be representative of the UKCI. Similarly, respondents will be individuals who may not accurately reflect the status and dynamics of BIM within the companies they work for. There are also potential difficulties in trying to obtain accurate responses from non-BIM using respondents who may have limited or no knowledge of BIM. Having acknowledged these, given the approach taken to build upon, while addressing the gaps in previous literature, the potential to make a unique contribution to knowledge and practice remains strong.

1.5 Structure of Thesis

1.5.1 Literature Review

While the research methodology is described comprehensively in the Research Methods chapter of this thesis, it is worth at this stage, highlighting the approach taken as a preface. In reflection of the pragmatic focus identified in the introduction, this research is carried out using a hypothetico-deductive approach using mixed methods. The former of these is characterised by Burney (2008, p.8) as a top down approach where in its purest form, the activity of research is guided by theory (Bryman and Bell, 2007, Easterby-Smith et al., 2009, Henn et al., 2009)

Reflecting this hypothetico-deductive approach, the literature review is broken down into two chapters. Field theory is introduced and the UKCI covered in the first, while BIM and innovation literature are considered in the in the second, along with a synthesises of the literature to suggest dynamics and patterns of

BIM adoption. In doing so, these four sections of the literature review, spread across two chapters, mirror the four research objectives illustrated at Figure 1.1.

Each section firstly defines the individual subject, as a means of introduction and to set boundaries. This is followed by a critical review of representative literature which explores core concepts. The fact that this is a management doctorate, combined with the broad scope of these three fields, each of which could be the subject of a thesis by itself, along with the stated aim of proving representative coverage, means that the researcher has been selective in their representation and has focused on key concepts. Wider concepts, of potential interest to the reader, but outside the focus of this research, are therefore not covered.

While this section reviews a broad range of literature form a range of sources, key literature includes field theory (Lewin, 1951), applied as an organising framework and Diffusion of Innovations (Rogers, 2003), which as a significant item of innovation literature, is also used as an organising framework. Also of note are the references from trade articles, which provide valuable and up to date insights on BIM adoption issues within the UKCI, albeit from a journalistic rather than academic perspective.

1.5.2 Methodology

The literature review is followed the methodology chapter, which firstly introduces the paradigm, ontology and epistemology which underpin this study as well as a declared position as an insider researcher. The methodology is described along with the justification for the application of concurrent mixed methods and methodological triangulation, and the use of a cross sectional design. As a key aim of this study is the assembly of robust results which can be generalised to the wider UKCI, the approach to stratified random sampling is covered in some detail, including the identification of different categories and sizes of companies. The researcher also describes the relevant ethical considerations and approach to compliance with the Data Protection Act (1998).

This chapter also explains the processes for data capture, through both semi structured interviews and online surveys, including the use of pilots to identify and resolve any unintended consequences of the questionnaire or interview design and techniques. The process of analysis is explained, including the application of factor analysis and inferential statistics using SPSS for the quantitative data and thematic analysis using Nvivo for the qualitative data. This chapter concludes with a conceptual model of potential results from the methodological triangulation including convergent, divergent and contradictory results. This model is then applied within the next chapter, Results.

1.5.3 Results

This chapter summarises the qualitative and quantitative results, full details of which are given at Appendices 10 and 11 respectively, before methodological triangulation is applied to identify those supported by both methods. In doing so, the current pattern of BIM usage is established, along with those dynamics which are significant and variations by both company size and type. Also highlighted, are results where those from each method contradict each other and for completeness divergent results are presented.

1.5.4 Discussion of Results

Reflecting the pragmatic driver for the research, this chapter explores the potential reasons behind the level of BIM adoption, the significant dynamics as well as variation by company sizes and types. The results are used to better understand the adoption of BIM through the lens of the key innovation literature applied above, suggest ways in which the adoption of BIM can be better supported and the potential consequences of BIM. Finally, the limitations of this study are explored along with further questions arising from the results.

1.5.5 Conclusion and Contribution to Knowledge

Within this final chapter, a contribution to knowledge is supported through the development of a model representing the dynamics of BIM adoption, along with the researchers suggested amendments to Rogers's characteristics of innovations, categories of innovation adopters and innovation diffusion profile.
A contribution to practice is informed by the suggested changes to the UKCI resulting from BIM, along with personal comparisons by the researcher, as a declared insider, on the adoption of BIM and its' predecessor CAD. Following recommendations for further research, the thesis concludes with the researcher's personal perspective on the adoption of BIM.

Chapter 2 - Literature Review, Introduction and The UKCI

2.1 Introduction

2.1.1 Structure of The Literature Review

In exploring the UKCI, the first chapter covers some of the key metrics, characteristics and structures of production, as well as the strong influence of procurement, the two key methods most frequently used and the different types of companies involved in a typical project. The long term performance issues noted above, that have led the Government to mandate the use of BIM are reviewed, as well as the current state of the UKCI in these times of public sector austerity.

The second chapter explores the stated benefits of adoption BIM during the construction phase, as well as touching on the much longer operational phase of the building. Next, the results of previous surveys from literature on BIM usage within the UKCI and some of the barriers to adoption are covered. In the same chapter, the concept of innovation is presented and scoped, along with the drivers and barriers, key innovation literature including the generic characteristics of innovation and categories of innovation adopters suggested by Rogers (2003) is reviewed. Also covered are as those specific to the UKCI and its characteristics of production noted in the previous chapter. Finally, BIM is categorised using a range of innovation frameworks, to better predict the dynamics of adoption.

Within the third and final chapter of the literature review, synthesis is drawn from discussion in the previous two chapters. As well as suggesting patterns of BIM adoption, the generic characteristics of innovations (Rogers, 2003) and force field analysis (Lewin, 1951), are applied as an organising framework for the identification of dynamics of BIM adoption, along with the suggested impact of company size and type on these.

2.1.2 Sources of Literature

To provide representative coverage, the information selected, cited and evaluated for this review, is gathered from a wide range of sources. These are listed below in below in broad order of their academic quality and robustness.

1. Academic Journal Articles.
2. UK Government commissioned and published reports.
3. Books.
4. Information from construction related professional bodies e.g. Chartered Institute of Building (CIOB).
5. Construction industry magazines and sources.

While some may consider items 4 and 5 to be of questionable quality from a research perspective, not having being peer reviewed and in many cases being written by an organisation with a vested interest in BIM or with a particular agenda in mind, these sources remain of value. Given the longer timescales for the publication of the other sources, these provide valuable up to date and anecdotal information on the recent developments on BIM and the UKCI, both fluid and dynamic subjects

2.1.3 Organising Frameworks

While this study considers BIM as an innovation within the UKCI and applies the work of Rogers (1996), on innovation diffusion theory within Chapters 3 and 4, a further key theory applied as an organising mechanism for the dynamics of BIM adoption was field theory, developed by Kurt Lewin (1951).

According to Cartwright (1951), the original rationale for field theory was Lewin's belief that all behaviour arises from the interaction between an individual or group and their environment[2] and results from the forces that apply within, what Lewin and Lorsch (1999, p.401) describe as a “life space”. Field theory states that it is possible to understand the basis for a change, in this case the option of BIM as an innovation, by constructing a life space made up of the relevant forces, in this case those which influence the behaviour of companies within the UKCI in respect of BIM.

Within the majority of current literature, for example Senior (2012) and Huczynski & Buchanan (1998), the variant of field theory commonly applied is referred to as force field analysis, and is typically illustrated in the form shown at Figure 2.1.

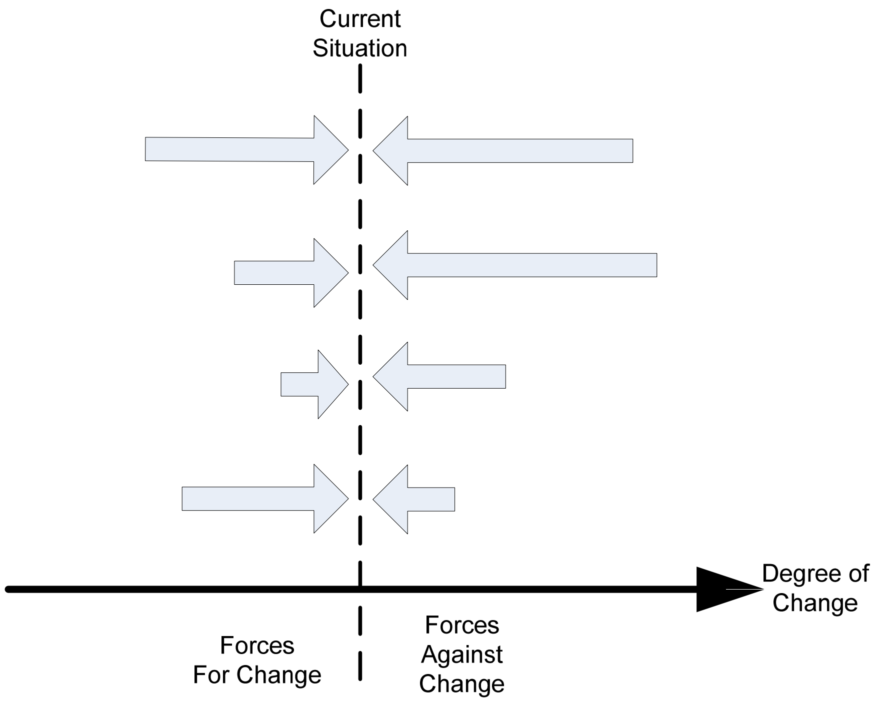

Figure 2.1 – Typical Representation, Force Field Analysis.

[2] Lewin originally expressed this as the formula: B = *f(p,e)*. Where B represents behaviour, *p* represents person (or group) and *e* represents the environment. With *(p,e)* being the group’s “life space”.

Here, the horizontal arrow indicates the scope for a change being considered, with the current position of the individual or group shown by the central vertical dashed line. The arrows to the left of the dashed line represent forces which support the change, while those to the right represent forces which inhibit the change. The length of each arrow reflects the strength of each force, with Lewin (1951), describing how a change or issue is held in balance by the sum of these forces. Lewin also suggests that in order to best support the change, not only do forces for the change need to be increased in value, but also the forces against the change should be reduced in value.

In contrast, illustrated below is an example of how Lewin (1951) originally applied mathematical topology as a tool to better represent the forces within a life space. This not only shows the forces that apply to an individual or group, but also the fundamental interconnections which he argued exist between these, which are not reflected in force field analysis.

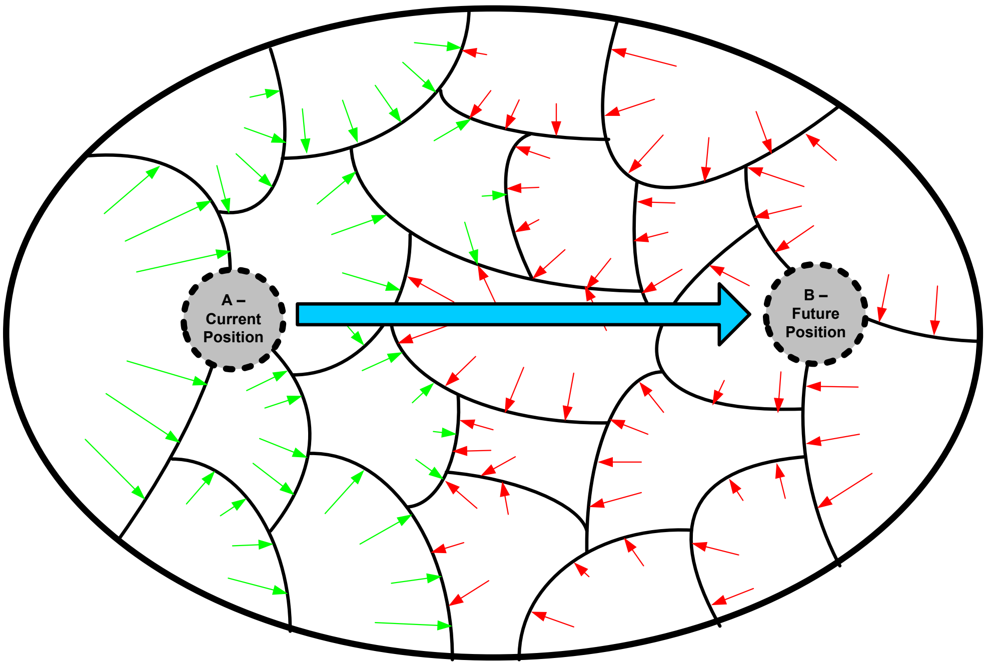

Figure 2.2 – Illustration of a Life Space

Within the life space above, represented as the oval, the current position is shown at point A and the desired future position at point B, with the blue arrow representing the change necessary to move from A to B. Indicated as regions with green arrows around point A are the individual forces which support the change, and the regions around point B with red arrows are those forces which resist the change, at a given point in time. This method better illustrates the interrelationships between forces, suggested by Lewin, with the result that increasing the size or pressure of one force, will not only effect immediately adjacent forces, but also the overall life space.

Force field analysis therefore provides a basic tool which is initially applied within this study to categorise individual dynamics of BIM adoption as either forces for (supporting dynamics) or forces against (inhibiting dynamics) BIM adoption. However, if applied in isolation, this would according to Bruce and Cooke (2008, p.417) "... only provide a very partial understanding of the situation, if not a misleading one" and lose what Schein (2013) describes as field theory's capacity to develop life space models that not only identify forces, but also how they interact with each other. Consequently, within this study, while force field analysis is applied for the initial categorisation of dynamics as either supporting or inhibiting the adoption of BIM, the resulting dynamics are represented using both force field analysis and a life space diagram to overcome these issues.

2.2 The UK Construction Industry

2.2.1 Defining the UKCI

While the terms "construction" and "construction industry" are both broadly used and understood in common usage, it is worth exploring a number of definitions to commence this exploration of the UKCI and the key characteristics of relevance to this study, shown at Table 2.1.

Source	Perspective	Definition
(Office of National Statistics, 2012, Appendix 2 - p.2)	Formal economic, Divisions 41 – 43 of the UK Standard Industrial Classifications of Economic Activities (2007)	"This industry definition includes general construction and allied construction activities for buildings and civil engineering works. It includes new work, repair, additions and alterations, the erection of prefabricated buildings or structures on the site and also construction of a temporary nature".
(H M Government, 1996, Section 105)	Primary Legislation – The Housing Grants Construction and Regeneration Act of 1996	"… all normal building and civil engineering works, including operations such as scaffolding, site clearance, painting and decorating as well as contracts for repair and maintenance".
(HMRC, 2012, p.63)	Tax – Section 74 of Finance Act, 2005 -	"… construction, alteration, repair, extension, demolition or dismantling of buildings or structures (whether permanent or not), including offshore installations".
(Jones and Saad, 2003, p.1)	Academic	"… those enterprises and individuals whose main activity is the construction and maintenance of the built environment".

Table 2.1 - Definitions of the Construction Industry

These demonstrate a number of common themes including: the construction of buildings (e.g. houses, offices), civil engineering works (e.g. roads, railways) and structures (e.g. bridges and tunnels). Also mentioned are those of both a temporary (e.g. portable classrooms) and permanent nature (finished buildings), as well as alterations to existing items, the last of these including the wide range of maintenance and refurbishment activities carried out to buildings and structures during their long life.

For the purposes of this study and in reflection of the above themes, the following definition will be applied moving forward as a means of framing this review, as well as being critical to achieving accurate respondent sampling which is representative of the UKCI.

> **The creation of buildings, civil engineering works and structures of both a temporary and permanent nature, as well as alterations to existing entities.**

2.2.2 Historic Context

Historically the need for shelter has led mankind to undertake building works from the days of the earliest civilisations. The scale of some projects, such as fortifications, temples, towns and even structures such as the Pyramids of Giza and The Coliseum of Rome have led to the formation of some of the earliest large scale organisations to deliver buildings across the world.

As technology has increased and societies have become more complex, the organisation of construction activities has undergone many changes to reflect increases in specialisation, while basic materials such as timber, brick and stone remain the same. These included the formation of guilds of craftsman according to trade in the middle ages, such as (stone) masons, and the formation of some of the earliest professional bodies such as the Royal Institute of Architects (RIBA), which was granted royal charter in 1837, and the Royal Institute of Chartered Surveyors (RICS), formed in 1868. More recently, this increased specialisation has continued with the formation of new dedicated disciplines such as project management, design management and fire engineering, as well as increases in the number of parties involved in a project and the number of formal and contractual interfaces. These changes are anecdotally illustrated in the pictogram by Paterson at Figure 2.3 below.

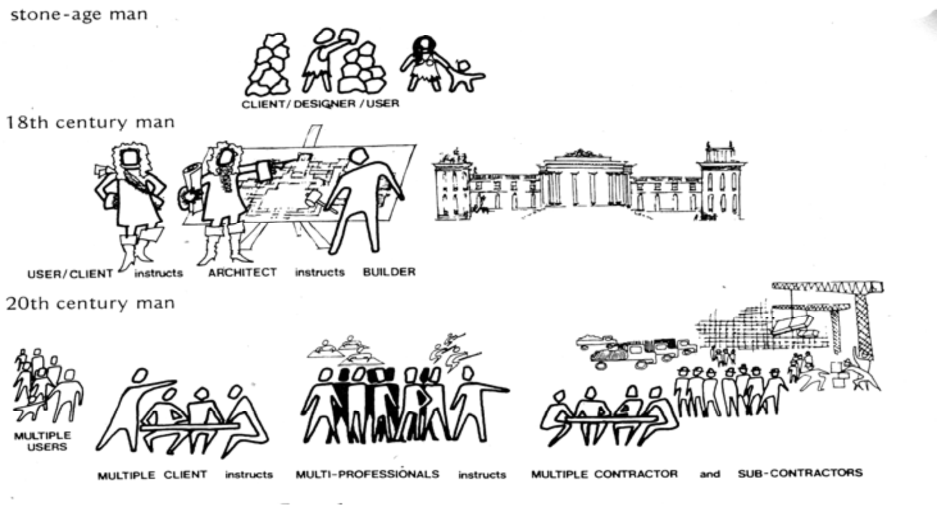

Figure 2.3 - The Historical Development of Construction Activities

(Paterson, 1977, p.18)

2.2.3 Significant UKCI Statistics

An understanding of the UKCI can be introduced by reference to data provided by the Office of National Statistics (2012), in their annual report on the UKCI. While the researcher acknowledges a number of issues with official statistics, including the exclusion of construction work within the black economy, accuracy of classifications and the inclusion of civil engineering and maintenance works (which are outside of the researchers own definition above), these statistics provide a suitable set of metrics for this introductory purpose.

These figures for 2011 show the delivery of £122Bn of work within the UKCI comprising £78Bn of new work (new build and refurbishment) and £44Bn of repair and maintenance works. This shows the large size of the UKCI, which employs a total of 1,150,000 individuals and its importance in contributing 8% to overall UK GDP. The distribution of companies within the UKCI is strongly skewed towards sole traders and small companies, with 98% of the 253,000 UK construction companies falling within The European Commission (2009), definition of SMEs and is one of the significant characteristics of the UKCI. In contrast, examination of the number of employees and value of work undertaken by companies, shows this is strongly skewed in the opposite direction, with the remaining 3,000 companies above SME size (2% by number), securing some £70Bn of work (57% of the total) and employing 504,000 individuals (43% of the total), the implications of which are covered below and are also significant within the UKCI.

2.2.4 Strategic and Recurring Issues

The commissioning of no less than twelve reports into the UKCI since 1944 is one of the strongest indicators that from the Government's multiple perspectives there are a number of recurrent long issues of concern. A common and often cited statistic used to illustrate this, is an analysis of construction against non-farm labour productivity undertaken in the United States. While the US is a different environment to the UK, and one which is arguably more competitive and dynamic, there are in the view of this researcher, sufficient similarities to illustrate the issue of poor productivity. Notwithstanding the problematic issue of classifications of industry, the graph at Figure 2.4 shows that between 1964 and 2003, while general non-farm productivity has increased from a nominal index value of 100% to around 215%, construction productivity has consistently and gradually fallen to a nominal index value of around 80%.

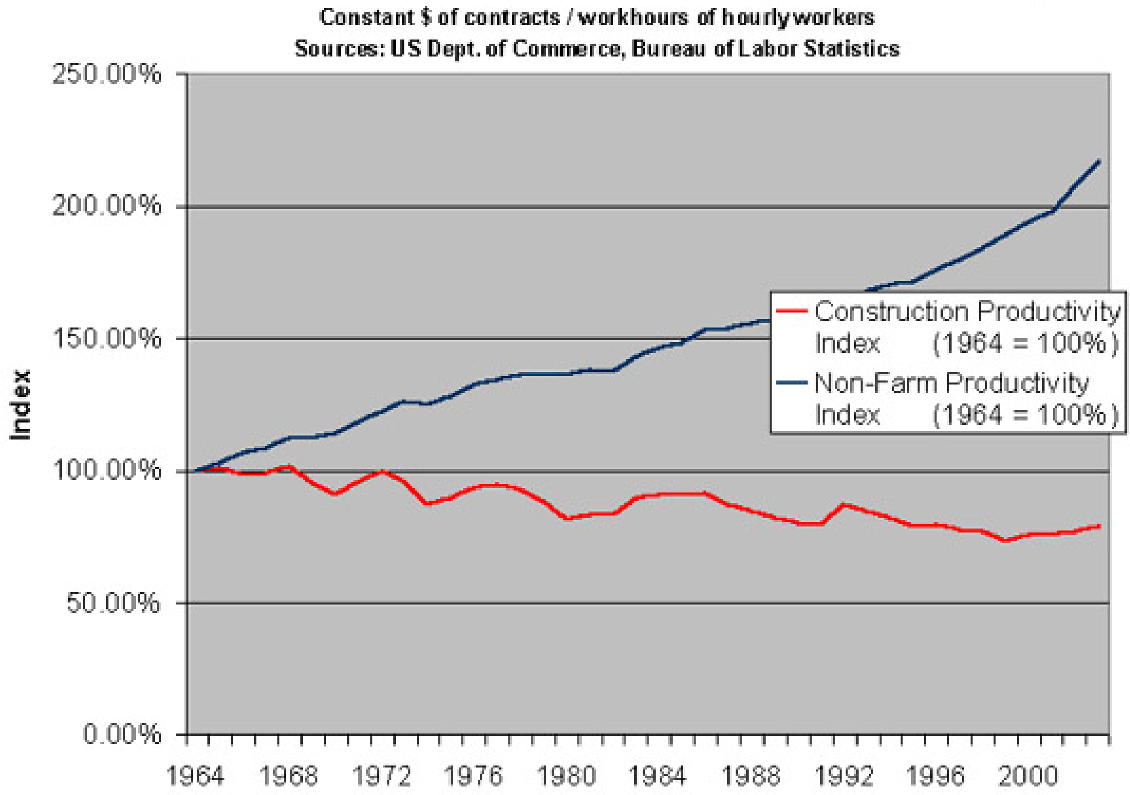

Figure 2.4 - Construction against non-farm labour productivity (1964-2003).

(Teicholz, 2004)

This is supported by a number of academics, including Manseau and Shields (2005, p.543) who comment that "Productivity levels are still relatively low in comparison to other sectors …". Koskela and Vrijhoef concur and in the opening sentence of their paper on Innovation and Construction, cite both Winch (1998) and Gann (2000) before stating that:

> The performance of the construction industry in terms of productivity, quality and product functionality has been low in comparison to other industries. (Koskela and Vrijhoef, 2001, p.198).

This performance issue, is also a common theme among Government initiated reports, with Latham examining the seven prior major reviews undertaken since 1944 and concluding that:

> Previously, reports on the industry have either been implemented incompletely, or the problems have persisted. (Latham, 1994, p.vii).

The next report by Egan, some four years later also demonstrates a lack of progress and points out that "… there is deep concern that the industry as a whole is under-achieving" and "… too many of the industry's clients are dissatisfied with its overall performance" (Egan, 1998, p.4). Moving on another four years, Fairclough, again supports this issue and argues that it is "… universally recognised that the industry must improve its performance" (Fairclough, 2002, p.6).

In 2011, at a time of recession and austerity and from a perspective of the Government as The UKCI's largest client seeking value for money, the Cabinet Office again describes a broad consensus of UKCI under-performance. Their report goes on to assert that the principal barriers to addressing this are:

> … the lack of integration in Construction, compounded by a lack of standardisation and repetition in the product. (Cabinet Office, 2011, p.6)

With this perhaps being a result of large number of SMEs and fragmentation of the UKCI.

In addition to the subjects described above, other potential reasons behind these performance issues can be illustrated by reference to Jones and Saad (2003), who quantitatively considering the most commonly occurring themes across the twelve Government commissioned reviews, the first four of which are noted below. In addition to the focus on short term cost discussed above, eight of the reviews identified the separation of design and construction activities as a factor, this despite the close interdependence between the two and the growth in design and build. The lack of development of, plus the poor utilisation of the specialist skills of sub-contractors input and intellect was also identified as a factor in eight reviews. Finally, the issue of increasing technical complexity and tightening of regulations was identified in seven reviews, although this researcher notes that this factor is one that is not unique to the UKCI and has been successfully overcome in a number of other industries.

The final characteristics of note within this section are the UKCI's volatility and close linkage with the wider economic environment. These are demonstrated by Crotty (2011), who compares the percentage change in wider GDP with the percentage change in output in the period 1956 to 2006. This analysis shows three major dips in UKCI output, with the first of these in 1973-4 of around 20%, coinciding with the oil crisis, the second in 1977 to 1980 of around 15%, coinciding with the broader recession of the early eighties and the final reduction over 1986 to 1992 of around 5%, somewhat preceding but again mostly aligning with the wider recession again. This volatility and wider economic linkage has been further demonstrated by changes within the UKCI since the financial crisis of 2008. Since its peak in 2007, the sector has shrunk 11% in terms of value in 2011 and is now 18% lower (Broadbent, 2012, p.2). Further examination of the source data supports these statements and also indicates that employment within the wider UKCI fell from 1,914,000 at its peak (Office of National Statistics, 2008, p.158) to 1,455,000 in 2012 (Office of National Statistics, 2012), a significant reduction of some 24%.

A recent analysis not only reflects the decline articulated above, but goes on to predict a continuing decline in output in 2013 of between 2.4% to 3.9% before some slight recovery in 2014 at the earliest (Fordham, 2012).[3] Reflecting the UKCI's focus on lowest cost, the author also notes a substantial fall in tender prices of 17% since a peak in 2008, with little opportunity for potential increases until 2014.

2.2.5 Procurement

The method of procurement used is one of the most influential factors within the UKCI, as reflected in the twelve UKCI reviews analysed and discussed above. There are many procurement routes that clients can chose when commissioning construction works. While the wide range means that construction procurement is a broad and detailed topic in itself, a high level introduction to some of the main parties, their roles / relationships, plus the complexity of construction projects can be illustrated by exploring two of the most widely used procurement routes. This is achieved using both the researchers own tacit knowledge, as an insider within the UKCI, the work of Clamp et al. (2007)[4] and the Joint Contracts Tribunal (JCT)[5]. This exploration also introduces the different types of companies involved in a typical project.

The first of these, traditional procurement, can be summarised as a serial process of design followed by procurement and then construction. The client firstly appoints a consultant team, which usually includes an architect, structural and service engineers as well as a cost consultant. This team work up the clients requirements, into a design of sufficient detail to be taken to market in the form of a tender package (JCT, 2012b). Up to six pre-qualified main contactors are then asked to competitively price the project on the basis of these documents and submit prices. Following advice and evaluation by the cost consultant, the client will appoint a main contractor to undertake the work, with the selection

[3] This analysis was produced by Davis Langdon, a large and well respected international consultancy and applied a wide range of official statistics.
[4] Contained within professional guidance for architects, issued by the RIBA.
[5] One of the major publishers of construction contracts within the UKCI.

predominantly being based on price (Clamp et al., 2007). The main contractor, often by means of multiple sub-contractors then delivers the works on site, in accordance with the consultants' information and is usually paid as work progresses on a monthly basis, in arrears.

The relationships between the parties under this procurement route are shown at Figure 2.5 below.

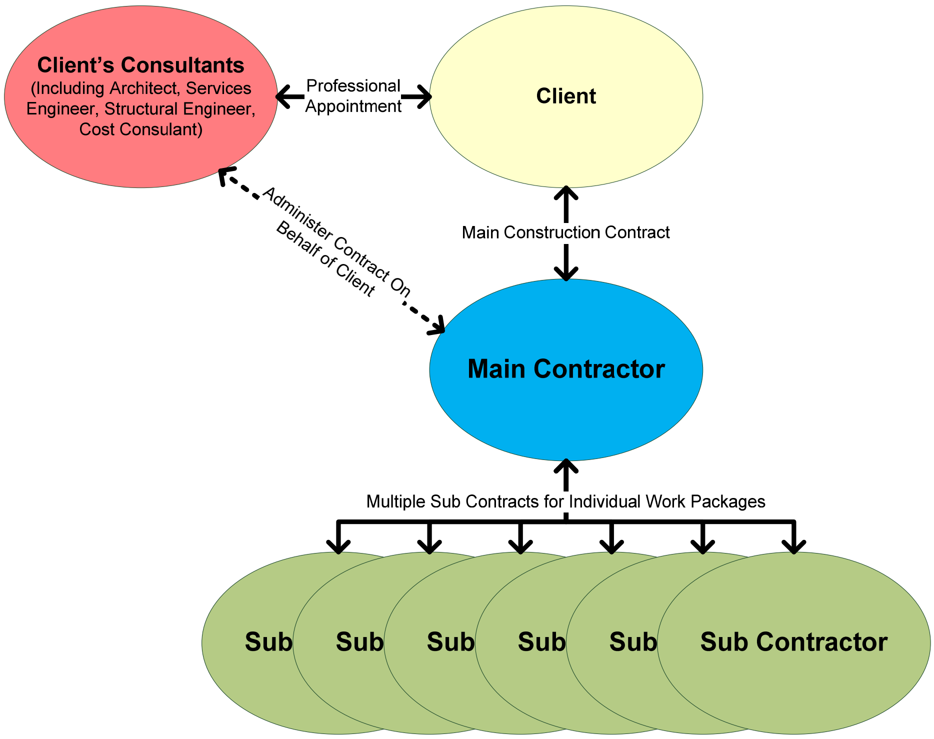

Figure 2.5 – Traditional Contracting,

Based on (Clamp et al., 2007, p40)

One key aspect of this route is that there is usually no opportunity for the main contractor or sub-contractors to lever their delivery expertise, or collaborate with and influence the client or design team. Thus the processes of design and delivery remain distinct and separate, with a rigid and formal contractual interface. These and the relationships dictated to parties by the contracts used, mean that this form of procurement is widely recognised as giving the client a good quality of design, but one which is both expensive and uncertain in terms of total procurement time as well as cost, in comparison with alternative procurement routes (JCT, 2012b).

The second route, design and build, was developed in the late 1970's as a means of overcoming some of the shortcomings of traditional procurement, by transferring more control and risk to the contractor, and by better integrating the processes of design and construction on site.

Under this form of procurement, the client's requirements are developed by their appointed design team and may include high level design, outlined in the form of a tender package. A number of Main Contractors are then asked to submit prices for the delivery of the works. However, due to the incomplete nature of the tender package, this may require some further development of the design by the main contractors and sub-contractors, sufficient to price the project. The client again selects a single main contractor, again usually on the basis of lowest price. (Clamp et al., 2007). The main contractor, then works up the design to a detail level using a design team that they, rather than the client, have appointed and proceeds to deliver the work on site. To complicate matters further, in some cases the design team originally appointed by the client to produce the high level design, can be transferred or contractually novated across to complete the design under appointment to the contractor, during construction, thus providing some design continuity (JCT, 2012a)

The arrangements using this procurement method are also shown at Figure 2.6, below.

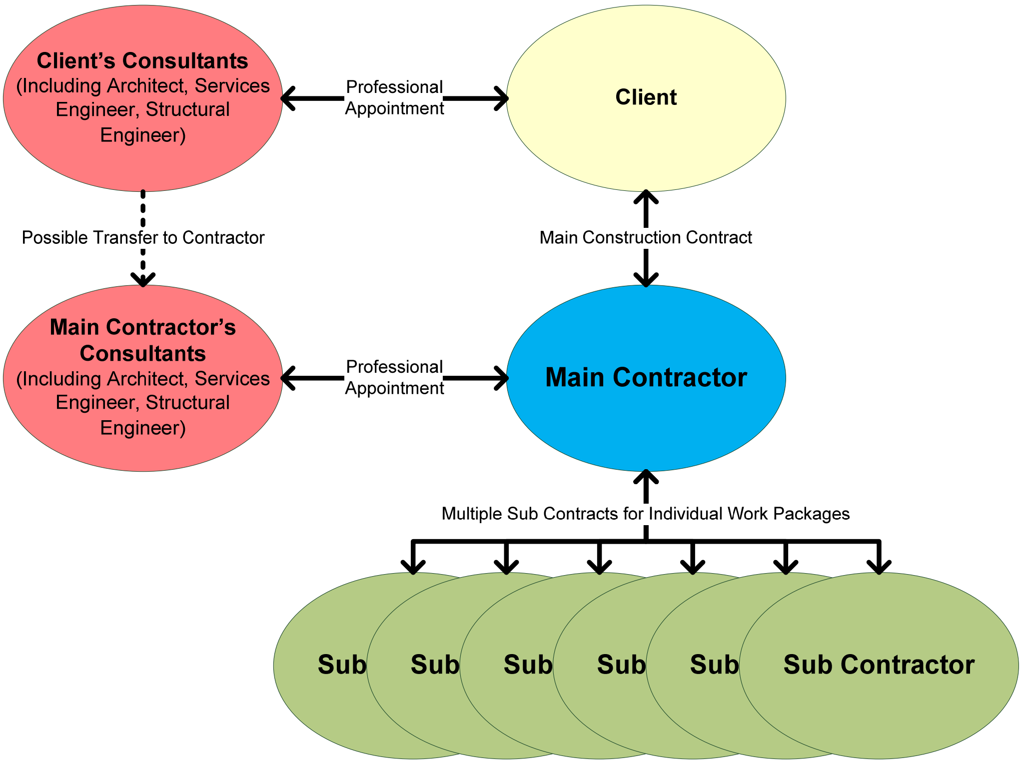

Figure 2.6 - Design and build.

Based on (Clamp et al., 2007, p41).

One key advantage of this route is that it allows some overlap between the processes of design, procurement and construction, providing a shorter overall route than traditional procurement. In addition, during the detailed design process the design team are appointed by and can collaborate closely with the Main Contractor, thus avoiding the separation of these two functions that occurs under traditional contracting. This route is also widely recognised as providing the client with greater certainty of cost, albeit at the expense of design quality (JCT, 2012a).

A wider recognition of the advantages of design and build, have led to an increase in the use of this route, with design and build use growing from 8% of contracts by value in 1985 to 32.6% of contracts by value in 2007 according to the RICS (2007, p.8). In contrast this source notes that traditional procurement accounted for 31.4% of contracts by value in 2007, having fallen from 70% in 1985.

2.2.6 Types of Companies in the UKCI

As well as highlighting some key differences between the two most commonly used procurement routes, the section above also highlights the different types of companies within the UKCI. In addition to the client, based predominantly on the researchers tacit knowledge, Figures 2.5 and 2.6 introduce three main categories of company typically involved on the delivery of any construction project: Consultants, Main Contractor and Sub-contractors. As described above, each of these has a very different role in the project, becomes involved at different times and is therefore subject to different financial, commercial and competitive pressures which, unsurprisingly impact the way they do business and transact other companies. This is important to this research, given the stated aim to identify any differences there are in terms of both the level and dynamics of BIM adoption across the types and sizes of company within the UKCI. Table 2.2 below provides a side by side comparison of these three types including their different sizes, when they generally become involved in a project, degree of influence and the degree of cost pressure each is subject to.

Company Type	Typical Comparative Size	Time of involvement on a project	Degree of influence on project processes	Degree of cost based competitive pressure
Consultant (Design Team and Professional Advisors)	Majority are SME's with some mid-size and a very few large companies (Construction Industry Council, 2006).	From inception to advise client and undertake design (JCT, 2012b).	Some in design stage, limited otherwise with exception of advice on procurement route.	Medium – some, but appointment may be based on a value based proposition, subject to limits on cost (Clamp et al., 2007).
Main Contractor	Across full spectrum. Majority are SMEs, but with some mid-size and large companies, the last of whom are responsible for a substantial percentage of Construction turnover (Office of National Statistics, 2012).	Usually from procurement stage, with some earlier involvement where projects are negotiated with clients or use more innovative procurement routes such as Private Finance Initiative (Clamp et al., 2007).	High level of control of construction stage of project. No influence on design stage without appointment at earlier stage (JCT, 2012a).	Medium / High due to tendency to focus on lowest cost in most procurement routes (Egan, 1998).
Sub-Contractor	Across full spectrum, but tend to be smaller than main contractors (Office of National Statistics, 2012), due to more limited scope of works on any one project.	Usually from procurement stage, unless sub-contractor secures early involvement due to a unique degree of specialist skills, service or product.	Usually none outside own area of works, unless this impacts on other areas of the project.	Generally high due to give main contractors' maximum opportunity to reduce overall project cost and low switching costs (RICS, 2007).

Table 2.2 – Comparative Characteristics, Types of Companies in the UKCI.

This shows that while Consultants are often involved from the start of the project, they tend to be smaller companies with their influence limited to design processes, while Main Contractors are likely to become involved in the project later, but have a major role in determining processes during the construction stage. In contrast, Sub-Contractors, tend to have later involvement in the project, when processes have already been established and are also subject to the highest degree of cost based competitive pressure. Given these differences, the ability to adopt BIM and realise the benefits, is likely to vary across the three groups.

2.2.7 Characteristics of UKCI and their Impact on Innovation

The UKCI statistics described above, as well as the sheer number of different organisations involved on a typical construction project, support the notion that Construction is highly fragmented. This issue is widely recognised by authors from a range of backgrounds including Gajendran and Brewer (2007), Yitmen (2007), Ibrahim (2011) from an academic perspective as well as Fairclough (2002) and Cabinet Office (2011) from a Government review perspective. Egan's influential Rethinking Construction, which was commissioned by the Government in 1998, considered both the reasons for and impact of this fragmentation. The author notes that fragmentation has resulted from the number of disciplines involved as well as the complexity and length of construction supply chains. The report goes on to note that while fragmentation provides flexibility in respect of variable demand, it inhibits performance improvement and has "… brought contractual relations to the fore" (Egan, 1998, p.8).

The nature of relationships between the many organisations involved in a single construction project is another area upon which there appears to be a broad consensus, both in terms of Government commissioned reviews and academic literature. These are reflected in the final report of a 2008 enquiry into the sector by a committee of cross party MPs, which included a number of observations on the nature of relationships. They noted that adversarial relationships are common and often the result of the hierarchical structure of the UKCI. A manifestation of this is the extensive sub-contracting actual work by main contractors to smaller specialist contractors with "… most parties operating in silos, and the transferral of risk along the supply chain", (House of Commons Business and Enterprise Commitee, 2008, p.44). They also noted that on only 20% of major projects did the clients and contractors team work together (House of Commons Business and Enterprise Commitee, 2008, p.45). As well as supporting this view of widespread adversarial relationships, Fairclough (2002) argues that these are the result of both low profit margins within the UKCI, combined with traditional procurement methods, which as discussed above tend to focus on price rather than value.

From an academic perspective, Davidson (2001) also acknowledges this characteristic, before going onto describe prescriptive contractual documents, as a common response, albeit one which the author asserts is another constraint to innovation. Blayse and Manley (2004) also recognise the issue however, are of the view that it is the procurement and contractual framework which promotes adversarial and self-protective behaviours, rather than the other way round. Both Yitmen (2007) and Whyte et al. (2002) also cite this as an issue on most construction projects, while in their exploration of electronic collaborative working for the Institute of Civil Engineers, Carter et al (2002, p.10) are of the view that "… adversarial contractual relationships … inhibit inter-organisational communications".

The discussion so far suggests as a result of the focus on lowest cost, the temporary and contractual relationships, the UKCI has many characteristics of a market from an economic perspective. This, along with the issues discussed below, may offer some of the reasons that the UKCI, left to its own devices, has previously performed so poorly in terms of the adoption of cross organisation innovations such as BIM.

Moving onto innovation within construction, one of the best known and well respected studies into innovation within UKCI was undertaken by Slaughter in 1998. While this work has been substantially built upon and developed by subsequent researchers, it highlights a number of differences of note between the UKCI and manufacturing industries, which are of relevance to this research. Slaughter notes the products of the UKCI are physically large, complex and long lasting. In terms of process and in contrast to the longer term supply chains within manufacturing, they are created in situ on construction sites, by a "… temporary alliance of disparate organisations" (Slaughter, 1998, p.277). While there has been substantial effort in the UKCI to reduce the temporary nature of relationships within the past 20 years, including proposed changes to procurement arising from Rethinking Construction (Egan, 1998), as well as initiatives to encourage off site construction methods, these differences remain very relevant today.

In building upon their previous research and proposing the application of strategic planning for the UKCI, Betts and Ofori (1994) support the perspective of the UKCI being different, and in particular noting its complexity as a sector. They suggest that this is due to its historical evolution and structure, with the latter of these supported by the large number of small companies within the sector, as well as the issue of fragmentation, discussed below. A further perspective on the UKCI was presented by Sir John Fairclough, who undertook a Government initiated review of construction innovation and research. Fairclough notes in terms of process, the "…time taken to design and construct …" and on product, the "… inseparability from the real estate it occupies …" (Fairclough, 2002, p.14). A further feature of the UKCI is the temporary or one-off nature of construction projects, described by Doubois and Gadde (2002) in their research into construction from a coupled systems perspective, as one of the most difficult features of production.

Alongside Slaughter (1998), a further well respected academic exploration of innovation within the construction is that of Winch (1998). In this work, the author notes a number of characteristics of construction which place it within the domain of complex systems. One of these is the project based nature of Construction with the conclusion that construction projects are among the most complex of all production activities Winch (1998). A similar observation is made by Bertelsen, who applies complex systems theory to construction and notes that:

> … construction should also be understood as a complex, dynamic phenomenon …. using a number of general characteristics of complex systems. (Bertelsen, 2003, p.1)

A recent academic author who also notes that construction work is based on projects, where the extensive collaboration of a diverse range of firms have to be co-ordinated, is Harty (2005). In this work on innovation within the UKCI, the author firstly acknowledges that construction work is projects based, before suggesting that consideration of the organisational and social context is critical to understanding innovation, as well as developing concepts based around the sphere of influence of an innovation, Harty (2005). This suggests that in order to encourage innovation, as well as economic drivers, social and organisational issues also need to be carefully considered.

Other academic authors who also give prominence to this particular characteristic of Construction include Yitmen (2007), who in addition to noting that “Projects are discontinuous and temporary” (p.1321) goes onto note the poor link between business process and projects. In examining the UKCI from a technology perspective, Davidson (2001) not only recognises the project focused nature of production, but also concludes that this constrains innovation, while Doubois and Gadde (2002, p.623) in considering the adverse impact of this on both innovation and productivity, describe the typical relationships between construction companies as “loose couplings”. On this particular point, it is worth returning again to Egan who notes that the project based nature of construction has prevented the continuity of project teams, which the author considers essential to efficient working. The author also notes another widely accepted characteristic of the UKCI , in terms of its focus on lowest cost rather than value, with “… too many clients are undiscriminating” and “… selecting designers and constructors almost exclusively on the basis of tendered price” (Egan, 1998, p.7).

In their relatively recent and comprehensive exploration of Innovation in the sector, Manseau and Shields (2005) also recognise this emphasis on lowest initial cost rather than best performance, particularly in the public sector where more formal and rigid procurement policies prevail, and they conclude that this is one of many impediments to innovation. This is a view supported by Davidson (2001, p.234) who argues that innovation is also constrained by a “… customary competition on price only”. In aiming to develop a better understanding of innovation within construction, Jones and Saad (2003, p.9) also note the “…undue emphasis placed on price … by clients” not only as a demand side weakness, but also one which contributes to the poor overall performance of the UKCI. This perspective is supported by their qualitative analysis of the twelve major reviews of the UKCI undertaken between 1944 and 2002, within which criticism of competitive tendering is identified in ten of the reviews and is the most consistent theme within the analysis.

Before concluding, an overview of the reviews on the UKCI and the events described above can be obtained by considering a timeline of the UKCI from 1944, shown at Figure 2.7. Also shown on this are the introduction of CAD and BIM software, discussed in the next chapter.

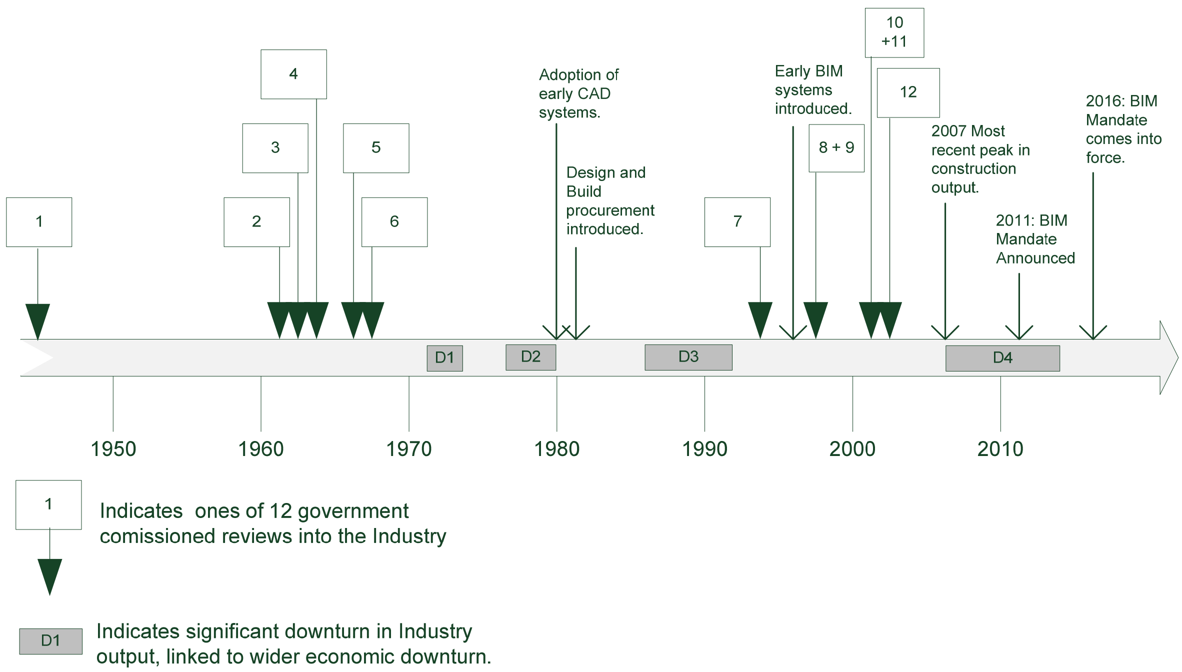

Figure 2.7 – UKCI Timeline

2.2.7 Summary - UKCI

As well as framing the UKCI, a number of pervasive market and structural characteristics are highlighted within the discussion above. Construction is of high value in the UK (£122Bn) and contributes significantly to GDP (Office of National Statistics, 2012), by providing employment for nearly 1.5 million people across 253,000 companies, of which 98% are SMEs.

In contrast to other production industries, the one off product, project and cost focus, high level of fragmentation (Egan, 1998), plus the transitory (Slaughter, 1998) and adversarial nature of relationships (Carter et al., 2002), all appear to be key issues. Both the processes and products of the UKCI are complex in comparison with manufacturing goods and tend to be one offs, leading to a project based approach, with lots of companies involved on any one project, often on a short term temporary basis. Procurement itself is a complex and influential issue and despite initiatives to reverse the trend, remains based predominantly on lowest construction cost. Therefore, relationships are predominantly short term, project based, contractual and are frequently adversarial in nature.

Based on this review, it is clear the UKCI is highly complex (Betts and Ofori, 1994), with many potential variables influencing both the behaviour of companies within it and its output as a whole. This also indicates that in contrast to the potential financial benefits of innovation discussed below, which one would be expected to be encouraged by the lowest cost focus, innovation is highly influenced and inhibited by the social nature of the UKCI, particularly in response to number and types of relationships.

There is a perceived long term issue among many stakeholders of under-performance and poor productivity, best illustrated by 12 major reviews commissioned since 1944 (Jones and Saad, 2003). Construction is relatively volatile and is closely linked to the wider economy; it has also experienced a substantive reduction (17%) in workload since the last peak in 2007 and is recognised as being in long term recession, with some way to go before recovery (Fordham, 2012). These performance issues support the researchers own experience of the UKCI as being resistant to change due to its maturity, the long established and clearly defined roles and risk aversion. Despite the cyclic nature of the UKCI and widely recognised long term performance issues, its ability to innovate successfully (Fairclough, 2002), and fully apply information technology appears to have been limited (Cabinet Office, 2011), resulting in a rare intervention by the Government.

Before moving onto to BIM, it is also worth pausing to consider a few of the many different relationships the Government has with the UKCI. From an economic perspective, a healthy UKCI is of value to the wider UK in terms of value creation, employment and tax revenue. However, the Government, via public sector capital projects, is also the largest client of the UKCI and in doing so will also be seeking the best value for money. Finally, from a wider political perspective, the Government also impacts on the sector, both in terms of setting both the legislative and regulatory framework within which it operates.

Chapter 3 - Literature Review, BIM, Theories of Innovation and Synthesis of Literature

3.1 Introduction.

Despite the cyclic nature of the industry and widely recognised long term performance issues discussed above, the ability of the UKCI to innovate successfully and fully apply information technology appears to have been limited.

This chapter therefore introduces, defines and discusses BIM, firstly from a technology perspective, before considering a broad range of literature covering both generic and construction specific innovation literature, including that relating to companies of different sizes.

In the final part of this chapter and the literature review, potential dynamics and patterns of BIM adoption are then identified following synthesis of the literature discussed.

3.2 BIM

3.2.1 Defining BIM

The BIM Industry Working Group[6] provide a good introductory perspective of BIM, in their description below and note that BIM goes beyond technology, including process and the words “and Management”:

> Building Information Modelling and Management is Digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for

[6] The industry wide working party was tasked by the Government to support the adoption of BIM within the UKCI.

during its life cycle, from earliest conception to definition. (BIM Industry Working Group, 2011, p.100)

Both process and management are important to this study, given the apparent adverse impact of the social structure of the UKCI on innovation highlighted in the previous chapter.

However, for the reader unfamiliar with BIM, it is worth returning to a technological perspective with a screen image of one of the mostly widely used BIM Software Suites, REVIT[7], at Figure 3.1.

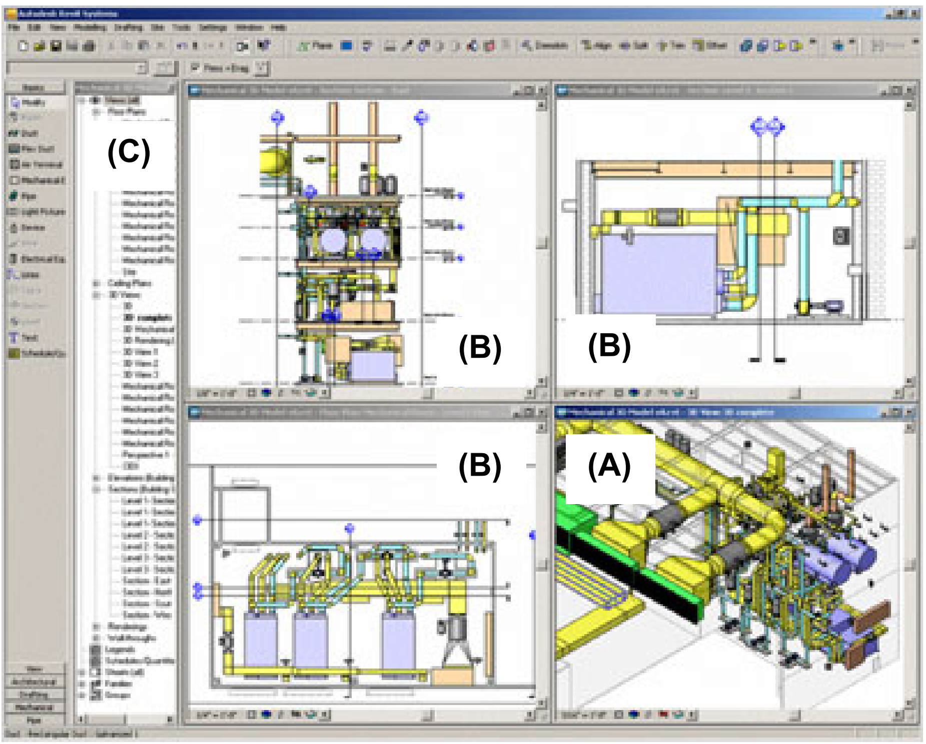

Figure 3.1 - Screen Shot from REVIT Software

(Cadalyst, 2005)

[7] This software is produced and sold by Autodesk, who are arguably the largest BIM software vendor in the world and is used to produce "building models".

This illustrates three main elements. Firstly, the bottom right graphical pane **(A)** illustrates that the design (a plant room) is being developed in three dimensions as a digital model and includes information from other design disciplines including the building structure (from the structural engineer) and building enclosure (from the architect). Secondly, the remaining three graphical panes **(B)** show the representation of more traditional 2D information, with the key factor being that these are all generated automatically from the 3D model. Finally, the tree like structure shown on the left hand side **(C)** indicates that the 3D model contains non graphical data e.g. cost, specification or C02, which is structured into representative objects, each of which has non graphical data attached to it.

Autodesk[8] describe BIM by means of three main characteristics:

1. Information is created and operated on digital databases for the purpose of collaboration [Illustrated at **(A)** and **(C)**]
2. Change on these databases is managed so that a single change can be co-ordinated across all other parts of the database [Illustrated at **(B)**].
3. Information is captured for re-use for discipline and industry specific tasks and their corresponding specialist applications.

(Autodesk, 2006, p.2)

As highlighted above, BIM is not just about technology or software and a wider UKCI perspective is articulated by Eastman et al (2011)[9] who acknowledges a blend of technology and process in their definition:

> A modelling technology and associated set of procedures to produce, communicate and analyse building models" (Eastman et al., 2011, p.16).

[8] Although Autodesk have a vested interest in promoting BIM to generate revenue, their publications are useful in this context.
[9] This practically focused and comprehensive book has been is extensively used within the Industry by a wide range of BIM stakeholders.

The building models referred to above and described as digital databases in the previous description by Autodesk, are then described further by reference to four main characteristics:

1. Components are represented digitally by objects that carry graphical and non-graphical information, as well as parametric rules which allow them to be intelligently manipulated.
2. The representation of these components includes data on how the component will behave, for the purposes of analysis and work processes e.g. take off of quantities, specification and energy analysis.
3. Data is consistent such that changes to a component are represented in all views of a component or an assembly of which it is a part.
4. Data is synchronised such that all views of a model are represented in a co-ordinated way.

(Eastman et al., 2011, p.16).

Moving towards more formal academic definitions, the evolution from paper based methods, to 2D CAD onto 3D CAD and finally to BIM is reflected by Succar (2009), whose comprehensive article seeks to set out the key foundations of BIM for subsequent researchers and stakeholders, and introduces it as:

> An emerging paradigm in the AECO [Architectural, Engineering, Construction and Operation] industry that has followed paper based drafting and CAD. (Succar, 2009, p.357).

From a practical perspective, a key aspect of BIM as a paradigm is the provision of a single repository of information that is used by all companies working on a project, and is often referred to, from an information systems perspective, as a single source of truth. While not a requirement of the Level 2 BIM mandated by the Government, this is shown as the central BIM model and database within Figure 3.3, which illustrates Level 3 BIM.

In exploring the impact of information technology on the complexity and new form of architecture it facilitates, Pinttila (2006) acknowledges the synthesis of technology along with the policies and processes used, to describe BIM as:

> A set of interacting policies, process and technologies generating a methodology to manage the essential building design and project data in a digital format throughout the buildings life cycle. (Pinttila, 2006, p.395).

While Race (2015)[10], asserts that "Currently there is no single, agreed explanation or definition of what BIM is" the author goes on to eloquently express "… that BIM, like beauty, is in the eye of the beholder" (Race, 2012, p15). In again noting that BIM is more than just about technology, this author makes reference to the definitions of both Pinttila (2006) above and Succar (2009) below, before concluding that the concept of BIM is likely to change moving forward as usage both grows and develops.

Despite the potential for change in the definition of BIM, this cross sectional study is being conducted at a single point in time. Therefore, the researcher has selected the definition by Succar as most appropriate for the purpose of this research. This author defines BIM as an:

> **Approach that fully integrates people, systems, business structures and practices into a collaborative and highly automated process**. (Succar, 2009, p.357).

[10] As an architect who has recently provided a guide on BIM for this profession.

Key to the researcher's selection of this definition are its broader scope, including technology, business and process, along with inclusion of the softer issue of people. Also of note is the collaborative aspect of BIM, which is significant given the different types of companies involved in a typical project and their often adversarial relationships.

<u>3.2.2 Drivers for the Application of BIM</u>

Before exploring the perceived advantages of BIM along with the varying degrees of supporting evidence, it is useful to explore some of the key drivers for its implementation within UKCI, as these later inform the supporting dynamics of BIM adoption. These comprise: Information flow and management, a historic low take up and realisation of benefits of technology, re-focus of effort to where it has the most impact, reducing the whole life cost of a building and the Government Mandate for use by 2016.

The first of these, information flow and management, is of particular relevance to the UKCI given the complexity of both product and process identified previously. The difficulties this presents are illustrated by considering the work of Hendrickson and Au (2009), who in the second edition of their industry focused guide on project management for construction , using secondary data compiled by a Canadian construction company, identify that large projects above $10M (£6M) not only typically involve a large number of organisations (420) and individuals (850), but also generates a wide range of different document types (50) across 56,000 individual pages.

This issue can be illustrated further by reference to the BIM Industry Working Group, who in their BIM Maturity Model, which has four levels and is discussed further below, describe the lowest level of maturity (BIM level 0) by means of Figure 3.2.

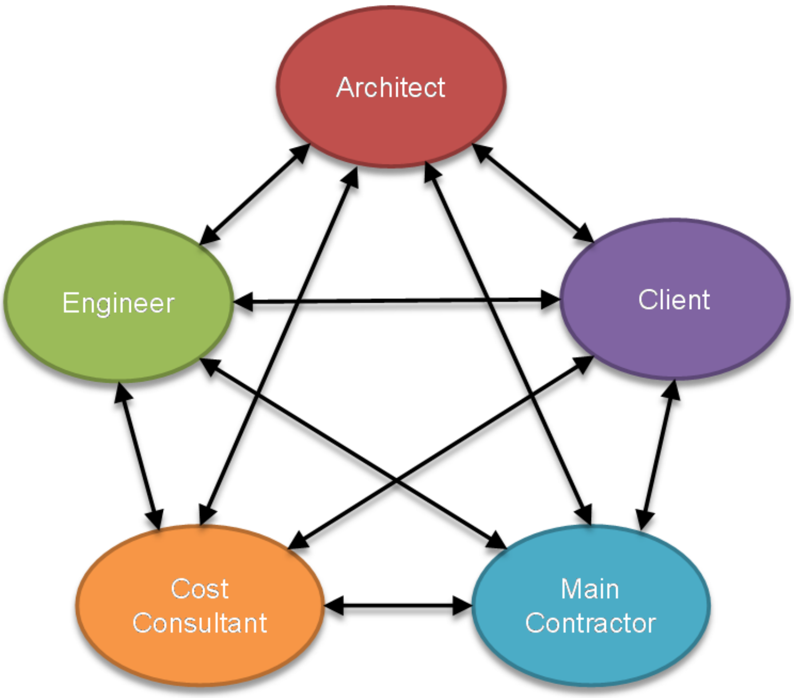

Figure 3.2 - Traditional Construction Project Communication, BIM Level 0

Based on (BIM Industry Working Group, 2011)

In this case, where five parties are shown for simplicity, the companies involved in a project would each hold their own data and relevant copies of other parties' data. Interaction between them is fragmented and complex, leading to a rapid increase in the number of possible communication paths and copies of the information as each new party becomes involved. This leads to a corresponding increase in the risk of discrepancies between or errors in the different copies held. Given the 420 different organisations on a typical large project noted by Hendrickson and Au above, the difficulties this presents are not difficult to perceive. This is a view supported by Eastman et al. (2011), who also note the obvious difficulties in managing flows and changes across such a broad spectrum of information, spread across a wide range of companies.

Using the same project example, the other end of the scale (BIM Level 3) shown at Figure 3.3 below, is described as a web hosted central model and database where all information is stored only once and accessed in real time as and when required by each party. This both negates the risk of out of date information and greatly simplifies the communication path, although there are potential issues if different parties / companies use different BIM software and processes. This is reflective of the inter-organisational span of BIM, which makes it harder to implement fully than technologies residing within to a single company.

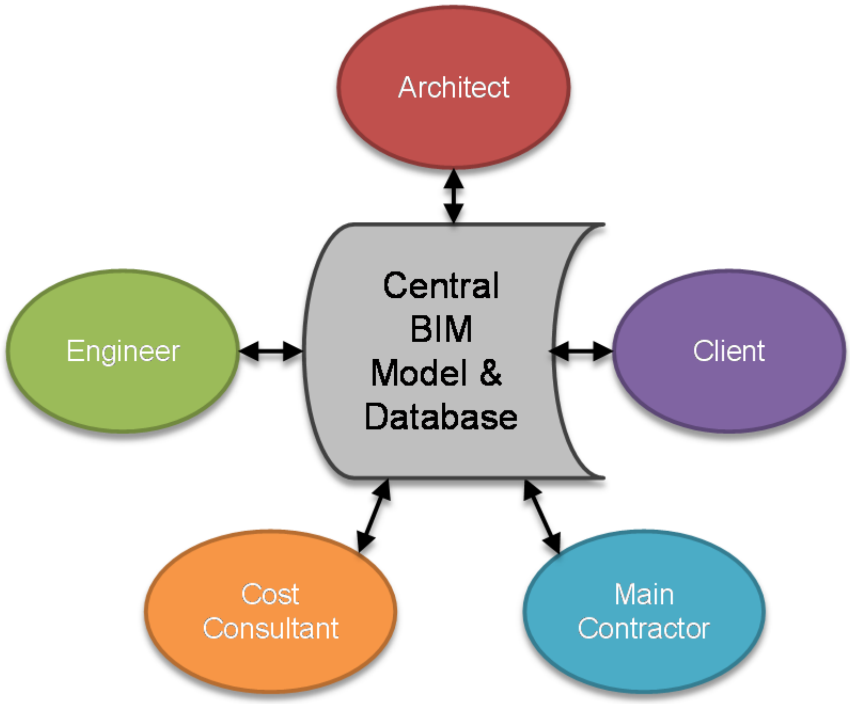

Figure 3.3 - Central BIM Model / Database Communication, BIM Level 3.

Based on (BIM Industry Working Group, 2011)

The second and related driver is the UKCI's failure to realise the full benefits of technology (Cabinet Office, 2011), despite the widespread adoption (Chan and Kamara, 2008, McGraw Hill, 2010) noted in the Introduction. While one of the earliest formal and comprehensive references to the potential use of ICT to enhance information management in design and construction can be found in the academic work of Paterson (1977), this failure is illustrated in that it is some time before early systems become widespread in the UKCI, when compared to the industries below.

In describing the origins of BIM, Crotty (2011) makes reference to many of the early CAD systems first implemented in the late 1960s and 1970s and describes how these were first used and became widespread in the manufacturing, automotive and aerospace industries before implementation in the UKCI in the 1980s. The author also describes this process of the application of information and communication technologies as “digitisation” and describes how this led organisations to both substantially improve the quality of information used in their production processes, as well as changing the nature of information exchange between the different organisations involved in a single product (Crotty, 2011, p.xii).

The third driver for BIM can be demonstrated by considering the application of what is commonly known as the “cost to change curve” on a construction project. The traditional version of this curve originally developed by Boehm (1981), in the field of software development, illustrates the cost of any change increases as a project proceeds towards completion. This concept is also applied extensively to construction, where in addition to an increase in the cost of any changes, the ability to add value to a project through changes, follows the opposite trend and decreases the closer one gets to completion of a project. Overlaying the potential impact of BIM on this model, produces what is commonly known as the “MacLeamy Curve”[11] with one of the many versions of this is shown at Figure 3.4 below.

[11] This name is reference to the CEO of HOK, a large international architects practice, who is widely considered to be the source of the illustration in this context.

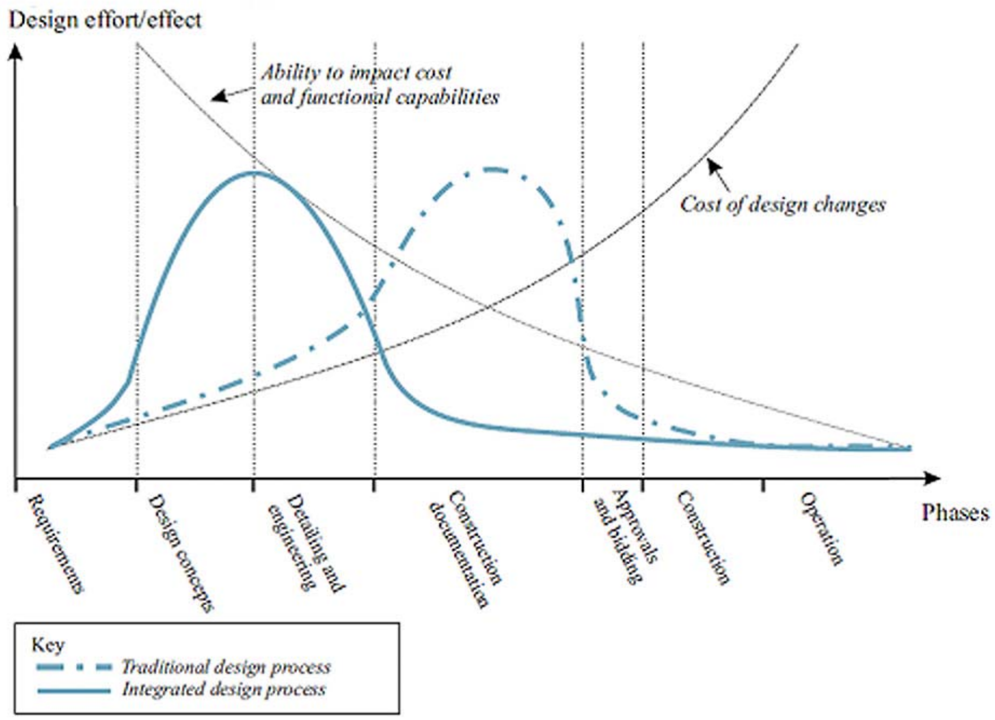

Figure 3.4 - MacLeamy Curve

(Light, 2011a)

This illustrates that how under a traditional design process, the peak in design effort occurs around the construction documentation stage of the project, at a time when the cost of change is starting to increase and the ability to add value has already shown a substantial decline. It also illustrates how an integrated design process, enabled and supported by BIM, can facilitate an earlier focus of design effort, to a stage when both the cost of any change is lower, and the ability to add value is increased.

Although the above discussion has focused on the process of design and its impact on construction, it is important to remember that one of the particular characteristics of construction noted above, is that its products are long lasting (Slaughter, 1998). Hence, consideration of the total life cycle cost of designing, constructing and maintaining a building over this long life, leads us to the fourth driver.

While there are many debates in construction about the accuracy and relative merits of different methods of accurately costing the life cycle of a building, there is a broad consensus in terms of the relative costs of each stage: conception (design), construction and operations and maintenance, illustrated at Figure 3.5.

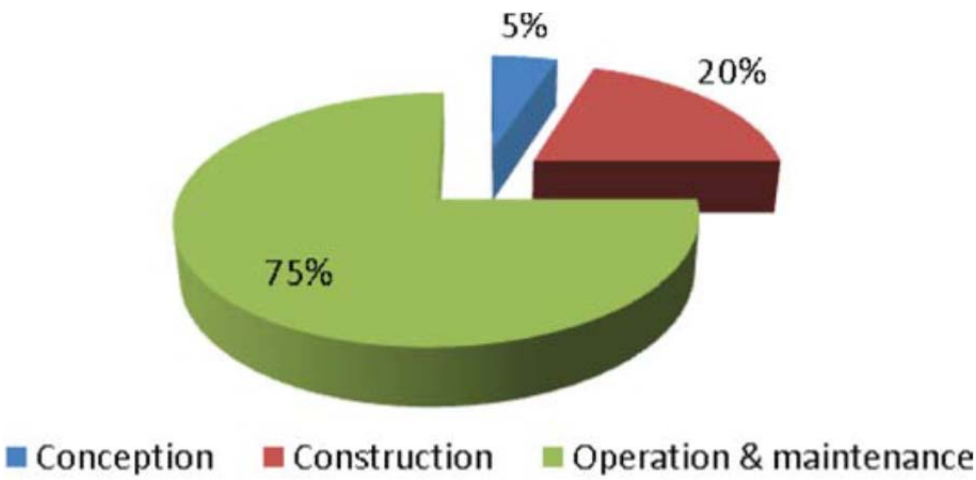

Figure 3.5 – Relative Costs of a Building Over the Life Cycle

(Boussabaine et al., 2012, p.43)

From this it is clear that while there appears to be a focus within construction on lowest capital cost, this only forms a small portion of the total cost of a building during its long life. Both of these perspectives are supported by Hardin (2009)[12], where the author notes operation and maintenance comprise between "60 – 85% of the total life cycle cost of a building" (Hardin, 2009, p.264), albeit over a much longer operational period.

[12] In this author's industry focused book articulating processes to successfully apply BIM

The potential for the application of BIM throughout the life of the building is reflected by the inclusion of “life cycle” within the definition of BIM by Pinttila (2006) above, as well as authors from construction, such as Crotty (2011), Deutch (2011) and Hendrickson and Au (2009). All of these authors describe both the potential benefit of BIM in reducing operation and maintenance costs, by enabling improved design and product (as illustrated above on the MacLeamy Curve) as well as the direct impact by provision of complete and up to date built asset information within the Building Information Model to enable more efficient operation and maintenance.

Therefore, as well as improving the construction process, BIM has the potential to deliver savings within the much higher cost but longer term operation and maintenance phase of a project. In doing so, there exists the opportunity to increase value to building funders, owners and operators. This is reflected by the BIM Industry Working Group, who when considering the opportunities presented by BIM to the UK Government, as a client who both commissions and operates many buildings, note that:

> Government as a client can derive significant improvements in cost, value and carbon performance through the use of shareable asset information. (BIM Industry Working Group, 2011, p.15).

However, this potential is somewhat hampered by the short term focus of the UKCI, highlighted in the previous chapter. Companies involved in the construction of a building are rarely incentivised to reduce the whole life costs of the building, and instead concentrate on reducing the capital costs as a means of both winning the project and maintaining or increasing their profit.

These have led to what is arguably the most influential driver for the use of BIM within the UKCI, namely the publication of the Government Construction Strategy in 2011. This strategy reflects the view that while leading edge companies had the capability to work collaboratively in 3D, the UKCI was behind other industries in its adoption of digital technologies (Cabinet Office, 2011). Most critically the strategy also included a mandate that:

> 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, p.14)

With public sector projects noted above as accounting for a high percentage of the UKCI's workload, it is clear that this mandate has been set to stimulate the uptake of BIM within the UKCI, with the implication being that any company who has not adopted BIM by 2016, will not be able to deliver public sector projects.

The strategy goes on to announce the establishment of a group to drive the adoption of BIM across Government. In advising the UK Government, this BIM Industry Working Group developed a maturity model to clearly explain the different levels of competency of those using BIM by means of Level 0 through to Level 3, illustrated at Figure 3.6. Level 0 involves the use of 2D CAD and paper or electronic paper (e.g. PDF) as a data exchange mechanism, while Level 1, which involves the use of both 2D and 3D CAD with a file based central collaboration tool, but with no integration of finance and cost management. Moving on, Level 2 involves the management and interchange of separate discipline (e.g. Architect, Engineer and Contractor) .

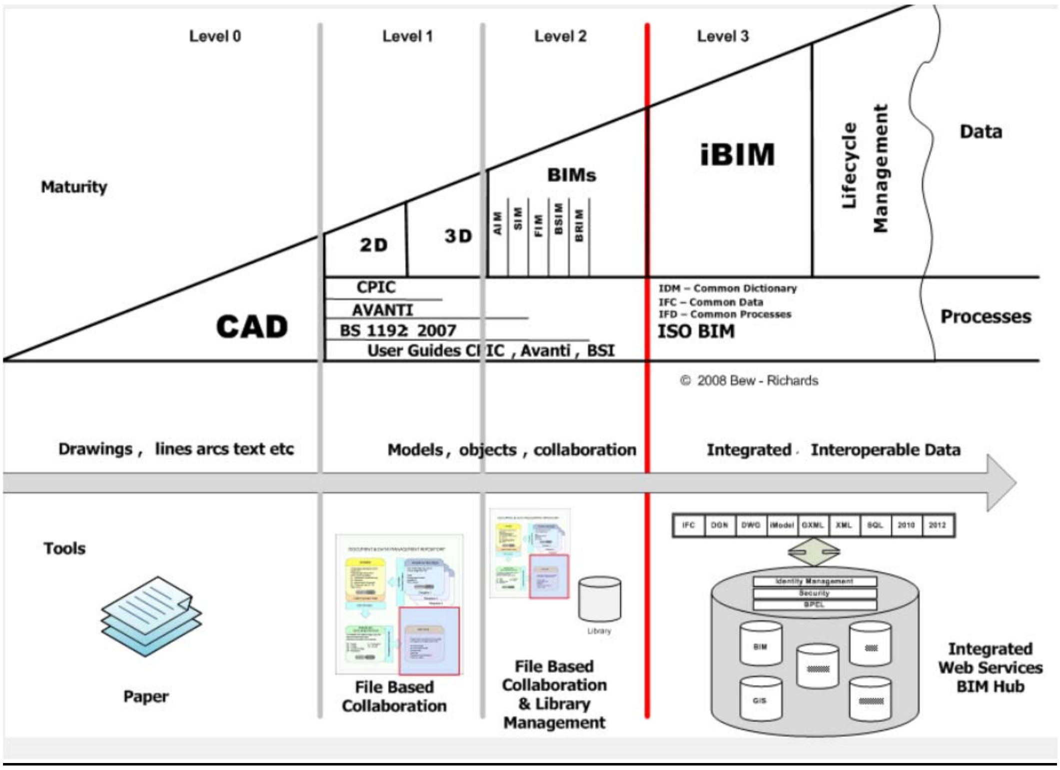

Figure 3.6 – BIM – Maturity Levels

(BIM Industry Working Group, 2011, p.16)

While Level 3 BIM is articulated as having much higher degree integration across different disciplines and companies, at the time of writing, no deadline for implementation has been announced.

To summarise, the drivers for the implementation of BIM include ensuring the UKCI takes advantage of digital technology (Cabinet Office, 2011), as have other industries with complex products such as automotive and aerospace, and in doing so improves its ability to better manage the large volume of information generated and flow across the many organisations involved in a typical construction project. In addition, BIM should enable a focus of design effort to when it has the best impact (Light, 2011b), therefore improve the quality of the completed product (the building) and therefore add value to owners and occupiers through reduced life cycle costs (Hendrickson and Au, 2009, Crotty, 2011, Deutch, 2011), which are by far the largest cost of a building. Finally, in seeking to take advantage of the above, the Government as the UKCI's largest client, has mandated the use of BIM to a prescribed level (Level 2) for all public sector projects from 2016 (Cabinet Office, 2011)

3.2.3 Benefits of BIM

Many of perceived benefits of BIM along with the varying levels of supporting evidence, as introduced below, build upon the aforementioned drivers and are subsequently used to inform dynamics of BIM adoption.

Many of the early publicised advantages in the use of BIM have their sources in the marketing information produced by either software vendors, who wish to sell software, related individuals and companies or larger construction companies and practices, who are seeking to differentiate themselves to clients in a competitive UKCI by articulating their use of and the resulting advantages to clients of BIM. Although these origins need to be taken into consideration when examining statements from these and similar non-academic sources, and the claims taken with a pinch of salt, they remain however worthy of consideration.

Bentley Systems Inc.[13] in their 2005 paper, the objective of which is reflected in the fact that the author is their Global Marketing Director (Roberts), espouses a number of advantages of BIM as part of an integrated approach, many of which are built upon the issues of fragmentation of teams, tasks and tools which typically occur within a project. Using referenced secondary data (Roberts, 2005), contends that this fragmentation costs the US construction industry around $16Bn (£11Bn) per annum.

[13] In addition to Autodesk, Bentley is another major BIM vendor who has sought to publicise the advantages of BIM through pseudo-technical "White Papers"

The first category of advantages relate to the shortened time taken to design, produce documentation and construct a building, as well as the increased pace of information exchange between disciplines. The paper goes on to explain that the time saved can be used to reduce costs, or alternatively allow the design team to increase the amount of time devoted to more productive tasks, as well as articulating the ability for all members of the team to co-ordinate late design changes, thus enabling strategic advantages for team members. The second category of advantages builds upon this last point and relates to the improved quality of both the design information, as well as the finished product. This includes the enhanced co-ordination of information, resulting in fewer omissions and errors, as well as the immediate communication of changes made in one discipline to other disciplines affected by the changes (Roberts, 2005).

Returning to Autodesk, who split the advantages articulated in their 2006 “White Paper” into three categories: (i) Higher Quality (ii) Greater Speed and (iii) Lower Cost. Under the first of these, they suggest advantages from the ability to cost effectively explore changes, the provision of more time for design and real problem solving, the production of better information for decision making, as well as the provision of a digital record for operation and maintenance of a building. Under greater speed, they cite the ability to design and produce documentation concurrently, automatic update of changes across documents, use of model for accelerated costing along with the ability to deliver buildings using standardised designs or components faster. Finally, under costs, they claim that design teams can get more done with fewer people, the cost of change is reduced through automatic updates, savings in construction due to higher quality of documentation and more time being spent on the result, rather than the process (Autodesk, 2006).

Moving away from vendors, to other organisations within global construction, but who it can also be argued have a vested interest in promoting BIM, can bring a perspective which is slightly different, but as expected, still supportive of BIM. McGraw Hill[14] in their 2009 SmartMarket Report[15], cite a further three advantages stating (i) that 7 out of 10 BIM users see a positive return on investment, with 1 in 5 seeing returns in excess of 50%, (ii) BIM provides competitive advantage by means of marketing collateral, provision of new services and maintenance of repeat business with clients, plus (iii) improved productivity through reduced design re-work, reduced conflicts and changes during construction, avoiding re-work on site through early clash detection (McGraw Hill, 2009).

The final organisation NBS[16], in their 2011 Research Report, explore the results of 400 industry responses to a survey undertaken in late 2010. Of the benefits perceived, the three highest were improved visualisation (85%), improved productivity due to easy retrieval of information (84%) and increased co-ordination of construction documents (81%). The remaining three were cost efficiencies (61%), increased profitability (53%) and increased speed of delivery (51%), with all percentages indicating survey respondents who either agreed or strongly agreed with the statement (NBS, 2011b, p.14).

Moving onto academic sources, there appears to be less empirically supported evidence of the advantages of BIM. The first of these is based on a survey undertaken by Yan and Damian in 2008, which generated a total of 67 valid responses from the USA, UK and other countries. While this study showed that at the time “BIM as a design tool has not yet been fully accepted” (Yan and Damian, 2008, p.3), the following six advantages of BIM were identified in rank order: (1) Reduce time (2) Reduce human resource (3) Reduce costs (4=) Improve quality (4=) Sustainability and (6) Creativity.

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[14] McGraw Hill is a large technical publisher who in conjunction with BIM software vendors undertakes industry research, publish and market BIM conferences.
[15] This report uses data from a range of primary and secondary sources.
[16] NBS is a specification software company which is a wholly owned subsidiary of the Royal Institute of British Architects (RIBA), and who’s software links closely to BIM packages.

From a single case study[17], which at the time was one of the largest BIM projects undertaken, Riese (2009) identified 21 predicted advantages of BIM along with those realised. Included within these predicted advantages are 11 items:

- The geometric co-ordination of all elements, widely accepted to achieve 10% in cost savings.
- “Provides an intelligent collaboration infrastructure …. use of e-mail is eliminated on construction projects”.
- “Automated identification, reporting and management of clashes …. reduced re-work on site”.
- Enhanced quantity take-off leading to improved speed and accuracy of tender.
- Direct integration with life cycle database and analyses software including structure, fire, environmental and code compliance.
- Reduction in construction waste.
- Reduction of contractor requests for information (RFIs).
- A reduction in claims on site resulting from incomplete design information.
- Quicker construction.
- Lower construction costs (10-30% achievable).
- Better build quality.

Based on (Riese, 2009, pp.126-127).

This author goes on to describe how circa 2000 clashes were identified and resolved prior to tender, before observing that tender returns were lower and all within 1% of each other, which was due to the enhanced quality of information. During works on site, there were far fewer requests for information, again reflecting enhanced quality of information and although the final metrics for the

[17] A review of the design and construction of $300M (£200M), 70 storey office tower in Hong Kong, which was completed in 2008 after a circa 4 year development phase,

project had not been completed at the time of writing, this author was of the view that BIM helped achieve a saving of at least 10% of the cost of construction, bringing the project in below budget, as well as being a key factor in the project being completed on time.

The importance of evidence backed information on the tangible benefits of BIM, is recognised by Becerik-Gerber & Rice (2010) as a primary motivator for the adoption of BIM and informed their research in this area. A key conclusion of their survey[18] is that 40.9% of respondents perceived an increase in profitability against 11.9% who perceived a decrease. Interestingly, for those respondents who use BIM on 100% of their projects, 73% perceived an increase in profitability against 3% who perceived a decrease (Becerik-Gerber and Rice, 2010, pp.190-196). Although no formal correlation was undertaken, this supports the premise that the benefits of BIM appear to increase as time passes and companies become more experienced in its application and use. Using a multiple case study approach[19], Barlish & Sullivan (2012, p.158) indicated improvements across seven key metrics[20] on BIM projects, including an average reduction in construction costs of 5%, as well as a substantial reduction in change orders and requests for information.

Before analysing results from a single case study Lee, Park, & Won (2012), highlight two significant points; that the actual return on investment is more important than the received ROI and the different benefits of BIM are of different levels of interest to the various parties to a project, for example designers being interested in reduced design costs, while contractors are more likely to be interested in reduced overall cost or a shortened project duration.

[18] Respondents comprised BIM users in the USA with a total of 424 respondent, 67% of these being designers, 22% contractors, 8% categorised as others and 3% being clients or commissioners of buildings.
[19] The small number of case studies (three) limits the generalisation of these results to the wider industry.
[20] These metrics were spread across two main categories of Return metrics and Investment metrics.

Their results showed an ROI that ranged between 22% and 97% (Lee et al., 2012, p.584)[21], with a mid-point of 60% which, being below a break-even point of 100%, indicates that the cost of BIM would not be recovered within the project on this basis. However, when the indirect impact of resulting avoided schedule delays for a period of one week was considered, the ROI increased and ranged between 172% to 247% (Lee et al., 2012, p.584). This ROI increased further to between 624% to 699% when the impact of an avoided schedule delay of one month was considered (Lee et al., 2012, p.585). On both of these assumptions, the application of BIM could be justified from a completed project costs basis, solely in terms of the costs of avoided design errors and related delays.

The above literature illustrates a significant number of process improvements offered by BIM, including better information flow and management, the focus of effort to where it has the most impact and improved design co-ordination. These improvements also appear to provide tangible benefits in terms of reduced construction costs, higher quality in design and finished project, plus a reduced delivery timescale.

3.2.4 Issues with Implementing BIM

Without pre-empting the identification of inhibiting dynamics of BIM, it is worth briefly noting some of the issues recognised so far, that have resulted from the adoption of BIM across the globe.

From an academic perspective Yan & Damian (2008) in the survey introduced above, also asked respondents about perceived barriers to the implementation of BIM. The largest issues relate to people, with 20% of UK respondents noting the

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[21] These authors focused on the impact on construction costs of avoided design errors, and by using relatively robust calculation methods and a probabilistic approach, sought to firstly establish the avoided direct costs of the 709 design errors identified by the use of BIM.

level of investment in training, which combines with a reluctance to invest due to the lack of case study evidence on the financial benefits. The study also notes a social and habitual resistance to change, particularly among architects on the basis of their personal satisfaction with traditional methods. These two main issues are reflected in the five barriers presented in more detail in the paper, shown below in rank order, with the percentage of UK respondents who cited the issue shown in brackets:

1. Cost, copyright and training (27%).
2. Unsuitable for projects (23%).
3.= People refuse to learn (18%).
3.= Waste time and human resource (18%).
5. Current technology is enough (12%).

(Yan and Damian, 2008, p.3)

From an industry perspective (Eastman et al., 2011, p.26) suggest[22] four main categories specific to BIM. The first of these is the opportunity for better collaboration and hence improving performance of the multiple organisations on any project, echoed in inter-organisational systems research (Dyer and Singh, 1998, Li and Williams, 1999), who note increased organisational efficiencies. Nevertheless, this is likely to be an issue on construction projects where different team members will be located within different organisations, all of whom may have different levels of competency in BIM, as well as using different software or manual processes for the production of information, under a wide range of company specific procedures.

The functionally specialist and predominantly contractual based relationships within the UKCI are reflected in the second challenge; that of the necessary legal changes to document production. This is an issue for BIM, where the formal

[22] Under the heading “What Challenges Can Be Expected?”

boundaries that traditionally existed between the different parties and the information they produce, starts to break down as more collaboration takes place and a central model / database is created. This raises complex issues associated with inter organisation systems, including ownership and accuracy of information, as well as potential liability for errors or omissions (Goethals, 2008, Mueller et al., 2013).

Eastman et al. (2011), also argue that the use of BIM is likely to encourage the closer integration of construction knowledge within the design process. Therefore, organisations that are able to change to work in this way and intensively collaborated via a shared model during design and construction, could be placed at an advantage in the market. They also however note that this will require significant time and education to make this change. The final challenge, concerns the degree of change required to successfully adopt BIM within an organisation, with the author arguing that:

> Effective use of BIM requires that changes be made to almost every aspect of a firms business (Eastman et al., 2011, p.26).

Referring back to the definition from Succar (2009), this includes integrated changes effecting business structures, systems, people and practices - a substantial challenge for any organisation.

3.2.5 Current Level of BIM Adoption within The UKCI

Currently, there appears to be little highly robust information about the degree of BIM usage within the UKCI. However, a high level understanding of the position, in what appears to be a rapidly changing context can be obtained by examination of two recent surveys.

McGraw Hill (2010, p.11)[23] show the UK lagging behind the US in the adoption of BIM, with only 35% of construction professionals having adopted BIM. This is led by architects (60%), followed by engineers (39%) and contractors (23%). However, moving forward, the use of BIM by contractors on over 30% of their projects is predicted to increase to over 50% by 2012 (McGraw Hill, 2010, p.11). The survey by NBS (2011b)[24] gives a different picture, with only 13% of respondents both aware of and using BIM, 45% who were aware but not using BIM and 43% of respondents reporting they were neither aware nor using BIM. (NBS, 2011b. p.10). This indicates a significantly lower level of implementation as well as identifying a substantial percentage of UKCI professionals that are not aware of BIM. Both reports therefore show while BIM is being used within the sector, albeit to very different degrees, there is scope for an increase in use with McGraw Hill (2010) in particular, predicting a large increase in usage in the short term, thus supporting the consideration of BIM as an innovation within this study.

3.2.6 Summary - BIM

BIM is a technology enabled way of working that integrates a range of organisational assets (Eastman et al., 2011), and appears to provide substantial benefits across the time, cost and quality aspects of construction projects (Autodesk, 2006, Roberts, 2005, Yan and Damian, 2008, McGraw Hill, 2009, NBS, 2011b), as well as in the operational phases beyond. Despite these benefits, the Government has felt the need to mandate its use on public sector projects from 2016 (Cabinet Office, 2011). This may be a response to the slow uptake of BIM within construction, which appears to be inhibited by a number of issues. Building upon the previous section, these appear to include the adversarial and short term relationships within the UKCI which impact on BIM as

[23] This surveys applied sampling techniques and a sample size of 948 degree of confidence stated as 95% and margin of error of +/- 5% for the UK results, which generated 458 responses.
[24] This report only sampled construction professionals and appears to be less robust from a methodological perspective.

an inter-organisational system, as well as BIM specific issues such as cost, copyright and people related barriers.

However, issues remain in the robust and accurate establishment of BIM usage within the UKCI. If the adoption of BIM is to become widespread, a fuller picture of usage and those dynamics which both support and inhibit adoption is required, to inform policies and interventions to encourage this. A final key point, introduced by Lee et al (2012) are the different benefits of BIM to the different parties to a project, hence this study seeks to better explore any differences that exist. The multiplicity of factors apparent at this stage in the review, both UKCI and BIM specific, supports the application of a multi-disciplinary, namely the consideration of BIM as an innovation within this study. This also provides the opportunity to identify additional dynamics and thus provide the comprehensive perspective this researcher is seeking to achieve.

3.3 Theories of Innovation

3.3.1 Introduction

Similar to procurement noted in the previous chapter, the topic of innovation is worthy of a thesis in itself. As this study is focused on the adoption and dynamics of BIM adoption within the UKCI, this section limits its discussion innovation literature which is relevant to BIM and the UKCI. In doing so, this study aims to fill the gap perceived by the researcher in previous literature, which does not appear to have specifically considered BIM as an innovation and hence may have missed valuable insights enabled by this perspective, the advantages of which are explored within Chapter 1.

3.3.2 Defining and Framing Innovation

In common use, the terms invention and innovation are often used interchangeably. A well-used distinction between the two is that made by Shumpeter (1976), between invention, as the generation of new ideas and innovation, the application of new ideas. In addition Garcia & Calantone (2001, p.112) note "an invention does not become an innovation until ….. [it] is diffused into the marketplace", while Marquis (1999), describes innovation as a matter of both the application and operationalisation of something new.

According to Tinnesand (1973)[25], the five most common interpretations of the word innovation were as shown below, at Table 3.1.

[25] Based on a meta-analysis of 188 innovation publications.

Rank	Interpretation of Innovation	Percentage occurrence
1.	Introduction of a new idea.	36%
2.	New idea.	16%
3.=	The introduction of an invention.	14%
3.=	Idea differing from existing ideas.	14%
5.	Introduction of an idea disruptive current behaviour.	11%

Table 3.1 – Common Interpretations of "Innovation",

(Tinnesand, 1973)

Slaughter (2000)[26] goes slightly further in her description of, a non-trivial improvement in a process, product or system that is actually used and is novel to those using it. While Rogers, who is arguably the best known of innovation researchers, notes "… an idea, practice, or project that is perceived as new by an individual or other unit of adoption" (Rogers, 2003, p.12).

The three common elements relevant to BIM which covers both those who have already adopted and those who have yet to adopt, are: (i) application / introduction, (ii) newness / significant difference and (iii) user perspective. These are reflected in the researcher's definition below which will be applied moving forward.

Innovation is the application or introduction of something which is either new or significantly different, from the perspective of the user.

In doing so, this definition reflects the fact that from the perspective of companies within the UKCI, that BIM is new (from the perspective of those who have not yet adopted it) and is significantly different from previous UKCI practices (from the

[26] This author is one of a more limited number to specifically consider innovation within the construction industry.

perspective of those who have adopted), from the viewpoint of individual companies within the UKCI as the users.

3.3.3 Overview of Relevant Literature

A review of both general and construction specific innovation literature was undertaken to ensure fuller coverage of this area and begin to fill the apparent gap in previous literature on BIM. A total of 51 articles covering both generic and construction specific innovations were identified, reviewed for relevance and organised thematically. This resulted in the identification of a total of 14 themes organised around the hierarchy illustrated at Figure 3.7.

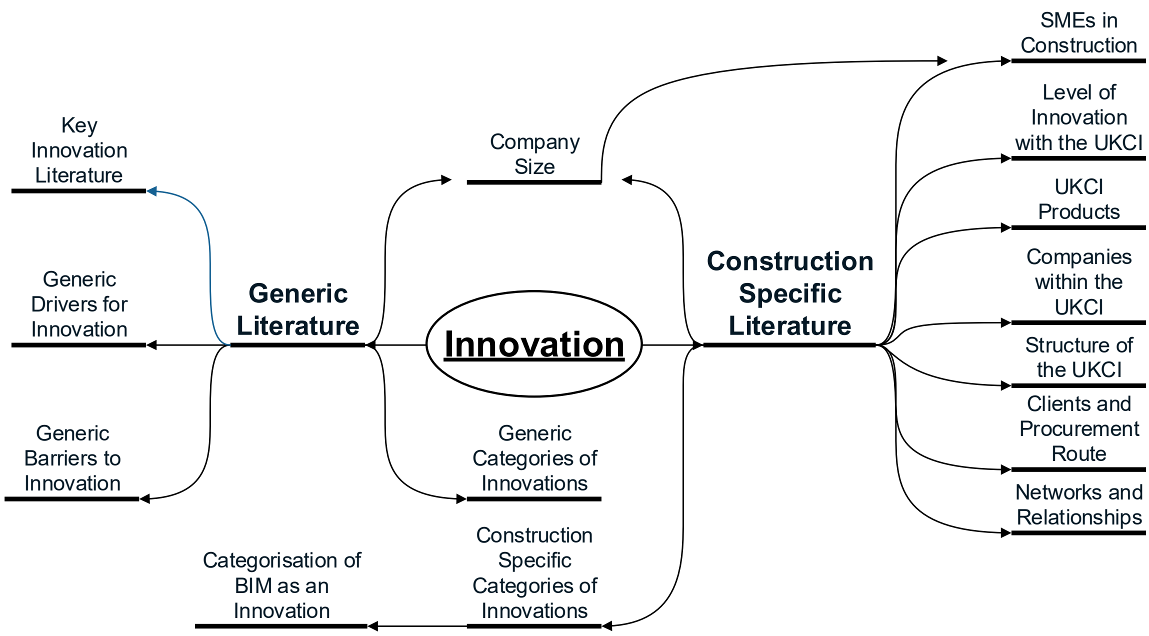


Figure 3.7 – Innovation Literature – Key Themes

At the highest level, these are organised around the categories of generic innovation literature and construction specific innovation literature. From these, 14 sub-themes were identified, including literature which seeks to categorise innovations, including Taylor and Levitt (2004b) and Slaughter (1998), and that which covers the impact of company size, including Sexton and Barrett (2003) and Chesbrough (2010). These sub categories are reflected within the following sections, within which innovation concepts from literature are applied to BIM and discussed, moving from the wider, comprising general innovation literature, to the specific, comprising innovation literature from construction.

3.3.4 Key Innovation Literature

The Diffusion of Innovations[27] by Everett Rogers is arguably the most important piece of innovation literature within this review. It is the most frequently cited, has been comprehensively and successfully applied to a wide range of innovations ,including technologies not conceived of at the time of original publication and continues to be applied and updated 60 years since original publication.

Defining the term diffusion as:

> … the process in which an innovation is communicated through certain channels, over time among the members of a social system. (Rogers, 2003, p.5),

This author also identifies five generic characteristics of any innovation, shown at Figure 3.8, which affect the rate of diffusion.

Of these, the author notes that the Relative Advantage of an innovation has the most influence on the rate of diffusion, with a positive relationship between the two. This characteristic also contains a number of key sub characteristics, including those relating to Economic Factors, Status, Incentives and Mandate. The next most significant characteristic is Compatibility, which also has a positive

[27] This seminal work Diffusion of Innovations was originally published in 1962 is now in its 5th Edition.

relationship with the rate of diffusion and contains a number of sub categories, including how closely an innovation fits within existing values and beliefs, previously introduced ideas and needs. The next two characteristics, Trialability and Observability, cover the ability to try out and quickly observe any benefits of an innovation respectively. These are less important, but also have an positive relationship with the rate of adoption, while the final characteristic Complexity, has an inverse effect on the rate of diffusion.

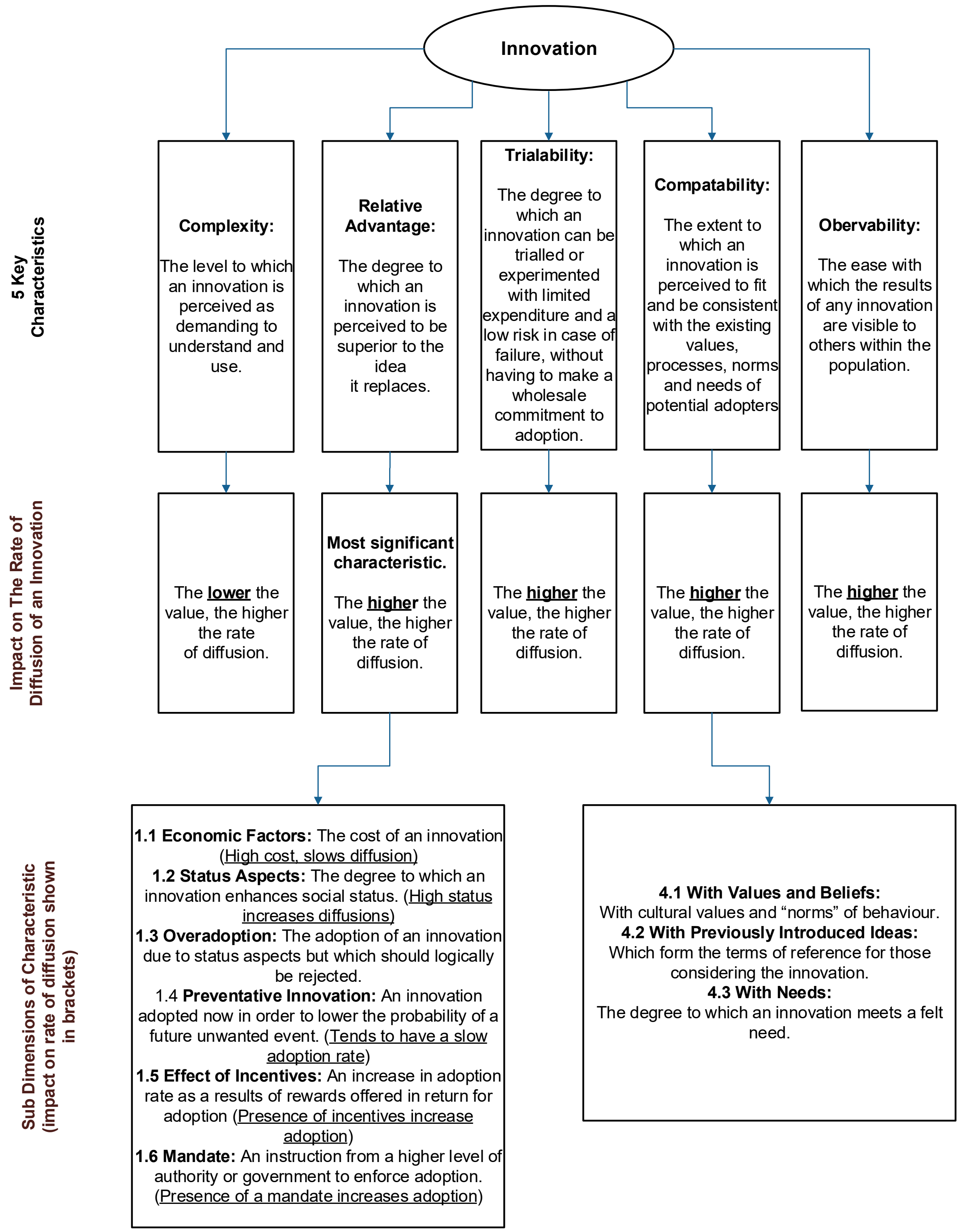


Figure 3.8 – Key Characteristics of Innovations,

based on (Rogers, 2003, pp.15-16)

Moving from the innovation per-se, to the individual adopting units within a social system, Rogers identifies five categories of adopters to illustrate their differences and characteristics, depending on the timing of their decision to adopt a particular innovation, which is termed “inventiveness”. These five categories are illustrated at Figure 3.9, including their individual characteristics, the typical percentages of the overall population and the cumulative adoption profile which typically follows an ‘S’ curve. The two largest groups are noted as Early Majority and Late Majority, both of which comprise approximately 34% of the population (68% in total), with the highest rate of adoption (i.e. steepest gradient on the ‘S’ curve) occurring at the transition between these categories of adopters. This model has been successfully applied to a range of technologies and innovations, including the adoption of the compact disk player (Hansman et al., 1999), CAD and ISO 9000 certification within the Turkish construction industry (Kale and Arditi, 2010) and safety innovations within the US construction industry (Esmaeili and Hallowell, 2012).

Both of Rogers’s models begin to assist the identification of generic dynamics which may influence the dynamics of BIM adoption. The ‘S’ curve model can, with a robust bench mark of current adoption, provide an understanding of the potential future adoption profile for BIM, as well as suggesting characteristics of companies who have yet to adopt, and in doing so, highlight the expected dynamics moving forward. From the researchers own review of literature, the application to BIM of Rogers’s model, appears not to have been undertaken, hence the opportunity for this study to fill the gap and provide a improved insights into BIM adoption.

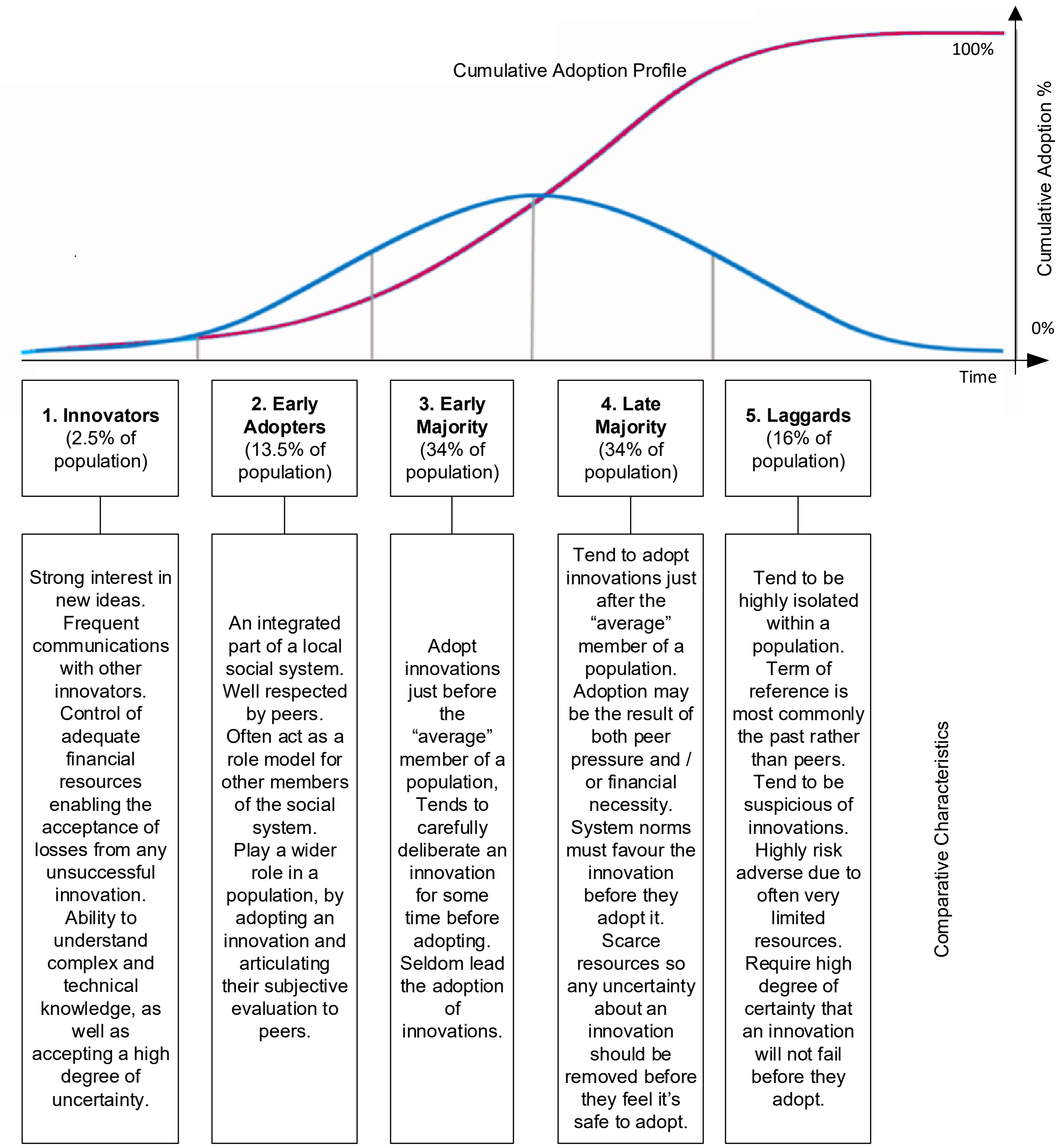


Figure 3.9 – Categories of Innovation Adopters

based on (Rogers, 2003, pp.279-285)

3.3.5 Generic Drivers for Innovation

Beginning with the work of Schumpeter, one of the earliest researchers to formally consider innovation, a number of drivers for innovation are shown at Table 3.2.

Driver	Authors	Detail of Drivers
Potential positive impact on bottom line.	(Schumpeter, 1942)	The author also acknowledges this is a calculated risk for the company.
Profit maximisation.	(Lim and Ofori, 2007)[28]	The authors note that "… the profit maximization goals of construction companies are shown to be a major driving force of innovation" (2007, p.963).
Technology push.	(Schumpeter, 1942)	Technology push describes the process of marketing an innovation which has arisen from a research and development process, rather than a demand within the market.
Market pull.	(Schmookler, 1962)	Market pull is where demand within a market leads to creative individuals or companies being drawn to address unsolved issues through innovation.
Supports growth.	(Drucker, 1985)	This author cautions that "if diligence, persistence, and commitment are lacking, companies are unlikely to succeed at the business of innovation" (1985, p.95).
Creation of competitive advantage.	(Porter, 1985)	In this well known work on strategy, Porter describes how innovation can support either differentiation or cost reduction.

Table 3.2 – Generic Drivers for Innovation

Of these, the potential positive impact on the bottom line (Schumpeter, 1942) and profit maximisation (Lim and Ofori, 2007) both relate the potential direct positive financial impact of innovation, while growth (Drucker, 1985) and competitive advantage (Porter, 1985) also relate to this, albeit indirectly (Porter, 1985). The remaining drivers, technology push (Schumpeter, 1942) and market pull (Schmookler, 1962) describe the relationship between innovations and the market. Within the context of this study, a potential impact on the bottom line by

[28] Based on interviews with a cross section of 21 construction professionals

BIM in terms of a positive ROI, is one such potential driver. Interestingly, Drucker also notes that: “Grandiose ideas designed to revolutionize an industry rarely work.” (1985, p.95), suggesting potential issues with the adoption of BIM.

3.3.6 Generic Barriers to Innovation

For those companies who choose to respond to the above drivers and undertake innovation, Table 3.3, below illustrates a number of significant barriers and impediments which may stand in their way.

Barrier	Authors	Details of Barriers
Cost of innovation.	(D'Este et al., 2009)[29]	The direct cost of innovation can be significant.
Availability of capital.	(Myers, 1984)[30]	This author notes: “Rare is the company that has all the capital available to meet its needs” (Myers, 1984, p.81).
Avoidance of risk.	(Myers, 1984)	Myers also concludes “There are always safe investments in equipment and hardware that are needed, well-known and proven.”
A belief that innovation is inherently risky.	(Loewe and Dominiquini, 2006)[31]	This aligns with the acknowledgement above by (Schumpeter, 1942)
Lack of time.	(Loewe and Dominiquini, 2006)	The time taken to innovate can be significant.
Short term focus.	(Loewe and Dominiquini, 2006)	This may be to repay finance or to ensure a rapid increase in profitability / impact on the bottom line noted above.
Payoff expected sooner than is realistic.	(Loewe and Dominiquini, 2006)	
A lack of management incentives.	(Loewe and Dominiquini, 2006)	Management and staff may not be incentivised to innovate.
Lack of availability of resources or staff.	(Loewe and Dominiquini, 2006)	Staff need to have adequate skills as well as being suitably incentivised and motivated.
Lack of qualified personnel.	(D'Este et al., 2009)	
Availabilit of finance.	(D'Este et al., 2009)	These reflect the difficulty companies may have in borrowing funds to innovate as well as the potential high cost of such borrowing.
Cost of finance.	(D'Este et al., 2009)	

[29] Their data set contained responses from a representative sample of 16,445 UK companies and the period 2002 to 2004, with the 11 barriers categorised into three groups, which in order of importance were: cost, knowledge and market factors.
[30] Following on research in the US paper industry, but of relevance to all industrial sectors.
[31] Based upon their work in a US innovation consultancy, the authors surveyed 550 companies.

Scarcity of information on market.	(D'Este et al., 2009)	All three fall within the market factors category.
Deficiency of information on technologies.	(D'Este et al., 2009)	
Market domination by rivals.	(D'Este et al., 2009)	
Uncertain demand for innovative goods / services.	(D'Este et al., 2009)	Before committing to innovation, companies need to be sure their will be a suitable market / demand for the innovation.

Table 3.3 – Generic Drivers for Innovation

While a number of these, e.g. availability of capital (Myers, 1984), relate directly to the financial aspects of innovation, others relate indirectly, e.g. lack of management incentives. Also significant are those barriers which link to the availability of resources, be they human (Loewe and Dominiquini, 2006, D'Este et al., 2009), or informational / technical (D'Este et al., 2009). Finally, the risk element of innovation (Myers, 1984, Loewe and Dominiquini, 2006), appears to be significant in this case, given the recession and relatively high cost of BIM.

3.3.7 Innovation in the UKCI

Again by introducing one of the earliest authors to consider innovation, this time within the UKCI, Table 3.4 summarises a range of views on innovation, specific to the sector.

Concept	Authors	Details of Conclusions
The industry tends to adopt innovations from other industries.	(Bowley, 1966)	This reflects the researchers own experience with the Industry's adoption of CAD, which originated within the engineering and aerospace industries.
Challenge the perception that Industry innovation is poor when compared with the automotive industry.	(Winch, 2003)[32]	When reviewed on a like for like basis, the automotive industry which is often compared favourably with construction "… proves to have a poor record of performance" (p.651).

[32] This author highlights issues within the Standard Industrial Classifications typically applied in such comparisons.

Issues with the measurement of economic benefits of innovation with the Industry mean this is understated.	(Ruddock and Ruddock, 2009)	They suggest that with the increased development of a knowledge based economy, investment in intangible knowledge based assets such as company based and human capital, has increased substantially in recent years. While they do not provide empirical evidence to support this conclusion, they note the under-measurement of this investment and the resulting often intangible outcomes, may again mean the level of innovation with construction, is higher than commonly accepted.
High influence and barriers presented by the wider Industry environment, which include: Financial, legal, attitudinal and conflict of interest challenges.	(Tangkar and Arditi, 2000)[33]	Although again untested by empirical evidence, they conclude that: *"Construction innovation occurs incrementally over a period of many years, and as a consequence, is often invisible. Regardless of its conservative reputation, the construction industry does innovate and adopt technological change, nonetheless slowly"* (p102).

Table 3.4 – Generic Drivers for Innovation

The work of Bowley (1966) combined with the researchers own experience is relevant to BIM, which is a construction specific development from CAD, which itself was first developed and applied within the specialist engineering and aerospace industries. The conclusions of Tangkar and Arditi (2000), also appear to be applicable to BIM, given the current relatively low adoption level within the UKCI. These introduced the different influences on innovation in construction, when compared with other industries, as well as challenging the notion that it innovates less than others sectors, suggesting it appears to do so, albeit in different ways and more slowly.

[33] Following a literature review the authors applied the concepts of both incremental vs. radical innovations plus technology push vs. market pull as a means of reviewing innovation models within Construction.

3.3.8 UKCI Products

By examining the products of construction, i.e. new or refurbished buildings and structures, Nam and Tatum (1988) identified 5 key characteristics that they suggest adversely impact on innovation:

1. Immobility: The finished product of construction is generally immobile, therefore construction activities are mainly site rather than factory based. This one off and site based environment negatively impacts on the ability to introduce innovations.
2. Complexity: A large number of different components, materials and skills are required for construction. Therefore construction companies are subject to a high degree of specialisation and The Industry is highly fragmented.
3. Durability: The products are required to be long lasting and durable, which generally results in the use of materials which are bulky and heavy. It is often difficult to predict with accuracy how new materials will perform over such a long period.
4. Costliness: The relatively high cost of the product of construction along with the durability of its products mean that construction, unlike other industries cannot itself generate demand for its products, therefore somewhat negating one of the widely accepted forces for innovation. The high cost of its product and therefore high risk of a failure of an innovation, means construction is risk adverse, tending to use well proven processes and solutions.
5. High Level of Social Responsibility: Construction is subject to a high level of social responsibility in terms of worker and public safety, as well as more recently the environment. This has led in most industrialised nations to the development of a complex set of construction related legislation and regulations, the effect of which is often manifested in terms of a highly conservative approach by companies and individuals.

While BIM itself is not a product of the UKCI, it has the potential to play a critical role in the delivery of such products, and is therefore indirectly influenced by complexity, costliness and high level of social responsibility, given the potential impact of BIM on the finished product, if issues occur with its application.

3.3.9 Structure of the UKCI

As an introductory perspective Nam and Tatum, introduced above, also consider the structure of the UKCI as a whole by considering the impact of specialisation (and by association the resulting fragmentation of construction) and describe the industry as a social system which is “locked”. In doing so, they articulate a social system in which individual people and companies may have and acknowledge that others have diverse goals. Hence, “… this system may regard innovation as a force that upsets the equilibrium state”. They conclude that as a result of this, “Changes to the system through the rapid diffusion of innovations are difficult” (Nam and Tatum, 1988, p.140).

A number of wider characteristics are suggested by literature, with those that support innovation shown at Table 3.5, and those that inhibit at Table 3.6.

<table>
<tr><th>Industry Characteristic</th><th>Authors</th><th>Details of Characteristic</th></tr>
<tr><td>Industry flexibility.</td><td>(Tatum, 1989).</td><td>Arising from the one off nature of construction projects and which should support change to adopt innovations..</td></tr>
<tr><td>Inter company relationships.</td><td>(Tatum, 1989).</td><td rowspan="3">Which are supported by the large numbers of companies involved on a typical project.</td></tr>
<tr><td>Collaboration with different types of contractor.</td><td>(Brochner, 2011).</td></tr>
<tr><td>Relationships with the supply chain.</td><td>(Doree and Holmen, 2004)</td></tr>
<tr><td>A recognition that the UKCI needs to improve it’s performance.</td><td>(Fairclough, 2002)</td><td>Market push noted by Schmookler (1962) and Bossink (2004).</td></tr>
</table>

Innovative and stimulating regulations.	(Bossink, 2004)	In contrast to Hartmann below, this author notes the positive effect of performance enhancing regulations, which stimulate change and give companies the flexibility to innovate.

Table 3.5 - Characteristics of the UKCI, Supporting Innovation

Industry Characteristic	Authors	Notes
Fragmentatiation.	(Egan, 1998) (Betts and Ofori, 1994) (Fairclough, 2002) (Gajendran and Brewer, 2007) (Yitmen, 2007) (Cabinet Office, 2011) (Ibrahim, 2011)	This is one of the most influencial characteristics of construction, with (Hendrickson and Au, 2009) highlighting the high number of companies involved in a typical project. This results in issues of management and co-ordination, compounded by a lack of shared objectives.
Focus on lowest cost.	(Tatum, 1986) (Egan, 1998) (Davidson, 2001) (Fairclough, 2002) (Jones and Saad, 2003)	Again, this is one of the most influencial and recognised characteristics of the industry which is a major driver of adversarial and self protective behaviours.
Recession within the industry.	(Sexton and Barrett, 2003)	This author notes that SMEs, which make up the majority of the industry, only innovate once the higher and more immediate needs of survival and business stability have been met.
Degree of regulation.	(Hartmann, 2006)	Suggests that prescriptive regulations have an inhibiting effect of innovation due to difficulties in ensuring compliance.
Complex Products and Systems (CoPS).	(Hobday, 1998) (Bertelsen, 2003)	This author argues that construction should be considered a CoPS, which is defined by Hobday (1998, p.690) as "… high cost, engineering-intensive products, systems, networks and constructs". Hobday also argues that the unit of competition and delivery in CoPs is usually a multi company, project based organisation which requires a high degree of co-ordination. As a result, many innovation decisions are taken in production, are inter-company and are therefore more limited in scope.

Table 3.6 - Characteristics of the UKCI, Inhibiting Innovation

Significant within these characteristics, is the apparent conflict between the support provided to innovation by collaboration (Brochner, 2011), supply chain

(Doree and Holmen, 2004) and inter-company relationships (Tatum, 1989), which should support innovation, and the inhibiting effect of fragmentation (Betts and Ofori, 1994, Egan, 1998, Fairclough, 2002, Gajendran and Brewer, 2007, Yitmen, 2007, Cabinet Office, 2011, Ibrahim, 2011) within this sector, compounded by the nature of relationships between companies introduced below.

3.3.10 Companies within the UKCI

Moving onto construction companies, the different types of which are introduced in the discussion on two key procurement routes, suggested below at Table 3.7 are a range of company characteristics considered to be barriers to innovation, many of which are arguably responses to the structure of the UKCI.

Company Characteristic	Authors	Details of Barrier
Low Expenditure on R&D.	(Jones and Saad, 2003)	When comparied to industries of a similar size.
Lack of R&D.	(Dulaimi, 1995)[34]	This author observes that while "… investing in R&D does not guarantee a company's ability to innovate" but goes on to note that "… innovation is much harder without a company foundation built on effective R&D" (Dulaimi, 1995, p.106). Reasons cited for a lack of R&D included: A lack of financial and physical resources with a significant number of the view that R&D was not applicable to them.
Short term culture.	(Dulaimi, 1995)	
Risk adverse culture.	(Dulaimi, 1995)	
Low levels of co-operative behaviour.	(Hartmann, 2006)[35]	As a result of the adversarial and self protective behaviour noted below.
Poor financial strength.	(Hartmann, 2006)	Also noted by Dulaimi (1995) above, as a lack of financial resources.
Lack of depth of knowledge.	(Hartmann, 2006)	The degree of specialisation is reflected in the fragmentation of the UKCI (noted below). This also means companies knowledge is focused on their own specialist area, often unrelated to innovation.
Highly specialised nature of companies.	(Nam and Tatum, 1988),	
Time pressures..	(Hartmann, 2006)	Limited time for innovation compared with the day to day activities of construction companies.

Table 3.7 - Characteristics of Construction Companies, Barriers to Innovation

[34] Based on an industry survey, although the data collection and sample size were not stated.
[35] A single in-depth case study of a Swiss construction firm.

Given their poor financial strength(Hartmann, 2006) combined with the perceived risk of innovation and cyclic nature of the UKCI noted earlier, it is not surprising that construction companies tend to focus on the short term (Dulaimi, 1995) and have low levels of R&D expenditure (Jones and Saad, 2003).

3.3.11 Clients and the Procurement Route

The literature also highlights clients, as the commissioners of construction projects, have the potential to support and inhibit innovation within the UKCI, shown at Table 3.8, as does their choice of procurement route, summarised at Table 3.9.

Client Influence	Authors	Details of Influence
Clients perceptions of risk.	(Ivory, 2011)	This author notes that some clients "…. actively police innovation to ensure it did not threaten the project …." (p.868).
Client acceptance.	(Hartmann, 2006)	Some clients may not be willing to accept innovation on their projects due to the perception of risk.
Inability to influence clients requirements.	(Sexton and Barrett, 2003)	For larger scope innovations, the authors describe the need for " …. An enabling interaction requirement", which companies wishing to innovate can influence (Sexton and Barrett, 2003, p.629).
The development of top down supporting policies from the client.	(Harty, 2005)	Identified as supporting innovation, from the authors analysis of Heathrow T5 project. A single case study to explore the successful implementation of 3D CAD (a previous incarnation of BIM) across the plethora of companies involved in this major project.
Early mandate for application of an innovation.	(Harty, 2005)	
As a driver of innovation.	(Hartmann, 2006)	While noting some clients may not accept innovation, the author also acknowledges others may choose to play a significant role in encouraging it on their projects.

Table 3.8 – Client Influences on Innovation

These illustrate the potentially significant supporting or inhibiting role that clients may play in the adoption of BIM, dependent on both their degree of involvement and attitude to innovation. These range from the active supporting role taken by

BAA on T5 (Harty, 2005), to those described by Hartmann (2006) and Ivory (2011), where the client actively seeks to avoid innovation.

Procurement Influence	Authors	Details of Influence
Traditional procurement.	Researcher synthesis	Under this route the processes of design and construction are separated, with generally little / no ability for the Main / Sub-contractor to influence the design.
Formal procurement processes.	Manseau and Shields (2005)	Reflecting the cost focus of the UKCI, tender processes are rigid, with evaluation usually giving greatest prominance to lowest price and offers little scope for alternative innovative solutions to be suggested.
Prescriptive contractual documentation.	(Craig, 1997a) (Davidson, 2001)	
Procurement route.	(Hartmann, 2006)	Identifies procurement as having either a positive or negative influence on innovation.
Decline in traditional procurement.	Researcher synthesis	The increase in alternative procurement methods which brings together the design and construction teams allows greater interaction among Consultants, Main contractors and Sub-contractors and hence allows all parties to consider cross process innovations.
Increase in application of design and build.	Researcher synthesis	
Novation of design team under D&B.	Researcher synthesis	The novation of the design team from the client to the contractor under this form of contract provides continuity and supports innovation.

Table 3.9 – Impact of Procurement Route on Innovation

Again, this table illustrates a range of potentially inhibiting and supporting effects that the procurement route may have on the adoption of BIM. Of particular note is the inhibiting effect of traditional procurement, where the functions of design and construction are contractually separated, and where irrespective of the benefits that the Main Contractor can lever through the use of BIM, this is dependent on the adoption of a suitable system by the client appointed Consultant design team, long before the Main Contractor is brought on board. However, from a practical perspective, the long term trend of increased use of design and build procurement, is likely to neuter this issue as should an overall increase in BIM usage among the design team members, resulting in more and more project being undertaken using BIM from the outset.

3.3.12 Network and Relationships

In a sector noted for its extensive fragmentation and use of sub-contractors, the nature of the networks and relationships between companies is also highlighted as having some positive, but mostly a negative impact on innovation, as illustrated at Table 3.10

Network / Relationships Influence	Authors	Details of Influence
Links and relationships with the supply chain.	(Doree and Holmen, 2004).	The authors suggest that learning from inter-company, inter project coupling, couplings resulting from contracts with clients and couplings with companies in the supply are the most important in supporting innovation.
Inter company relationships.	(Tatum, 1989).	Based on an analysis of successful construction innovations, these support innovation.
Adversarial and self protective behaviour.	(Blayse and Manley, 2004)	Which these authors argue inhibit innovation and are promoted by the procurement methods used.
Relationships tend to support short term innovations.	(Doubois and Gadde, 2002)[36]	These authors highlight the negative impact of relationships on innovations, describe the typical relationships as "loose couplings" before concluding that they tend to support short term innovations.
Degree of control across a project.	(Slaughter, 1998)	This author notes this as being critical for innovations which span organisational boundaries, however in practice this is very difficult to achieve.
Sphere of influence on a project tends to be outside control of any single party.	(Harty, 2005)	Bounded innovations are defined as those "where the implications of innovation are restricted within a single, coherent sphere of influence" and Unbounded innovations are those "where the effects of implementation spill over beyond this" (Harty, 2005, p.512).
Project focused relationships.	(Egan, 1998) (Winch, 1998)	Noted as having a negative impact on innovation due to short term nature of relationships (Also reflected in the short term culture noted above).
	(Taylor and Levitt, 2004a).	Argue that systemic innovations tend to diffuse more slowly than local project based innovations.

[36] The authors conceptualise construction networks as coupling on two independent layers, with tight coupling taking place at a project level and loose coupling coming into play in the wider permanent network, where collective innovations (such as BIM) take place.

Table 3.10 – Impact of Networks and UKCI Relationships on Innovation

Many of these issues reflect both the multifarious structure of the UKCI and the complex, project focused means of production, both of which result in the short term culture (Dulaimi, 1995), that appears to have inhibited the adoption of longer term inter organisational innovations such as BIM. Neither collaboration to innovate per se in the adoption of BIM, nor BIM facilitated project based collaboration are helped by the adversarial and self-protective behaviours noted by Blayse and Manley (2004).

3.3.13 Company Size

This theme reflects the stated aim to establish any variation in the dynamics of BIM adoption across companies of different sizes by reviewing literature relating to innovation in both large companies (Table 3.10), which although are low in number in the UKCI, undertake a significant percentage of construction work, and small companies (Table 3.11), who make up the vast majority of the UKCI by number.

Issue	Authors	Notes
Inadequate funding.	(Andrews, 2006)[37]	This aligns with the findings above (Loewe and Dominiquini, 2006) (Myers, 1984).
Risk avoidance.	(Andrews, 2006)	This reflects the negative impact of risk on innovation (Schumpeter, 1942, Myers, 1984, Nam and Tatum, 1988, Hartmann, 2006, Loewe and Dominiquini, 2006, D'Este et al., 2009, Ivory, 2011).
Desire for predicatable and consistent results for shareholders.	(Chesbrough, 2010)	
Risk / reward profile for staff does not encourage innovation.	(Chesbrough, 2010)	
Application of incorrect metrics for success.	(Andrews, 2006)	

[37] The author is marketing manager for IBM, a company widely recognised for its pedigree in innovation and identifies in a marketing oriented "Technology Executive Report" the five most common obstacles that innovators face within the context of large organisations.

Internal defence of divisions within a company.	(Andrews, 2006)	This suggests larger companies tend to have multiple divisions and products, hence the perceived negative impact on an innovation in a different business unit, in contrast to a small single product / company.
Fear of cannibalisation.	(Aulet et al., 2011)[38]	
A lack of time.	(Andrews, 2006)	These reflect the increase bureaucracy and specialisation of roles that tend to existing within larger companies.
Employees are trained to run existing businesses rather than innovate.	(Chesbrough, 2010)	

Table 3.11 – Innovation in Large Companies

While smaller companies are less complex organisationally, the issues they encounter when innovating, as summarised in Table 3.12, appear significantly inhibiting and are reflective of the lower level of skills and resources they are likely to have available.

Issue	Authors	Notes
Positive impact on the bottom line.	(Tovstiga and Birchall, 2008)[39]	Noted as the driver for innovation in 87% of SMEs and as being achieved through either differentiation within the marketplace, neutralisation of a competitors innovation or by improving company level skills and learning.
Access to finance.	(European Commission, 2000)	This recurring theme for small companies is worsened by the current recession within the UKCI.
Shortage of financial resources / access to finance.	(Proinno-Europe, 2011)[40]	
Suitable business skills to implement.	(European Commission, 2000)	While many innovations are developed, many companies fail to successfully implement or commercialise them.
Protection of intellectual property.	(European Commission, 2000)	To take the risk of funding innovation, small companies need to be confident the results of their investment will be protected to enable them to receive any rewards.
Shortage in skills to manage intellectual peroperty.	(Proinno-Europe, 2011)	

38 Who explored the desire to innovate as a means of supporting organic growth.
39 This study was based on empirical evidence, gathered from survey data from over 100 SMEs on their drivers for innovation.
40 Based on analysis of online survey generating 330 results.

Insufficient use of puplic procurement to foster innovation.	(Proinno-Europe, 2011)	This is highly relevant in an UKCI where a large percentage of work is commissioned by the public sector through formal procurement processes which are often difficult for smaller companies to navigate.
Weaknesses in networking and co-operation with external companies.	(Proinno-Europe, 2011)	Again, this is particularly relevant in an industry where relationships are noted above as being short term and adversarial.

Table 3.12 – Innovation in Small Companies

These suggest the supporting effect of a positive impact on the bottom line (Tovstiga and Birchall, 2008), is inhibited directly by financial resources issues (European Commission, 2000, Proinno-Europe, 2011), knowledge related resource issues, such as business skills to successfully manage the implementation of innovations (European Commission, 2000) and the knowhow to manage and protect their intellectual property (Proinno-Europe, 2011). The last of these is particularly relevant in a multi organisational BIM environment where by its very nature, valuable data is extensively shared outside the source company. Notwithstanding these, in mandating the use of BIM on public sector projects, the Government clearly is using public sector procurement to promote the adoption of BIM, hence overcoming the issue noted by Proinno-Europe (2011).

3.3.14 SMEs in Construction

Moving back to the UKCI which is dominated by SMEs, Table 3.13 illustrates authors who have specifically considered the issues small construction companies face when seeking to innovate,

Issue	Authors	Notes
Immediate needs of survival and business stability take priority over .innovation.	(Sexton and Barrett, 2003)	This a particular issue for SMEs in the UKCI given the recession and resulting higher levels of insolvency, where innovation can be seen as a distraction.
Cashflow needs to be maintained.	(Sexton et al., 2006)	These align with the issues of short termism discussed above, but this time is arguably driven by the result of direct financial pressures resulting from a lack of available finance.
Seek short term improvements.		
Successful innovation tend to deliver tangible short term improvements.		
Innovation tends to take place in response to the external environment.	(Sexton and Barrett, 2003)	The authors also note that SMEs tend to innovate on the basis of key events in the external environment, rather than internal considerations or drivers. The first and most common type of innovation, labelled by the authors as "Mode 1", which tends to comprise smaller (incremental) changes that provide short term, cost led gains and are based within single projects. "Mode 2" innovations, such as BIM, are larger in scope and are based on progressing multiple project value oriented relations.
Lack of skilled resources.	(Abbott et al., 2006)[41]	This mirrors the lower level of overall resources (including finance) available to smaller companies when compared with their larger competitors.
Successful innovations tend to fit the existing skills of the company.	(Sexton et al., 2006)	They also note that: "Any technology that is too far removed from this 'comfort zone' is seen to require too much investment and to contain too much risk, and thus tends to be intuitively and swiftly sifted out". (p.11).

Table 3.13 – SMEs in Construction

These issues are of particular relevance, given the importance of SMEs to the wider economy (European Commission, 2000), which is reflected in the Government's efforts to ensure SMEs are successful in delivering public sector construction projects (Cabinet Office, 2011). These indicate potential challenges for SME's seeking to adopt BIM, an innovation that is unlikely to fit within their

[41] Based on a single case study of a single small UK heating and plumbing company.

existing comfort zone (Sexton et al., 2006), be subject to a lack of skilled resources (Abbott et al., 2006) and is a long term improvement that may adversely affect cashflow (Sexton et al., 2006), in the early stages of implementation.

3.3.15 Generic Categories of Innovations

Another way of seeking to understand the adoption of BIM as an innovation, is to consider the range to which innovations are categorised within literature. Using this approach provides the opportunity for further insights into the adoption of BIM, through the application of established innovation frameworks and models.

While Rogers's definition above, introduces a number of potential categories of innovation by the inclusion of the terms "… ideas, practice or project …" (Rogers, 2003, p.12), Smith (2006) seeks to categorise innovations as either product innovations (i.e. a tangible item), service innovations (i.e. new or established services provided in a different way) or process innovations (related to the working practices behind the first two categories). The OECD introduces two further categories to those of Smith, marketing innovations: a new marketing method and organisational innovations: new methods in business practices, external relations or workplace organisation (OECD and Eurostat, 2005, pp.49-51)

Taylor and Levitt (2004b) considered an innovation by the level of adjustment required in other parts of a wide business process or product, for it to be successfully implemented. In doing so, the authors describe a systemic innovation[42] as "… requiring multiple companies to change in a co-ordinated

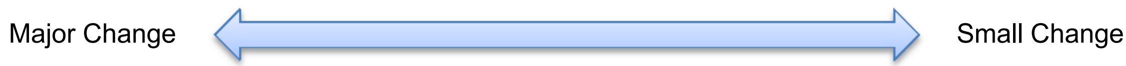
[42] An example of a systemic innovation, is the introduction of the Blu-Ray DVD, which not only required the development of new hardware and in built decoding software to play these new format discs, but also distributors to invest in technology to produce films in this format, as well as wholesalers and retailers to accept the standard and supply material in this format to customers. In contrast, the introduction of power steering to cars can be considered an autonomous

fashion” (Taylor and Levitt, 2004b, p.2). These contrast with autonomous innovations, which can be introduced without modification to other equipment or parts of the process.

3.3.16 Construction Specific Categories of Innovations

A number of authors have considered categories specific to construction and therefore reflected the particular characteristics of construction in the categories defined, making these particularly relevant to the adoption of BIM.

Of these, Slaughter (1998) is one of the most cited in this area and developed a scale of innovations with incremental and radical categories at opposite ends. Each of the five modes of innovation sits on the scale, illustrated at Figure 3.10 below, depending degree of change from the current practice, with detail of each provided below:



5	4	3	2	1
Radical Innovation	System Innovation	Architectural Innovation	Modular Innovation	Incremental Innovation

Figure 3.10 - Scale of Innovation Categories

Based on (Slaughter, 1998, p.229)

1. **Incremental:** Based in current knowledge and practice. Occur constantly, predictable impacts. Negligible impact on other components or systems.
2. **Modular:** Significant change within a component or system in isolation. Leaves links to other components or systems unchanged. Often developed

innovation, as when first introduced, it did not require any major alterations to the design of the car or the engine.

within a company and implemented without the need for co-operation from other parties involved in the project.

3. **Architectural:** Small change within a component or system itself. Major changes in links to other components or systems. May be developed by a company that does not have a vested interest in maintaining the status quo, but to succeed, the introducing party must understand and be able to influence these linkages.
4. **System:** Integration of multiple individual innovations which interact to improve performance or provide new functions. As with Architectural, these are may be developed by a company that does not have a vested interest in maintaining the status quo. Innovator able to exercise technical competence and co-ordination / control across a project. Requirements to effectively use this category of innovation often conflicts with current practice.
5. **Radical:** Potential to change the character of an industry. Often based on a breakthrough in technology or science. Rare and unpredictable. High impact on other components or systems.

Based on (Slaughter, 1998, p 227-229)

The author proposes that this scale should be used as a basis supporting the implementation of different types of innovation in construction and goes on to identify four supplementary considerations required to enable this to take place, shown below at Table 3.14, with their suggested application to BIM.

Secondary Consideration	Application to BIM
Timing of commitment.	To achieve the maximum benefit and avoid the need to retrospectively capture design information produced elsewhere in a BIM form, BIM is best used from the start of the project.
Degree of co-ordination.	A high degree of co-ordination among the large and diverse members of the project team is required from BIM. This may complicate and lengthen the adoption process.
Need for specialist resource.	BIM requires relatively expensive hardware and software as well as specialist skills to use it. This may inhibit the adoption process.
Level, type and competency of supervision required.	BIM may require a high level of supervision, particularly around changes in existing processes, e.g. semi-automatic generation of quantities or costs direct from the model, which if inaccurate may have signification cost implications for main and sub-contractors who rely on this information for pricing.

Table 3.14 – Supplementary Considerations and application to BIM,

Based on (Slaughter, 1998)

From their research, which sought to investigate the contribution of innovation to business strategy within construction, Lim & Ofori (2007)[43] propose that this is best supported by the classification of innovations in accordance with the resulting returns and types of benefits, which then justify the initial effort and investment in their application. The authors draw attention to two interesting respondents' comments and one interim conclusion. These comments are particularly relevant during the current recession, when UKCI output has contracted so sharply.

> Survival comes before R&D. There must be available profit to fund R&D …
>
> … there has to be adequate demand for construction work to sustain the survival of contractors before you can talk about improving contractors' technologies.

(Lim and Ofori, 2007, p.972)

[43] Based on interviews with 21 construction professionals.

Their interim conclusion was that none of the contractors interviewed perceived innovation as being able to support competitive advantage in the UKCI by means of increased margins and lower costs than their competitors. This appears to indicate that one of the commonly perceived generic drivers for innovation may not be significant within the UKCI. The authors then conclude their study by identifying three classes of innovation in construction:

1. Innovations that consumers are willing to pay for.
2. Innovations that reduce contractors' construction costs.
3. Innovations that encompass intangible benefits, thus providing contractors with competitive advantage.

(Lim and Ofori, 2007, p.963)

The final categorisation is based on the work of Harty (2005), who from a sociological perspective, considers two categories of innovations based on the level of influence of the originator. Bounded innovations are defined as those "… where the implications of innovation are restricted within a single, coherent sphere of influence" and Unbounded innovations are those "… where the effects of implementation spill over beyond this" (Harty, 2005, p.512).

3.3.17 Categorisation of BIM as an Innovation

Applying the above classifications to BIM as an innovation, suggests the categorisations shown at Table 3.15.

Category	Author	Rationale for Categorisation.
Process Innovation.	(Smith, 2006)	BIM enables the design and construction service to be provided in a different way than currently.
Systemic Innovation.	(Taylor and Levitt, 2004a)	BIM requires change in multiple organisations involved on a construction project.
System Innovation.	(Slaughter, 1998)	BIM builds upon multiple innovations (3D CAD, the Internet, more powerful PCs and software) to provide a new function. It requires technical competence and control across a project and requires change to current common practice. In terms of secondary commitments, BIM should be applied at the start of a project, requires a high degree of co-ordination and specialist resource and may require a high level of supervision, particularly changes in existing processes relating to costings and cost control.
Innovations that reduce contractors' construction costs.	(Lim and Ofori, 2007)	One of the benefits of BIM is the provision of reduced wastage and therefore reduced construction costs.
Unbounded Innovation.	(Harty, 2005)	The implications of BIM are likely to be outside the sphere of influence of any one party on a project.

Table 3.15 - Categorisation of BIM as an Innovation

This analysis suggests that BIM adoption is supported by its classification as an innovation that reduces contractors' costs, albeit, this is a benefit which may accrue to Main Contractors and Sub-Contractors rather than Consultants. Critically, Consultants are unlikely to be directly financially incentivised to achieve this goal, but their early adoption of BIM is critical to its successful application across a project. In contrast, the categorisation of BIM as a process innovation (Smith, 2006), systemic innovation (Taylor and Levitt, 2004a), and system innovation (Slaughter, 1998) all highlight the inhibiting effect of the degree of change required for adoption. This is further compounded by the fact that BIM spans the boundaries of the large number of companies likely to be involved in a project, combined with its categorisation as an unbounded innovation (Harty, 2005), suggesting these are likely to be outside the control of any one party.

3.3.18 Summary – Theories of Innovation

Following definition of the term innovation, through consideration and synthesis of generic and construction specific literature, this section identifies a range of potential issues, which arise from the consideration of BIM as an innovation.

The discussion of generic innovation literature begins with the key work of Rogers (2003) including characteristics of innovations, with the author suggesting that relative advantage has the most impact on the rate of adoption, followed in rank order by compatibility, complexity, trialability and observability . Rogers also identifies five categories of innovation adopters, each with different considerations, and suggests that cumulative innovation adoption tends to follow an ‘S’ profile.

From generic literature, the drivers of the adoption of BIM as an innovation appears to be driven by the desire to realise competitive (Porter, 1985) and financial benefits (Schumpeter, 1942, Lim and Ofori, 2007), but is tempered by cost (D'Este et al., 2009) and lack of resources, including financial (Myers, 1984), human (Loewe and Dominiquini, 2006, D'Este et al., 2009) and informational / technical (D'Este et al., 2009).

Reflecting the unique characteristics of the UKCI, construction specific innovation literature is reviewed to suggest that construction does innovate (Winch, 2003), albeit in a different way (Ruddock and Ruddock, 2009) and slower rate than comparative industries. Given the key role of BIM in project delivery, also significant are a number of the key characteristics of buildings and structures, as the output of the UKCI, including their complexity, costliness and a high level of social responsibility (Nam and Tatum, 1988). Consideration of the structure of the

UKCI, highlights a range of issues, such as the supporting effect of industry flexibility (Tatum, 1989), plus a recognition of the need to improve performance (Fairclough, 2002), tempered by the significant inhibiting effect of fragmentation (Betts and Ofori, 1994, Egan, 1998, Fairclough, 2002, Gajendran and Brewer, 2007, Yitmen, 2007, Ibrahim, 2011) and the focus on lowest cost (Tatum, 1986, Egan, 1998, Davidson, 2001, Fairclough, 2002, Jones and Saad, 2003). The key role that clients may play as both the supporters (Harty, 2005) or inhibitors of innovations (Ivory, 2011) are reviewed, as are the impact of procurement routes, particularly those which impact in the ability to integrate design and construction activities, the closeness of which is critical to maximising the benefits of BIM.

The short term project focused (Egan, 1998, Winch, 1998) and often self-protective and adversarial (Blayse and Manley, 2004) nature of relationships appear inhibiting issues, particularly as BIM requires extensive collaboration across companies to both initially adopt and then apply fully. Returning to the skewed structure of the UKCI, with its high number of SMEs and small number of larger companies, the latter of whom are responsible for a disproportionate percentage of its output, a range of issues related to company size are considered. These include particular issues for SMEs, such as a lack of resources (European Commission, 2000, Proinno-Europe, 2011) from general literature and the mostly short term approach (Sexton et al., 2006). Issues from both generic and construction specific literature are then considered to suggest categories of innovation which apply to BIM, using a range of frameworks / classifications (Slaughter, 1998, Taylor and Levitt, 2004a, Smith, 2006, Harty, 2005, Lim and Ofori, 2007), the majority of which appear to inhibit the adoption of BIM.

Within the next section, the researcher synthesises information from the field on BIM and the UKCI with innovation literature as theory, to identify a broad range of potential dynamics[44] of BIM adoption, along with suggested variations due to company size and type. In this way, the study aims to differentiate itself from previous literature in both the consideration of BIM as an innovation, as well as the examination of potential differences across companies of different sizes and types, within the UKCI.

3.4 Suggested Dynamics and Patterns of BIM Adoption

The rationale for considering BIM as an innovation within this study, are covered in the introduction and include the successful application of innovation theories to to inter organisational systems (Ibrahim, 2003), suitability for technological innovations (Rogers, 2003) and practical application to inform programmes to accelerate the diffusion of an innovation (Dearing and Rogers, 1996).

The seminal work of Rogers (2003), including the five generic characteristics of innovations described earlier, also provides a well-recognised and relatively comprehensive framework, around which the wider construction and BIM specific dynamics identified within the literature review can be organised. Applying the results obtained, this approach also enabled reflection on Rogers's model within the final chapter. Also applied as an organising framework, is the version of field theory (Lewin, 1951), commonly referred to as force field analysis. Although this particular tool is subject to the criticism described earlier, it provides a means of organising potential dynamics into two categories: Those which support the adoption of BIM (supporting forces) and those which inhibit the adoption of BIM (resisting forces). Categorised in this way, the suggested dynamics are summarised at Appendix 2, while criticism of force field analysis is addressed by the use of life spaces, a topological method also developed by Lewin (1951), to represent the dynamics of BIM within the final chapter.

[44] The rationale for the use of the term "dynamics" is explained within Section 1.3.1 of the introduction.

To ensure comprehensive coverage of a wide range of potential dynamics, a broad range of literature covering the UKCI, BIM and innovations has been reviewed above. This sets this study apart in terms of the wide range of issues identified and supports the stated aim of achieving a balanced view of BIM adoption, which covers the issues as well as advantages. Although this study was undertaken from a positivist perspective, key to the synthesis of dynamics from the literature was the researcher's substantial experience within the UKCI, including their extensive involvement in the adoption of CAD. Through a combination of occurrence within the literature and the researcher's tacit knowledge, a wide range of supporting and inhibiting dynamics were therefore identified on the basis of their perceived application to BIM. The position of the researcher within the context of this study is also declared within the methodology chapter, along with the ways in which potential associated issues were addressed.

The synthesis of literature and identification of a range of potential dynamics of BIM adoption, provided the study with a link between literature and research methods to support the stated aims of the research. These dynamics are described and summarised below, organised around the five generic characteristics of innovations noted above, whether they support or inhibit BIM adoption, along with potential variations in these by company size or type. Following the development of a range of hypothesis arising from this review, the synthesis and dynamics were operationalised to an interview guide and questionnaire, as described in the next chapter, enabling the researcher to capture a substantial amount of qualitative and quantitative data for analysis.

3.4.1 Relative Advantage

This characteristic is suggested by Rogers (2003, p.233) as the most significant and most accurate predictor of the rate of adoption of an innovation. It contains a number of sub-characteristics, the first of which is noted as Economic Factors. Within this, a wide range of benefits of BIM have been identified, are therefore categorised as supporting dynamics and summarised at Table 3.1.

From a general business and competition perspective, a number of authors describe the importance of innovation including Drucker (1985), who describes it as a key skill to remain successful (i.e. profitable) and Porter (1985), who describes how innovation can create competitive advantage and hence increase profitability. The financial benefit of avoided delays from BIM use is noted by Lee, Park, & Won (2012, p.585)[45]. A positive ROI also is noted by McGraw Hill (2009) as well as increased profitability (Becerik-Gerber and Rice, 2010, Lim and Ofori, 2007, p.963, NBS, 2011a). These suggest a dynamic: Benefits Financial Tangible. In addition, Becerik-Gerber and Rice (2010) also notes that companies who use BIM for 100% of project, tend to perceive a higher increase in profitability, leading to the dynamic: Use Benefit Level, along with: Investment Benefits, the latter of which reflects the slightly different potential for those who invest most in BIM to receive the most benefits.

Non-specific cost reductions on BIM projects, are noted by the a number of authors, including in rank order of robustness Yan and Damian (2008), NBS (2011b) and Autodesk (2006), and are captured in the dynamic, Project Cost. The dynamic, Construction Cost, arises from the earlier categorisation above of BIM as an innovation that has the advantages of lowering specifically the construction costs, and is supported by the findings of Barlish & Sullivan (2012) and Reise

[45] Who note a positive return on investment (ROI) generally accruing to the main contractor, ranging between 172% to 247% for avoided delays of one week, plus 624% to 699% for avoided delays of a month duration.

(2009). Autodesk (2006) claim this is as a result of a higher quality of construction documentation, as well as more time being spent on the result, indicated by the MacLeamy Curve, rather than the creation of documentation. The latter is supported by Light (2011a), who also notes the positive effect of the MacLeamy Curve, plus the BIM Industry Working Group (2011), who note the potential of BIM to add value to construction through the focus of effort when it can best deliver benefits. These result in the dynamics: MacLeamy and Valued Added. As the main contractor is the first party to accrue any benefit in reduced construction costs, competitive tensions may lead them to reduce their prices as a result, captured by the dynamic: Main Contractor Costs. In a competitive tender situation, this can provide a competitive advantage against non BIM main contractors, or those who choose not to pass on the savings, reflected in the dynamic: Tender Winning. As well as the cost and time improvements to the construction stage, Riese (2009) also notes that BIM enables an improvement in the quality of work on site, reflected in the dynamic: Quality of Build.

From the perspective of the much longer and more expensive, operational phase of a building, Riese (2009) also notes that BIM allows direct integration of construction information with a life cycle database, reflected in: Life Cycle Information. Both Autodesk (2006) and BIM Industry Working Group (2011) note that BIM can enable a decrease in life cycle costs, noted as the dynamic: Life Cycle Cost, with the latter author also citing the potential for a decrease in carbon emissions during operation, reflected in: Carbon Emissions. One wider aspect of this is are improvements resulting from the BIM enabled delivery of more sustainable projects (Yan and Damian, 2008, NBS, 2011b), captured in the dynamic: Project Sustainable.

Returning to a design perspective, the advantages of BIM fall into two categories: those arising from improved consistency across multiple information sources and secondly: the creative process of BIM enabled design development itself.

Reflecting the former, Roberts (2005) identifies improved quality of design information, while Autodesk (2006) cite the automatic update of changes across documents and The NBS (2011b) highlight increased co-ordination of construction documents. Roberts (2005), also argues for an improved quality of design information in terms of consistency. Collectively these are noted within the dynamic: Design Information Quality, with Productivity Design Rework, arising from the identification of improved productivity through reduced design re-work (McGraw Hill, 2009). The ability to spend more time designing and problem solving, cost effectively explore changes and a reduction in overall design time (Autodesk, 2006), are captured within the dynamics: Design Team Focus, Design Change Cost Effective and Design Time respectively. Also from a design development perspective, the issue of co-ordination of often complex three dimensional information to avoid physical clashes on site, is one of the most often cited advantages of BIM (Autodesk, 2006, McGraw Hill, 2009, Riese, 2009, NBS, 2011b), and is captured by the dynamic: Quality of Design.

Incomplete or inconsistent design information in construction documentation often results in what is commonly known as requests for information or RFIs. These are issued by the contractor to the designer or sub-contractor as a means of obtaining or clarifying design information, required to address a particular issue on site. Both Barlish and Sullivan (2012) and Riese (2009), note that these and resulting change orders (Barlish and Sullivan, 2012) are reduced where BIM is used, being captured in the dynamics: Requests For Information and Site Variations respectively.

From a viewpoint of improved information flow and management, the potential offered by digital technology to the UKCI is noted by Cabinet Office (2011), with improved productivity through easy retrieval of information identified by NBS (2011a), reflected in the dynamic: Productivity Information Retrieval, and BIM providing an intelligent collaboration platform (Riese, 2009) captured in: Collaboration Platform.

A reduction in human resource, is noted as a benefit of BIM by both Yan and Damian (2008) and Autodesk (2006), the latter of whom specifically note this in terms of the design team, who they suggest can get more done with fewer people. These are respectively captured in: Staff Level and Design Team Size. The ability to develop a cost plan direct from the BIM model, is reflected in the potential for accelerated costing (Autodesk, 2006) and enhanced quantity take off (Riese, 2009), which are reflected in: Cost Plans Duration, the latter of whom also notes that BIM enables quicker construction, noted in: Construction Duration. On a similar vein, the positive return on investment (Lee et al., 2012), gave significant emphasis of BIM usage leading to the avoidance of delays on site through the early identification of issues, and captured in the dynamic: Site Delays. This reduction in construction duration, combined with the reduction in design time noted above, should lead to an overall reduction in the time to undertake a project, reflected by the dynamic: Project Duration. From a service delivery viewpoint, McGraw Hill (2009), also argue that the changes resulting from BIM may enable both the provision of new services e.g. the on-going update of the BIM model during operational phase of a building, reflected in the dynamic: New Services.

Moving outside of the UKCI, many UK academic institutions have increased their level of teaching and research on BIM. These reflect the positive impact on innovation of evaluation and stimulation of research (Bossink, 2004), realised through the formal evaluation and demonstration of the business benefits of BIM, captured in: Formal Evaluations, as well as supporting the development of the skills needed for BIM.

Suggested Dynamic	Details of Dynamic
Benefits Financial Tangible	BIM generates a greater profitability for companies who adopt it., a positive impact on the bottom line / a positive ROI / competitive advantage.
Use Benefit Level	Those who use BIM on 100% of their projects obtain the highest increase profitability.
Investment Benefits	The benefits that individual companies receive from BIM, reflect the levels of investment they make.
Project Cost	BIM reduces the total costs of construction project.
Construction Cost	BIM reduces the construction cost.
MacLeamy	BIM focuses design effort at to a time that reduces the cost of any changes.
Value Added	BIM presents the opportunity to add value to construction activities.
Main Contractor Costs	BIM reduces the main contractors' costs.
Tender Winning	BIM supports winning more work in a formal tender process.
Quality of Build	BIM results in an improved quality of build.
Life Cycle Information	Construction information from BIM can be integrated directly into a life cycle / operations database.
Life Cycle Cost	BIM enables a reduction in the life cycle costs of a building.
Carbon Emissions	Carbon emissions from buildings designed using BIM are reduced.
Projects Sustainable	BIM enables the delivery of more sustainable buildings.
Design Information Quality	Construction documents are better co-ordinated and the consistency of design information is improved using BIM.
Productivity Design Rework	BIM increases productivity through reduced design re-work.
Design Team Focus	BIM allows the design team to spend more time on design.
Design Change Cost Effective	BIM allows possible design changes to be cost effectively explored.
Design Time	The design team can spend more time on problem solving BIM and the time taken to design is reduced using BIM.
Quality of Design	BIM results in improved design quality.
Request For Information	BIM results in a reduction in Requests for Information (RFIs) from site.
Site Variations	Site led change orders / variations are reduced using BIM.
Productivity Information Retrieval	Productivity is improved through the easy retrieval of information from BIM.
Collaboration Platform	BIM provides an intelligent collaboration platform.
Staff Level	BIM results in a reduction in human resources.
Design Team Size	The design team can be smaller when using BIM.
Cost Plans Duration	BIM enables the development of accelerated cost plans direct from the model.
Construction Duration	Construction is quicker when using BIM.

Site Delays	There are less site delays due to design issues when using BIM.
Project Duration	BIM enables an overall reduction in the time taken to deliver a construction project.
New Services	BIM enables the provision of new services to clients.
Formal Evaluations	BIM is supported by the formal evaluation of its benefits.

Table 3.16 – Supporting Dynamics of BIM Adoption, Relative Advantage, Economic Factors

From both general innovation and construction specific literature, a smaller number of inhibiting dynamics can also be inferred. The significant cost of BIM (Matthews and Withers, 2011, Open BIM Network, 2012) is also highlighted in trade article by Miller (2013), with this author suggesting an indicative cost of £10,000 for a single workstation, comprising BIM Software, Hardware, IT Infrastructure and Training. These are captured in the dynamics: Cost Implementation, Hardware New Specialist and Software Investment. From generic theories of innovation, the inhibiting effect of a lack of available capital (Myers, 1984, Andrews, 2006, D'Este et al., 2009), is captured in: Capital Availability, with the need to maintain cashflow (Abbott et al., 2006) noted in: Cash Flow. The dynamic: Payback Short, reflects the short term focus of the UKCI and inhibiting effect of this on payback requirements for innovation (Loewe and Dominiquini, 2006).

Given that this study has explored the UKCI at a time of deep recession where many companies are struggling, Sexton and Barrett (2003) note that SMEs only tend to innovate once the higher business needs of survival and stability are met, reflected in the dynamics: Industry Recession, Company Stability and Company Survival. Returning to generic innovation literature, D'Este et al. (2009) cite the significant inhibiting effect on innovation of uncertain market demand, captured within: Demand Uncertain.

Suggested Dynamic	Details of Dynamic
Cost Implementation	The cost of BIM is high.
Hardware New Specialist	BIM requires access to new specialist hardware.
Capital Availability	BIM is inhibited by a shortage / lack of available capital.
Cash Flow	Difficulty in maintaining cash flow while implementing BIM.
Payback Short	Short term payback for BIM is required.
Industry Recession	The wider recession in construction does not support BIM.
Company Stability	Company stability is more of a priority than BIM.
Company Survival	Company survival comes before implementing BIM.
Demand Uncertain	The market demand for BIM is uncertain.

Table 3.17 – Inhibiting Dynamics of BIM Adoption, Relative Advantage, Economic Factors.

Within Rogers's sub-category Status Aspects, a single dynamic : Marketing, reflects the development of competitive advantage through BIM related marketing collateral (McGraw Hill, 2009), although any advantage this provides will be eroded as BIM becomes more widely adopted and its use increasingly publicised. This is illustrated in a trade article by (Withers, 2011) who describes how Laing O'Rourke claim their BIM approach was key in securing a £300M large scheme in the City of London, known as the Cheesegrater. As well as noting the advantages of BIM on this project, the article also notes the project wide advantages that Laing O'Rourke bring to their clients through their advanced use of BIM on all projects.

Suggested Dynamic	Details of Dynamic
Marketing	The adoption of BIM supports company marketing.

Table 3.18 – Supporting Dynamics of BIM Adoption, Relative Advantage, Status Aspects

While there do not appear to be any dynamics solely within Rogers's sub-categories of Overadoption or Preventative innovation, a number of supporting dynamics appear within the sub-category Incentives. Through its BIM Task Group, the Government has supported innovation (Bossink, 2004) through a number of pilot projects to demonstrate the benefits, promotion of access to technology and supporting the sharing of information on BIM through knowledge networks such as the CIC BIM Hub and BIM4SME group, reflected in the dynamics: Projects Pilot, Promotion Technology Access and Networks Knowledge. Returning to the role of the academic community in BIM, this author also notes the positive effect of academic research on innovation, captured in the dynamic: Research Academic.

Suggested Dynamic	**Details of Dynamic**
Projects Pilot	BIM is supported by the funding of pilot projects.
Promotion Technology Access	BIM is supported by programmes promoting access to technology.
Networks Knowledge	Knowledge networks (e.g. the CIC's BIM Hubs) support the adoption of BIM.
Research Academic	Stimulated research supports the adoption of BIM.

Table 3.19 – Supporting Dynamics of BIM Adoption, Relative Advantage, Incentives

Within Rogers's final sub-category, Mandate, two significant dynamics are apparent. Although BIM was previously categorised using Harty's framework as an unbounded innovation, projects such as T5 where the client played a major role in the adoption of 3D Cad (Harty, 2005), demonstrate the supporting effect of a client mandate made at the start of the project, and is reflected in: Client Mandate Early. The second and arguably more significant dynamic: Government Mandate, reflects the requirement for BIM to be used on all public sector projects by 2016. One consequence of this, is that BIM can also be categorised as a Preventative Innovation "… that an individual adopts now in order to lower the probability of some future unwanted event" (Rogers, 2003, p.234), in this case being locked out from an important part of the UKCI.

Suggested Dynamic	Details of Dynamic
Client Mandate Early	Early client mandating of BIM increases its level of adoption.
Government Mandate	The Government mandate for BIM usage on projects by 2016 supports its implementation.

Table 3.20 – Supporting Dynamics of BIM Adoption, Relative Advantage, Mandate

3.4.2 Complexity

This second key characteristic of innovations, is noted as having an inhibiting effect on the diffusion of innovations, the higher its value (Rogers, 2003), reflected in the dynamic: Complexity. With BIM a highly complex innovation, the degree of technical competence required across the project and need for specialist resources to operate an innovation (Slaughter, 1998), are reflected as the dynamics: Competence Technical and Staff Specialist, with the latter also reflecting the inhibiting impact (Loewe and Dominiquini, 2006, D'Este et al., 2009) noted from generic innovation literature.

The level of training required to adopt BIM, as a complex innovation requiring new skills, is noted by reference to costs by both Matthews and Withers (2011) and Miller (2013), the former of whom estimate the cost of BIM training for Quantity Surveyors at £2,000 per person in a trade article. From a more rigorous academic perspective, both the cost and amount of training required are cited by Yan & Damian (2008) and reflected in the dynamic: Training Level. Finally, combining BIM as an innovation that crosses organisational boundaries with the general lack of co-ordination across construction companies business networks (Tovstiga and Birchall, 2008), is captured in: Co-ordination Different Companies.

Suggested Dynamic	Details of Dynamic
Complexity	BIM is a complex innovation.
Competence Technical	BIM requires a degree of technical competence across a project.
Staff Specialist	Specialist staff are required to use BIM.
Training Level	BIM requires a high level of training and knowledge.
Co-ordination Different Companies	A high degree of co-ordination across different companies is required for BIM adoption.

Table 3.21 – Inhibiting Dynamics of BIM Adoption, Complexity

3.4.3 Trialability and Observability.

These third and fourth of Rogers's categories are noted has having a positive effect on the rate of adoption. With BIM being an innovation that spans organisational boundaries, best works with a high degree of change to existing roles and process, it is difficult to undertake a trial and observe the potential benefits, without a substantial degree of both investment, change in process and time, which are captured in the inhibiting dynamics: Trialability and Observability.

Suggested Dynamic	Details of Dynamic
Trialability	It is difficult to undertake a trial of BIM.
Observability	The benefits of BIM are difficult to observe.

Table 3.22 – Inhibiting Dynamics of BIM Adoption, Trialability and Observability.

3.4.4 Compatibility

This final of the five characteristics, is noted by Rogers as having a positive effect on the rate of diffusion, however given the fragmented, specialist and complex nature the UKCI as a mature industry, this has the largest number of dynamics within Rogers's sub-category Values and Beliefs, which support the adoption of BIM.

The acknowledgement that it is "….. universally recognised that the industry must improve its performance" (Fairclough, 2002, p.6) and the flexibility of the industry as a supporter of innovation (Tatum, 1989), are reflected in the dynamics: Industry Improvement Recognition and Industry Flexibility respectively. Innovation within construction is also supported by collaboration with contractors of different types (Brochner, 2011) and couplings with the supply chain (Doree and Holmen, 2004), captured in Collaboration Company Types and Relationships Supply Chain. Within construction companies, Tatum (1989) also notes the positive effect on innovation of supportive management policies, which is captured as the dynamic: Company Policies.

Returning to the successful T5 project (Harty, 2005), the supporting nature of top down client policies is reflected in: Client Policies, while the positive impact on innovation of stimulating standards (Blayse and Manley, 2004, Bossink, 2004) by means of the Government mandate is captured as: Stimulation. Related to this is the seemingly positive impact of the open systems approach to BIM recommended by the Government's Task Group and captured as: Systems Open as well as the apparent advantage offered by vendor neutral data exchange formats, such as IFC, which allow the transfer of data between different BIM software packages, reflected in: Exchange Formats Neutral.

The dynamic: Relationships Cross Project, reflects the supporting impact on innovations within construction resulting from a strengthening of relationships across multiple projects and weakening of relationships at a project by project level (Doubois and Gadde, 2002), plus increased inter-project linkages (Doree and Holmen, 2004). While innovation in construction is noted as being supported by inter-company relationships (Tatum, 1986) and inter-company linkages (Gann and Salter, 2000) this view is not universal. The effect of adversarial contractual relationships (Egan, 1998, Carter et al., 2002, Fairclough, 2002, Jones and Saad, 2003, House of Commons Business and Enterprise Commitee, 2008), the confrontational and self-protective behaviour promoted by procurement methods (Blayse and Manley, 2004), inhibit innovation. Therefore, the dynamic: Relationships Within Industry, may be either supporting or inhibiting to BIM adoption.

Suggested Dynamic	Details of Dynamic
Industry Improvement Recognition	The recognition that the UKCI needs to improve its performance supports BIM.
Industry Flexibility	BIM is aided by the flexibility of the construction industry as a whole.
Collaboration Company Types	Collaboration with companies of different types supports BIM.
Relationships Supply Chain	BIM is held back by links / relationships with the supply chain.
Company Policies	BIM is helped by supporting policies and priorities within my organisation.
Client Policies	The clients development of top down supportive policies supports the adoption of BIM.
Stimulation	BIM is supported by stimulating standards.
Systems Open	The open system approach to BIM recommended by the Task Group supports the adoption of BIM.
Exchange Formats Neutral	BIM is helped by vendor neutral formats (e.g. IFC) for exchange of data between different software packages.
Relationships Cross Project	Strengthening relationships with companies across multiple projects assists BIM and weakening those on a project by project basis.
Relationships Within Industry	BIM may be either supported or inhibited by the nature of relationships between companies.[46]

Table 3.23 – Supporting Dynamics of BIM Adoption, Compatibility, Values and Beliefs

Moving onto inhibiting dynamics, the project focus of construction, noted as: Project Focus, is considered by many as a barrier to innovation (Nam and Tatum, 1988, Egan, 1998, Davidson, 2001, Doubois and Gadde, 2002), with (Slaughter, 1998, p8), describing a "… temporary alliance of disparate organisations", who by nature of their temporary or one off relationships may not be willing to invest in or

[46] This may be either a supporting or inhibiting dynamic of BIM adoption.

adopt a project specific approach to BIM, which is different to their own. This temporary nature of relationships, is also reflected in the inhibiting dynamic: Relationships Temporary. The fragmentation of production in construction, captured as Industry Fragmentation, is a well recognised barrier to innovation (Betts and Ofori, 1994, Egan 1998, Gajendran and Brewer, 2007, Yitmen, 2007, Fairclough, 2002, Cabinet Office, 2011), with the resulting highly specialised nature of individual companies, a further inhibiting factor to innovation (Nam and Tatum, 1988), and noted as: Companies Specialised. Further well recognised issues within construction which inhibit innovation include a focus on lowest cost (Tatum, 1986, Egan, 1998, Davidson, 2001, Fairclough, 2002, Jones and Saad, 2003), and is illustrated as: Lowest Cost Focus, inappropriate risk transfer down the supply chain through procurement routes, captured as: Supply Chain Risk Transfer, as well as the generic business issue of short termism (Loewe and Dominiquini, 2006), captured as the dynamic: Short Term Focus. The issue of fragmentation and temporary relationships above, also leads onto problems of control across a project, which acts as an inhibitor to innovation (Slaughter, 1998). In addition, the resercher's categorisation of BIM as an unbounded innovation, outside the sphere of influence of any one party on a project (Harty, 2005), suggests a dynamic: Control Span Of. This author, also notes the robustness of existing practices within construction as an inhibitor of innovation, a dynamic noted as: Industry Practices Robust.

The potential role of the construction clients as drivers of innovation (Hartmann, 2006), the value brought to clients by innovation through the tendering process (Craig, 1997b), contrast with the clients perception of risk as a barrier to innovation (Ivory, 2011, p868), who notes some clients "…. actively police innovation to ensure it did not threaten the project ….", with a trade article citing a recent survey from the Royal Institute of Chartered Surveyors, within which 46% of respondents claimed that minimum client demand was impeding the use of BIM on projects (Haymen, 2013). These indicate the dynamic: Clients, may either be a supporting or inhibiting dynamic of BIM adoption. The lack of ability of the construction team to influence either the requirements or process set by the client, during a competitive procurement process (Craig, 2000) can also inhibit BIM and are reflected in the inhibiting dynamics: Influence Clients and Influence Client Requirements / Process. Finally, from a client perspective, the dynamic: Client Contractor Collaboration, reflects the negative impact on innovation by the widespread lack of collaborative working between clients and contracts (House of Commons Business and Enterprise Commitee, 2008, p44).

Considering construction with reference to the characteristics of complex products and systems, Hobday (1998) notes many innovation decisions are taken in production, suggests a further inhibiting dynamic: Decision Start of Project, reflecting the point at which the decision to use BIM is best made.
The nature of companies within construction (Tatum, 1989) and from a generic innovation perspective, a lack of time (Hartmann, 2006) also inhibit innovation, being captured as: Company Nature and Time Implementation. These structural characteristics of construction combined with the nature of the relationships "… seems to favour short term productivity while hampering innovation and learning" (Doubois and Gadde, 2002, p.621), therefore inhibit BIM as a long term systemic innovation, and is captured as: Innovations Quicker.

Looking within companies, a number of inhibitors to innovation are noted, including a desire for consistent and predictable results (Chesbrough, 2010), resulting from a risk adverse, consensus style management by boards and CEOs (Perel, 2002), a risk adverse approach (Tovstiga and Birchall, 2008), plus the inherent risk in perusing innovations (Myers, 1984, Loewe and Dominquini, 2006, D'Este et al., 2009) captured as the dynamic: Adoption Risk. Further inhibitors within companies are a lack of systemic processes to support innovation (Loewe and Dominiquini, 2006), captured as: Innovation Processes, a lack of appropriate leadership (Jones and Saad, 2003), resulting in the dynamic: Company

Leadership and a lack of management support or incentives for management to support innovation (Perel, 2002, Chesbrough, 2010), both reflected in the dynamic as: Management Supportive. Finally, within companies, the importance of a supportive and positive working environment (Ling, 2003) on innovation, is reflected as: Working Environment.

Suggested Dynamic	Details of Dynamic
Project Focus	The project based focus of the UKCI inhibits BIM.
Relationships Temporary	The temporary project based relationships in construction make it difficult to invest in common processes for BIM.
Industry Fragmentation	Construction industry fragmentation is a barrier to BIM.
Companies Specialised	The highly specialised nature of companies within construction is a barrier to BIM.
Lowest Cost Focus	A focus on lowest cost does not support BIM.
Supply Chain Risk Transfer	Risk transfer along the supply chain inhibits BIM.
Short Term Focus	A short term focus is a barrier to BIM.
Control Span Of	BIM is outside the sphere of influence of any one party.
Industry Practices Robust	Existing practices within the industry are too robust to enable a change to BIM.
Clients	Clients play a role in supporting or inhibiting BIM. [47]
Influence Clients	The difficulty in influencing clients inhibits BIM.
Influence Client Requirements	The inability of the construction team to influence the client's requirements under a formal tender process is a blockage to BIM.
Client Contractor Collaboration	BIM is held back by the lack of collaborative working between client and contractor teams.
Decision Start Project	The decision to use BIM needs to be made at the start of a project.
Company Nature	The nature of construction companies makes BIM difficult to implement.
Time Implementation	A lack of time to implement BIM.
Innovations Quicker	Construction relationships tend to support innovations with a shorter implementation time than BIM.
Adoption Risk	Adopting BIM is inherently risky.
Innovation Processes	A lack of systemic innovation process inhibits BIM.
Company Leadership	A lack of appropriate company leadership is a barrier to BIM.
Management Supportive	Management / management approaches are not supportive of BIM.
Working Environment	BIM requires a supportive working environment.

Table 3.24 – Inhibiting Dynamics of BIM Adoption, Compatibility, Values and Beliefs

[47] This may be either a supporting or inhibiting dynamic of BIM adoption.

A further sub category noted by Rogers is that of compatibility with previously introduced ideas, with there arguably being a high number of these within construction as a mature and well established sector. Within this, the inhibiting dynamic: Compatibility Existing Systems, reflects the fact that BIM does not fit within existing skillsets, identified from a generic innovation perspective in terms of comfort zone by (Sexton et al., 2006), along with the substantial changes to existing systems and roles required to achieve the maximum benefit from BIM. While the negative impact of general business skills on innovation (D'Este et al., 2009) is captured as: Skills General Business.

From a procurement perspective, the increase in use of design and build contracts and decrease in traditional procurement discussed earlier, along with the potential mechanism of novation by which the design team can work for both the client and contractor, both support BIM due to the closer integration of design and construction activities and are reflected in: D&B Increase, Traditional Procurement Decline and Design Team Novation[48] respectively. In contrast to this, the separation of design and construction activities under traditional procurement which inhibits collaboration between those undertaking each activity and therefore the use of BIM, is noted as: Separation Traditional Procurement. The adverse impact on innovation of highly rigid and formal procurement processes within the public sector (Manseau and Shields, 2005) and prescriptive contract documentation (2001) are reflected as inhibiting dynamics: Public Sector Procurement and Contract Prescriptive. While the MacLeamy Curve suggests more effort should be made at the earlier stages of a project (Light, 2011a), this may be counter-productive to multiple bidders in a tender situation, where up to six teams may commonly be involved in preparing their respective submissions. In this case, this would increase the amount of work they have to carry out at risk,

[48] Novation is the process of transfer of the design team appointment from the client to the contractor under design and build procurement.

in the knowledge that only one team will win the project and recover these, potentially increasing tendering costs and is reflected as: Design Risk Tender.

The project focus of the UKCI, the inter organisational nature of BIM and fragmentation of the UKCI, all highlighted above, are reflected in the inhibiting effect that different bespoke company systems have on systemic innovations. Combined with the poor linkages between the processes of the individual companies and a particular project (Gann and Salter, 2000), these are reflected in the penultimate dynamic: Systems Bespoke.

Finally, the diagram above of indicative BIM costs (Miller, 2013), notes the need for a high quality ICT network to enable the rapid sharing of BIM data, which tends to be large by comparison to e-mail or CAD files, as is captured as the dynamic: Infrastructure High Speed.

Suggested Dynamic	**Details of Dynamic**
D&B Increase	The increased use of Design and Build supports BIM.
Traditional Procurement Decline	BIM is supported by the decline in traditional procurement.

Table 3.25 – Supporting Dynamics of BIM Adoption, Compatibility, Values and Beliefs

Suggested Dynamic	Details of Dynamic
Compatibility Existing Systems	The lack of compatibility of BIM with existing ways of working or practices..
Skills General Business	A lack of generic business skills to successfully implement BIM.
Separation Traditional Procurement	The separation of design and construction under traditional procurement is a barrier to BIM.
Public Sector Procurement	Formal public sector procurement processes do not support BIM.
Contract Prescriptive	Prescriptive contractual documents inhibit BIM.
Design Risk Tender	The development of design work at risk in a tender situation is a barrier to BIM.
Systems Bespoke	The poor linkages between the processes of the individual companies involved and particular individual project do not support BIM.
Infrastructure High Speed	BIM requires a good ICT infrastructure to support the transfer of information.

Table 3.26 – Inhibiting Dynamics of BIM Adoption, Compatibility, Values and Beliefs

Having identified potential dynamics, an observation worthy of note at this stage, is that while the majority of the supporting dynamics relate directly or indirectly to economic advantages of BIM, the majority of inhibiting dynamics relate similarly to organisational issues. This aligns with the work of Beer and Nohria (2000), who suggested two models of organisational change, Theory E, based on economic value and Theory O based on organisational capacity.

3.4.5 Hypothesis Development

Key to meeting the stated research outcomes were the development of a number of hypotheses, for subsequent testing within each of the research methods. These were suggested from the literature review and were perceived by the researcher as offering insights into the adoption of BIM, which although potentially self-evident, do not appear to have been covered in depth by other researchers.

Firstly, a number of inhibiting dynamics, specific to smaller companies who are seeking to innovate and adopt BIM are identified from literature. This suggests the potential for a significant difference in BIM usage associated with company size and in particular, a higher level of BIM usage in larger companies, who are not subject to or are better able to overcome these issues. This is tested in the hypothesis:

> There will be a relationship between the size of company and the percentage of work carried out using BIM.

The significant cost of implementing BIM, low level of trialability and long learning curve combined with the benefits BIM offers, suggests that companies implement BIM on a small scale and then increase its application once benefits start to be realised, uncertainty in BIM has reduced and they become more competent and confident in its use. This suggests a positive relationship between the length of time since a company has adopted BIM and the usage it makes, tested in the second hypothesis:

> There will be a relationship between the length of time of BIM has been used and the percentage of work carried out using BIM.

Similarly, there may be a positive relationship between time since adoption and collaborative working / sharing of BIM data, for the same reasons, tested in the third hypothesis:

> There will be a relationship between the length of time BIM has been used and the percentage of work carried out using BIM and the sharing of data with other companies.

Within the qualitative analysis only, two further hypotheses were tested to statistically identify those dynamics which respondents considered to be relevant, and those which respondents specifically considered not to be relevant: For the former, the hypothesis was set as:

> The 95% lower confidence interval of the sample mean will be greater than the critical Likert response value (μ_0) for a neutral response.[49]

For the latter, the hypothesis was set:

> The 95% higher confidence interval of the sample mean will be lower than the critical Likert response value (μ_0) for a neutral response.[50]

The potential difference in BIM usage identified above, suggests a related potential difference in dynamics accompanied in company size, reflected in the hypothesis:

> There will be differences in the dynamics relevant to different company sizes.

Similarly, different types of companies have different roles within project, become involved at different stages, have different skill levels, are subject to different relationships and competitive forces and therefore, accrue different potential benefits from using BIM. This suggests a similar potential different in BIM dynamics associated with company type, reflected in hypothesis:

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[49] Given the 7 point Likert response used, with 4 representing the neutral response, μ0 was given this value, such that a value >4 represented a perception of "somewhat agree", "agree" or "strongly agree".
[50] Given the 7 point Likert response used, with 4 representing the neutral response, μ0 was given this value, such that a value <4 represented a perception of "somewhat disagree", "disagree" or "strongly disagree".

There will be differences in the dynamics relevant to different company types.

These potential variations in dynamics by company sizes and types are summarised in more detail in table form at Appendix 2.

3.5 Summary and Conclusion

The key output of this literature review has been the identification of potential patterns of BIM adoption due to company size and type, along with the identification of 104 potential dynamics of BIM adoption. These are organised around Rogers's (2003) five generic characteristics of innovations and categorised using force field analysis, a derivative of field theory (Lewin, 1951), as either supporting or inhibiting dynamics. These dynamics along with further potential variations by company type and size are summarised at Appendix 2. In addition, to better understand BIM as an innovation, it is also categorised using a range of construction innovation categorisation systems and modes of innovation (Slaughter, 1998, Taylor and Levitt, 2004a, Harty, 2005, Lim and Ofori, 2007).

Although this study has been undertaken from a positivist perspective, the researcher has applied tacit knowledge gained from their role within the UKCI in the synthesis of literature. Combining this with the review of UKCI, BIM and innovation specific literature has generated a more comprehensive and balanced range of potential dynamics of BIM adoption than appears to be the case in the majority of previous literature. This, combined with the research design described in the next chapter, not only supports the stated aims and objectives of the study, but also the researchers desire to build upon, but fill the gaps in previous literature and in doing so contribute to knowledge.

While there are a number of suggested supporting dynamics within what Rogers (2003) suggests is the most important characteristic of an innovation, Relative

Advantage, this also contains a number of inhibiting characteristics. BIM adoption also appears to be constrained by the high number of inhibiting dynamics within the characteristic Compatibility, with Rogers (2003) suggesting this is the second most important characteristic, with Complexity, Observability and Trialability also containing predominantly inhibiting dynamics. Applying a range of UKCI innovation categorisation models, including BIM as a system innovation under the model developed by Slaughter (1998), also highlight how difficult BIM adoption may be. These suggested categorisations, dynamics and characteristics of BIM, align with the limited level of BIM adoption so far within the UKCI and may go some way to explaining why the Government has chosen to intervene and mandate the use of BIM within the UKCI for public sector projects from 2016, thus providing what appears to be a strong supporting dynamic: Government Mandate.

The suggestion of a higher BIM adoption rate in larger companies along with variations in dynamics due to company size appears logical, given the financial resource and human capital issues often encountered by smaller companies. These also align with the researcher’s recent professional experience of BIM, where use tended to be limited to larger Consultants and Main Contractors, plus a very small number of large Sub-Contractors. Similarly, these mirror the researcher’s experience of the early adoption of CAD, which was initially limited to larger Consultants due to its high cost, complexity and the level of training required to use it, while smaller companies, Main Contractors and some Sub-Contractors only tended to adopted once the price had reduced, software became less complex and easier to use, and CAD skills became more widespread within the UKCI.

Chapter 4 – Methodology

4.1 Introduction

Beginning with the research paradigm and philosophy, this chapter justifies and explains the methodologies applied in this study, before describing the data collection and analysis methods used in detail. Ethical considerations are discussed, along with those of reliability and validity before concluding with the limitations of this research.

4.2 Paradigm and Philosophical Position

It is important when undertaking research at this level to consider and articulate the appropriate research paradigm as well as the research position in respect of ontology[51] and epistemology[52], as these have a significant influence on the way the research is undertaken (Flowers, 2009). At a detailed level, decisions made and approaches used should be compatible with the researchers stated positions and the objective of the research (Blaikie, 2000), if the final work is not to be undermined (Flowers, 2009).

4.2.1 Research Paradigm

Paradigm, is defined by the Oxford English Dictionary as “a world view underlying the theories and methodology of a particular scientific subject”. From a research perspective Burrell and Morgan (1979, p24), comment that “To be located in a particular paradigm is to view the world in a particular way”, while Pansiri (2005, p195), states that “one is inclined to adopt a paradigm ….. because of the extent to which one agrees with its basic assumptions”.

[51] Described by **BLAIKIE, N.** 1993. *Approaches to Social Enquiry,* Cambridge, Polity Press. as the study or science of being.

[52] A view about the most appropriate way of enquiry into the world **EASTERBY-SMITH, M., THORPE, R. & JACKSON, P. R.** 2009. *Management Research - Third Edition,* London, Sage Publications Ltd.

The three key considerations which informed the research paradigm were the type of study, research objectives plus application of the most appropriate perspectives. In terms of type of study, as this is a DBA rather than a PhD, the researcher is seeking not only to contribute to knowledge, but also impact on practice within the UKCI and their own professional domain. Secondly, the research objectives included developing and understanding both the status and issues relating to the adoption of BIM across the UKCI, taking an industry level perspective. Finally, the philosophical, epistemological and ontological perspectives, as described below, were set to best support the aims of this research, while remaining comfortable to and aligned with the researcher's own beliefs and experience. From a synthesis of these three considerations, the research was taken from a pragmatic paradigm.

According to the Oxford Dictionary of Sociology (Scott and Marshall, 2009), the rationale for pragmatism can best be described by James who focuses on the practical consequences of research and asks:

> What difference would it practically make to anyone if this notion rather than that notion was true? (James, 1907, p.28)

This perspective further supported by Rorty (1991, p27), who argues that research should "… aim at utility for us …" , while Powell notes:

> To a pragmatist, the mandate of science is not to find truth or realist, the existence of which are perpetually in dispute, but to facilitate human problem solving. (Powell, 2001, p.884)

These practical, utilitarian and problem solving aspects of pragmatism are particularly relevant to this study, given the researchers previous experience of the adoption of CAD and the current status of BIM adoption within the UKCI.

Despite what appear to be substantial benefits of BIM as an innovation, which in turn have the potential to address some of the long term performance issues within UK construction, there appear to be issues with adoption and utilisation rates. The researcher considers these to be important practical issues within the UKCI and therefore a problem, the solving of which can be supported in a small way through the application of pragmatism within this study.

While Hanson (2008) notes that pragmatism suggests the most important question is how far the research has assisted in helping the researcher find out what they want to know, Denscombe (2008) warns that this should not be confused with expediency or used as an excuse for slipshod research, a point acknowledged by this researcher and addressed through the application of a methodology which aims to be robust. One final point of note at this stage is that the researcher in selecting pragmatism, is not doing so on the basis of any perceived “perfection” or universally agreed evaluation criteria. Rather than when compared with alternatives, including interpretivist or post-positivist research paradigms, that this best supports the aims of the study, aligns closely to the researchers own personal and professional perspectives and reflects the nature of DBA research described above.

4.2.2 Research Philosophy

While the pragmatic approach adopted for this research is noticeable in the fact that it is underpinned by utility, rather than the dogmatic application of a particular research philosophy, it remains important to declare the ontological and epistemological positions applied and the justification for these.

Because this research seeks to understand the adoption of BIM across the UKCI, and in doing so considers the company as the unit of adoption, this research is undertaken from an ontological perspective of objectivity, an approach that suggests reality exists independently of those who life and observe it (Flowers, 2009). However, although the researcher has adopted this position, it should be noted that both data collection methods, i.e. questionnaire and semi structured interviews, relied on subjective perceptions of by the individual respondents. This research is also undertaken from supporting epistemological position of positivism, an approach which broadly suggests social research should be carried out in ways similar to the sciences (Henn et al., 2009). In adopting these positions, the researcher aims to maximise the generalisation and utility of the results across the UKCI as a whole, while continuing to contribute to knowledge.

One practical impact of this approach, has been the sampling design described below, which the researcher aimed to be both robust in terms of numbers of respondent and also representative in terms of the UKCI by output. While at face value this may appear to be at odds with pragmatism from a process perspective, the sampling design was set to maximise the utility of this study and therefore supports pragmatism in terms of outcome.

4.3 Position of the Researcher

Accepting the argument that "…. researchers approach their studies with a certain worldview that guides their inquiries" (Cresswell, 1998, p.74), it is important to explore the position of the researcher within this process as a means of controlling potential bias. While full details of the researcher can be found at Appendix 1, the researchers own experience has inspired their decision to both adopt this field of study, as well as a research paradigm of pragmatism. In addition, the 27 years of employment and current position within the UKCI, may lead to criticism of an insider-researcher role by others, as the researcher may be seen as an advocate of BIM rather than an objective and legitimate researcher. It is also important to declare, that from a personal and professional perspective the researcher is broadly pro-technology and pro-BIM.

Within a research context, the term “insider” is described by (Merton, 1972) as an individual who possesses a priori intimate knowledge of a community and its members. Concern about research undertaken by insiders, is noted by Gunasekaia (2007), who argues that both interpretations and observations are capable of being influenced by the informed perspective of the researcher. This insider position does however strengthen the study in two ways. Firstly, although undertaken from a positivist perspective, the researcher’s insider position and tacit knowledge of the UKCI were instrumental in the synthesis of literature. Secondly, these enable the researcher to develop an appropriate but good level of rapport and to gain an in-depth understanding of participants’ perspectives on the dynamics of BIM. Roland and Wicks (2009) also argue that insiders have the knowledge base necessary to better understand the information processes within certain professions. In the researchers view, this insider position brings value to this study, which is being undertaken in the context of a mature, complex, fragmented and often idiosyncratic sector.

A further significant factor is the researcher’s employment by a large construction and support services company, which has significant UK market share. This may presents issues when dealing with respondents in companies who are in competition with, or have a relationship with this employer, leading to reluctance to share information or social desirability bias.

In response to these issues, the study seeks balance by considering the wider dynamics of BIM adoption, rather than either the drivers to or barriers to BIM adoption. In addition, the researcher makes use of and documents in detail the methodology, methods and sampling used as a means of reducing any bias, increasing the validity of the research and ensuring the robustness of the results. Issues with competitors or partner companies were addressed by a clear articulation of the fact that in this study, the researcher is acting independently and not as an agent of their employer, along with assurances and written confirmation of respondent confidentiality, as covered below. All respondents were also offered, either a summary or a full copy of the study. This will be provided at the same time as a copy is issued to the researcher's employer, to avoid any perception of a loss competitive advantage through partaking in the research.

4.4 Research Design

4.4.1 Approach

The stated epistemological position of positivism, combined with the wide range literature on BIM and potential dynamics of adoption, have led the researcher to adopt a hypothetico-deductive approach as the most appropriate to this study. This approach is characterised as a top down approach (Burney, 2008) where in its purest form, the activity of research is guided by theory (Bryman and Bell, 2007, Easterby-Smith et al., 2009, Henn et al., 2009). This approach allows the researcher to tap into and be guided by work undertaken by previous researchers, while building upon this and contributing to knowledge by taking a broader more comprehensive perspective.

4.4.2 Mixed Methods

Given the pragmatic aims of the research, manifest in the desire to maximise the utility of this study, careful consideration was given to ensuring that the methods applied were suitably robust. Critical to this was the wish to overcome the weaknesses inherent in the application of a single data collection method, which led to the application of both qualitative and quantitative methods within this study, namely mixed methods. This is therefore an approach which is not rigidly rooted in the dogmatic application of a particular research paradigm or philosophy, hence is a more functional approach and one that is most often related to pragmatism. Among the many formal definitions Leech & Onwuegbuzie define mixed methods as a type of research where:

the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language in to a single study….(Leech and Onwuegbuzie, 2007, p.475).

While, Greene (2006, p.93) defines this approach as one way of investigating the social work that again “ideally involves more than one methodological tradition”.

A number of authors support the use of mixed methods including Fretchling et al. (1997), who state that this is of benefit to the researcher as combining approaches to refine understanding of the results, with Hanson et al., noting the use of:

> … both forms of data allow researchers to simultaneously generalise from results from a sample to a population and to gain a deeper understanding of the phenomena of interest. (Hanson et al., 2005, p.224).

The researcher acknowledges the practical issues presented by adopting a mixed method design, with Cresswell (2003) stating that mixed methods generally requires researchers to be informed in both methods, as well as taking them more time and effort. As with the sampling design described above, while this may be perceived as being at odds with the stated pragmatic approach, the researcher is of the view that mixed methods supports pragmatism through the increased utility of the study findings.

Two key considerations in the application of mixed methods are the sequence in which the methods are applied, e.g. one before the other or concurrently, and the weighting given to each method e.g. is one given more weighting or are both given equal status. One commonly used method of representing the different sequences and weighting of each of mixed methods was developed by Morse

(1999). This uses capitalisation to represent the weighting given to each method plus the symbols “+” and “>” to represent the timing of each method, as in the following example:

quan > QUAL

Where “QUAL” in uppercase against “quan” in lowercase indicates that greater weighting is given to the quantitative method against the qualitative method, while the “>” symbol indicates the quantitative method is applied first and informs the qualitative method.

For mixed methods research where triangulation is being applied, Onwuegbuzie & Collins recommend the concurrent capture of both qualitative and quantitative data. This is in order to maximise validity and to reduce the introduction of bias, where a sequential approach may mean that the “… findings from the first approach influence those from the second” (Onwuegbuzie and Collins, 2007, p.290). Therefore, both data capture processes will take place at the same time. Again, in order to maximise the robustness of the conclusions, both qualitative and quantitative data were given equal status in this research. This approach also reduces the risk of bias from data or findings from one method, to the other.

Using the mixed method notation system described above, this approach is represented as:

QUAL + QUAN

Where QUAL stands for qualitative, QUAN stands for quantitative, capitalisation of both denotes equal status and the “**+**” symbol represents concurrency from a time perspective (Goethals, 2008).

This deductive, mixed approach is illustrated at Figure 4.1, also introduces the data collection and preparation methods, the data analysis process and methodological triangulation, all of which are described in detail below.

Figure 4.1 – Mixed Methods Design,

based on Bryman & Bell (2007, p.11 p.155 p.406)

4.5 Data Collection and Analysis Methods

4.5.1 Sampling

As well as the consideration of BIM as an innovation, also critical to achieving the stated research aims and the generation of robust results is the explicit identification of the population under consider and the application of robust sampling design for both qualitative and quantitative methods.

Given the researchers consideration of the adoption of BIM within the UKCI, statistical data (Office of National Statistics, 2012) on the number of Main Contractors (total = 62,065) and Sub Contractors (total = 60,205) was used along with data (Construction Industry Council, 2006) on the number of Consultants (total = 27,947), giving a total population within the UKCI of 150,217 companies.

Based on the recommended minimum sample size of 82 (Onwuegbuzie and Collins, 2007) for a two tailed hypothesis, plus a suitable contingency , a total target sample size for the quantitative analysis was set at 330 respondents, with an equal number of respondents (110), distributed across each of the three company types described below. This number for each company type is in excess of the recommendation of 82 above, while allowing a suitable contingency of 28 respondents, should achieving the target number of responses turn out to be an issue. This equal target sample size across each type of company also enables more robust statistical analysis between the groups (ANOVA) to be carried out and is not an approach that appears to have been previously applied to research on BIM.

For exploratory factor analysis, a statistical technique explained below, a meta-analysis of literature recommendation by Zhao (2009)[53] notes an average sample size (n) of 300 and an average sample to variable ratio of 5:1. As the questionnaire contains 104 questions, the subject to variable ration (STV) of 4.29:1, appears to be appropriate for exploratory factor analysis from a statistical basis, given the practical limitations of the study in terms of time and resources.

When applying qualitative methods, Morse et al., (2002) argue that adequacy of sampling is usually measured by depth of data. However, where generalisability and transferability are required, as in this researcher, sample size is critical (Onwuebuzie, 2003) and needs to balance the need to be large enough while not being repetitious (Mason, 2010). For the qualitative analysis a target sample size of 8 was therefore established for each company type giving a total of 24, which significantly exceeds the minimum 12 recommended by Guest et al., (2006) to identify 97% of significant qualitative codes, while again achieving substantial headroom in case of a lower than expected response rate, and balancing the practical limitations of this study. No respondents were approached for both qualitative and quantitative data collection.

Similarly, in order to allow generalisation from this study to the wider UKCI is the selection of an appropriate sampling method. Two dimensional stratified random sampling was therefore used to ensure that the variety of respondents reflective of the wider UKCI in terms of two key characteristics:

1. Based on the roles introduced within the literature review, three company types were established to reflect their different roles on a typical project:

    - Consultants

[53] Sample size (n) ranged from a minimum of 100 to 1000 and the sample to variable ratio (*p*) ranged from 2:1 to 10:1.

- Main Contractors
- Sub-Contractors

2. Size of company, as measured by turnover and or equivalent number of staff.

For main contractors and sub-contractors, stratification of the population was carried out by reference to ONS data. Rather than stratifying the sampling frame on the basis of the number of companies within each category[54], the researcher chose to stratify the frame using the value of work produced by each category. This is on the basis that this gives a better representation of the output of the UKCI, where official data (Office of National Statistics, 2012) clearly shows larger companies form a very small percentage by number (2%), but undertake a large percentage of construction work (57%).

As with the ANOVA described above, this approach does not appear to have been applied to BIM research previously, with the largest studies within the literature review, appearing to use convenience sampling. The calculations behind this stratification, which includes target sample sizes established in the sections below, are shown at Table 4.1 for Main Contractors, and for Sub-Contractors at Table 4.2 below.

Within the first two of these tables, the first column breaks down the population into six categories of company size, based on the number of staff employed. The second column then identifies the turnover in £thousands of those companies within the size category, before representing this in column three as a percentage of the total turnover for this type of company, This percentage is then applied to the target sample sizes of 110 (quantitative) and 8 (qualitative) to suggest target samples size for this size category in columns four and five, for the quantitative

[54] This would have resulted in a sample dominated by SME's, who make up 98% of construction companies by number.

and qualitative methods. Hence in table 3.1, Main Contractors with 1 – 7 employees had a total turnover of £9,286K per annum, which represents 15% of the total Main Contractor turnover of £62,065K per annum. Therefore 15% of the total target sample size of 110, i.e. 16 respondents should be from this size of company for the quantitative analysis, and 15% of the target sample size of 8, i.e. 1 respondent should be within this size of company for the qualitative analysis.

Main Contractors								
No. of employees		**Total Turnover (£K) of Category**		**Percentage of Total**		**Quantitative - Target Category Sample Size**		**Qualitative - Target Category Sample Size**
1-7		9286		15.0%		16		1
8-34		8854		14.3%		16		1
35-79		6731		10.8%		12		1
80-299		11253		18.1%		20		2
300-1199		10549		17.0%		19		1
1,200 and Over		15392		24.8%		27		2
Total		**62065**		**100%**		**110**		**8**

Table 4.1 – Stratification of sampling frame, main contractors[55]

Sub-Contractors								
No. of employees		**Total Turnover (£K) of Category**		**Percentage of Total**		**Quantitative - Target Category Sample Size**		**Qualitative - Target Category Sample Size**
1-7		21857		36%		40		3
8-34		17069		28%		31		2
35-79		6220		10%		11		1
80-299		5829		10%		11		1
300-1199		3691		6%		7		0
1,200 and Over		5539		9%		10		1
Total		**60205**		**100%**		**110**		**8**

Table 4.2 – Stratification of sampling frame, sub-contractors[56]

[55] The data in the first two columns was obtained from Table 2.9, (Office of National Statistics, 2012).

For consultants, the ONS data does not provide a similar breakdown. Therefore, data from the Construction Industry Council (2006, pp 7-8) was applied. While this is some 8 years old, it breaks down construction consultants into four categories using fee incomes, as well as giving a total fee income for each category. To give the best representation of these companies, where a small number of large companies undertake the majority of the work by value, stratification of the frame was undertaken using the fee income for each category, again to better reflect the outcome of the UKCI, and is shown at Table 4.3 below.

The calculations within this table follow a similar basis to those in Tables 5.1 and 5.2 with the exception that it was only possible to break down consultants into four categories of size, and this was by fee income rather than turnover. Although there are 12638 consultants in the lowest fee income category of <£200K, some 45.2% by number, these companies only have a fee income of £0.2Bn a much reduced 1.4% of the total consultants fee income of £13.8Bn. Hence only 2 respondents within this category of consultant were required for the quantitative analysis, and 1 for the qualitative analysis.

Consultants										
Fee Income Category		**No of Companies**		**Total Fee Income (£Bn) per Category**		**Percentage of Total based on Fee Income**		**Quantitative - Target Cageory Sample Size**		**Qualitative - Target Category Sample Size**
<£200K		12638		0.2		1.4%		2		1
£200K - £1M		10178		0.7		5.1%		6		1
>£1M-£10M		4690		2.1		15.2%		17		1
>£10M		441		10.8		78.3%		85		5
Total		**27947**		**13.8**		**100%**		**110**		**8**

Table 4.3 – Stratification of sampling frame, consultants[57]

[56] The data in the first two columns was obtained from Table 2.9, (Office of National Statistics, 2012).

Identification of respondents within the sampling frames was initiated by reference to a wide range of professional bodies and trade literature, as well as financial databases available to the researcher, shown below at Table 4.4. Following compilation of a comprehensive list of potential respondents from these sources, these were randomly enumerated in Excel 2010[58] and then sorted to provide a randomised selection within each sampling frame.

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[58] Although this method actually uses a pseudo random algorithm within excel, it was considered sufficient for the purposes of this research.

Function of Organisation	Sources of Sampling Frame
Consultant – Architect	Directory of Royal Institute of British Architects - Chartered Practices.
Consultant – Civil and Structural Engineer	Institute of Civil Engineers – Directory of Corporate Members.
Consultant – Quantity Surveyor	Royal Institute of Chartered Surveyors – Directory.
Consultant – Mechanical and Electrical Engineer	Chartered Institute of Building Services Engineers – Directory of Practices and Firms .
Main Contractors	Construction Industry Council – Contractor Members.
Main Contractors	Trade Databases including National Building Specification, Barbour and HIS with validation of turnover by Experian.
Sub-contractors	Employers supplier and subcontractors database.
Sub-contractors	Trade Databases including National Building Specification, Barbour and HIS with validation of turnover by Experian.

Table 4.4 – Sources of Respondents

The degree of rigour applied to sampling within this research, is significant in that it appears to exceed those applied within the works cited within the literature review. For example, McGraw Hill (2010) has a high degree of variation in respondent numbers across the different countries and company types across which results were compared. Similarly, while one of the largest UK specific surveys (NBS, 2011b), achieved 800 responses, in the absence of detail on sampling, this appears to have been carried out on a convenience basis. The stratified random sampling method applied in this study, therefore appears to set it apart in terms improved representation of the UKCI. In addition, the reliability and validity of this research also aims to exceed reviewed works through the application of mixed methods. While these both presented the researcher with practical issues during the research process, in the view of the researcher they best support the stated research aims and objectives and once again support the pragmatic approach, in terms of quality and utility of output.

4.5.2 Qualitative Methods of Data Capture

Although undertaken from a positivist perspective, as mixed methods, this research includes the application qualitative techniques, which are traditionally associated with an interpretivist perspective.

Qualitative data was captured from semi structured interviews (SSI), which due to the geographic dispersal of respondents were undertaken by telephone. The advantages of using SSI include the ability to take a flexible questioning approach (Henn et al., 2009), to gather opinions, explore respondents motivations and experiences (Drewer, 2006) and generate rich detailed answers (Bryman and Bell, 2007). The use of SSI also supports the deductive approach taken by the researcher, in ensuring the opportunity for sufficient coverage of the key dynamics identified a priori within the literature review. In addition, the open approach, allows the researcher to probe further any issues, including additional suggested dynamics introduced a posteriori by the respondent during the course of the interview.

As well as the issue of geographic dispersal, the time and cost constraints of this research the widespread use of conference calls and the researchers own substantial experience with this medium, supported the use of telephone interviews. These advantages were viewed by researcher as overcoming the suggestions that qualitative interviewing is not best served by telephone (Rubin and Rubin, 2005), plus the difficulties in establishing a natural encounter and rapport between parties and a lack of non-verbal communication (Shuy, 2003). From a practical perspective, this was found to be time and cost effective (Sturges and Hanrahan, 2004) and although the topic discussed was not particularly sensitive, the anonymity provided by telephone rather than face to face interviews, noted by the same authors, may have been a factor in the open dialogue and discussion the researcher perceived as being achieved with most respondents.

Potential respondents were contacted to establish if they were willing to take part in the research by telephone interview. For those who were, link to a web hosted Telephone Interview Consent Form, shown at Appendix 4, was issued by e-mail. This enabled the respondent to give their informed consent easily and quickly via a web page. Following receipt of consent, each interview was undertaken at a pre-arranged time to suit the respondents' availability and hence improve the response rate. This and the similar parallel process for quantitative analysis are illustrated as a flow chart at Figure 4.2 below.

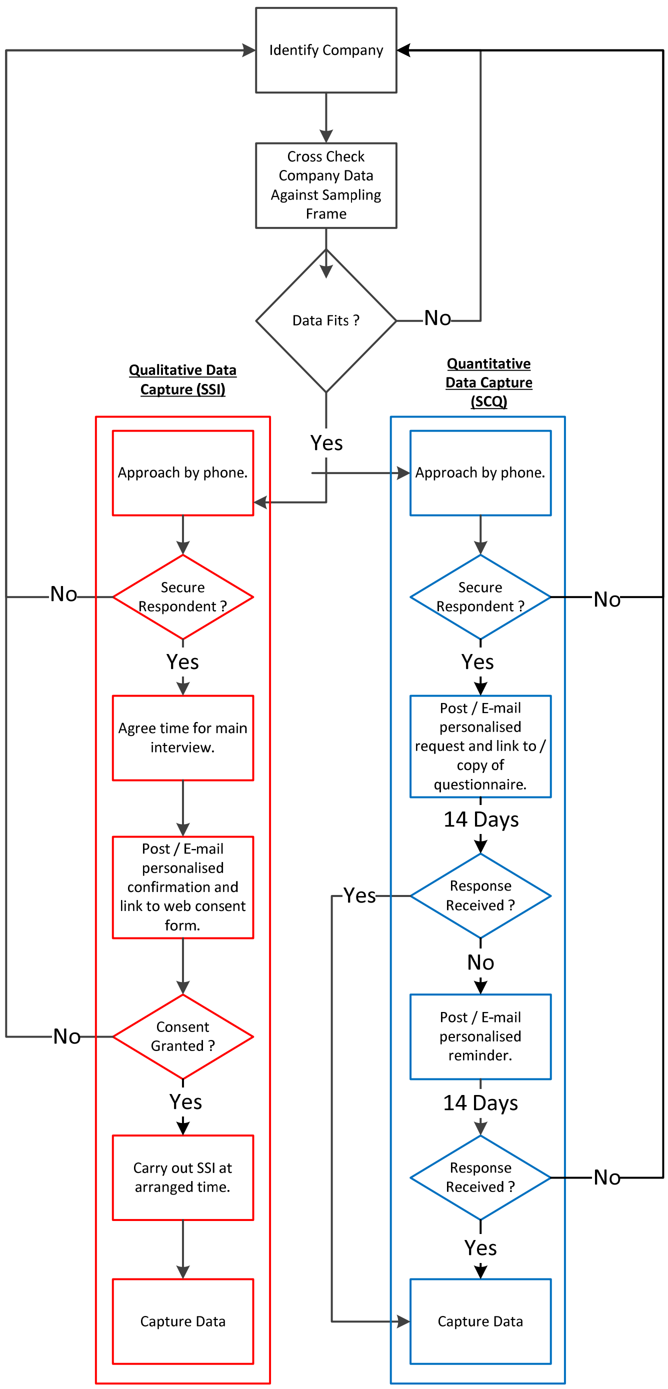

Figure 4.2 – Application of Research Instruments

To avoid the respondent incurring costs, the researcher made the interview call from a landline based voice over internet protocol (VOIP) handset based in a pre-booked meeting room at their place of work, with most calls being made to the respondent's landline rather than mobile phone. This method ensured the respondent did not incur any call charges, the audio quality of call (landline to landline) was generally good and the researcher was able, in accordance with the informed consent obtained beforehand, to record the call using CallCorder software. This software enabled all conversations to be saved as password protected secure .mp3 files. Each file and transcript was referenced in accordance with the process described in the Ethics section below, to ensure confidentiality.

Reflecting the deductive approach to the study, a coding template (Appendix 6) containing pre-defined / a priori codes was developed from the suggested dynamics of BIM adoption. For consistency, each code was given the same name as the related dynamic plus details of key terms being sought in the responses, with an example, Industry Flexibility, illustrated at Table 4.5 below.

Ref:	Dynamic / Code	Brief Description of Code in terms of what the respondent says / mentions (including influence on BIM adoption / usage in all cases).
1	Industry Flexibility	Adaptability / flexibility / openness of industry / construction / or similar.

Table 4.5 – Example from Coding Template.

As recommended (Bryman and Bell, 2007) a single sheet interview guide was developed (Appendix 5) and printed off at A3 size for use during the interview .Informed by coding template this offered a reminder to the researcher of the topics to be covered as well as neutral phrases to be used to prompt discussion and probe responses. The drafting of these followed guidance (Kennedy, 2006) in that it included questions to seek elaboration and understand influencing conditions, as well as the nine types of questions suggested by (Kvale, 1996)

During each interview, notes were made on the guide which covered key points of interest and guided subsequent transcription and analysis. To reduce the risk of bias, where there was the potential for the output of one interview to influence the researcher on those following, review of these notes and transcription from the audio files to Microsoft Word was only undertaken after the final interview had taken place and analysis, as described in section 5.5.5, was only commenced once all transcription was completed.

4.5.3 Quantitative Methods of Data Capture

Quantitative data was gathered by a self-completed survey, which was available to respondents online and in hard copy form. The latter ensuring that respondents, who do not make extensive use of e-mail or the internet, are adequately represented in the data. To reduce the potential for question order bias, the order of questions on potential dynamics was randomised using this feature within the host website and using a semi-automatic process utilising the random number generation within Excel, linked to Word for the hard copy questionnaires.

The use of a self-completed survey supported the deductive approach taken this research and allowed the testing of those the dynamics suggested a-priori within the literature review. The survey, shown in postal form at Appendix 6, contained a total of 112 questions, 8 of which gathered background information on the respondent and their company as well as their current and expected usage of BIM. As with the qualitative template / code book, the remaining 104 questions were developed directly from the potential dynamics identified, as illustrated at Figure 4.3 for the same dynamic as above, Industry Flexibility.

Q1. BIM is supported by the flexibility of the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Figure 4.3 – Example Question

These were both positively and negatively worded in equal proportions to avoid:

> … the tendency for respondents to agree with a statement, or respond in the same way to [different] items. (Rattray and Jones, 2005, p 237).

The development of the same number of questions and individual items within the coding frame, were the result of a conscious decision by the researcher to ensure that both methods adequately supported the research objectives, were of the same level of granularity, as well as facilitating the process of triangulation.

Given the opportunity for indifferent or neutral responses, the researcher accepted the recommendation of Grover & Vriens (2006) and used a response box with an odd number of categories to allow for these to be recorded. While an increased number of scale items allows for finer discrimination of responses, these authors also note that a large number can cause issues for respondents who "… cannot handle more than a few categories" (Grover and Vriens, 2006, p88). Based on this, along with negative feedback from respondents who completed the pilot questionnaire, which used nine scale items, the final questionnaire made use of seven scale items on a balanced scale. All questions also having the option of a "Not applicable" or "Don't know" response. This was on the basis that it provided a reasonable balance between granularity and response rates.

As with the SSI used for qualitative data capture, the questionnaire supports both the deductive approach to the study and generated data suitable for quantitative analysis, as one part of the mixed methods approach. In comparison to interview administered questionnaires, Sudman & Blair (1999) argue that this method reduces social desirability bias. From a more practical perspective, this method supports the generation of a higher response rate (Altschuld and Lower, 1984), ensuring the required sample sizes were met, and is widely recognised as being quicker and lower cost to administer. Hence, this aligned with the practical constraints of the study, while not undermining the purpose or methodological approach.

In common with the qualitative interview, provisional respondents were identified and contacted by phone to establish if they were willing to complete the questionnaire and if so, would they prefer to do this online and by post. Although there may be a perceived argument against mixing quantitative data collected both online and by post using a common instrument, a comprehensive meta-analysis of literature undertaken by Bowling (2005), failed to highlight any significant issues in the mixing of these particular approaches. This researcher is therefore of the view that the advantages of reaching respondents who may not be comfortable with or be able to use the internet, thus achieving a more representative sample, outweighs any potential issues.

For those who agreed to partake, a personalised e-mail or letter was sent (Appendix 7), with the latter including a hard copy of the questionnaire (Appendix 8) and a pre-paid return envelope, to the agreed address. A period of 14 days was allowed to elapse before a follow up e-mail or letter (Appendix 9) was sent to those respondents who had not returned the survey. After a further period of 14 days, those respondents who had still not completed the survey were noted, a replacement respondent was identified from the same sample segment and approached. The use of personalised invitations, a return envelope and polite follow up reminder were implemented to improve response rates.

4.5.4 Testing and Administration of Research Instruments

After drafting, both instruments were initially reviewed with two professionals with extensive BIM experience, one from the researchers' employer and the other from their wider professional network. After reading, the researcher described the individual dynamics of BIM that they aspired to measure to improve the content validity of the instruments (Bowling, 2002) resulting in a number of minor changes to both, based on the feedback.

Subsequently, both of these methods were piloted, as recommended by Rattray & Jones (2007), with a small number of respondents, four in the case of the questionnaire and two in the case of the semi structured interviews. This enabled the researcher to identify any unintended consequences of the questionnaire, the interview design and proposed techniques along with the initial coding template and code definitions. These pilots yielded valuable feedback and resulted in changes to the final instruments. Data from these pilots did not form part of the main dataset and to avoid the potential for any bias in responses, neither the two professionals who acted as reviewers nor pilot respondents were asked to respond to the main study.

4.5.5 Qualitative Analysis

As the first stage in analysis of the data itself, the researcher returned to each transcript and corresponding interview guide notes in turn to read and re-read it, thus ensuring full familiarity with the data as recommended by Braun and Clarke (2006). Four initial analyses were then carried out as follows:

1. Review of response rate: To confirm response rate was in line with expectations for this type of instrument.
2. Review of sampling accuracy: To ensure results were reflective of the UKCI.
3. Graphical analysis of BIM usage questions: To establish a profile of current BIM usage including BIM usage, time since adoption, percentage of work undertaken using BIM, sharing of BIM data and potential for increased usage.
4. Mapping of current BIM usage against Rogers's innovation adopter categories: To suggest which category the next adopters of BIM will fall into and therefore what characteristics these companies will have.

As deductive research, a template approach suggested by Crabtree and Miller (1999) using a-priori codes from a codebook was applied. This codebook, the development of which is described above and is shown at Appendix 6, reflected the 104 potential dynamics identified with the literature review. While this number of codes is higher than the 50 or 60 recommended for manual coding (Miles and Huberman, 1994), this number resulted from a decision to ensure that both methods were equally comprehensive and representative, of the same level of granularity and thus facilitated robust triangulation. This use of a codebook in this way also provided the researcher with "… a comprehensive map of the textual terrain …" (Braun and Clarke, 2006, p.144) thus enabling the researcher to focus on the research objectives and the identification of dynamics within the qualitative dataset, given the wealth of potentially distracting information available.

Based on the practical issues of manual coding with such a large codebook (Dyer and Singh, 1998), the advantages (Bryman and Bell, 2007) and suitability for application to mixed methods (Bazeley, 2002), the coding process was undertaken using computer aided qualitative data analysis software (CAQDAS). Despite a steep learning curve, Nvivo 8 was used, as this provided the required functionality and was available with extensive support at the researchers host institution. This provided an efficient means of coding and structuring of data, as well as allowing export of data to graphical packages such as Excel and Visio. While the researcher acknowledges that Nvivo aided the analysis process, they remained aware it would not undertake the analysis itself and were cognisant of its potential role as a distraction. Although potential dynamics were previously identified as either supporting or inhibiting BIM adoption, codes allocated included one of the following symbols to reflect whether the dynamic occurred in a supporting or inhibiting context within the data.

[+] - Dynamic mentioned as supporting the adoption of BIM.
[-] - Dynamic mentioned as inhibiting the adoption of BIM.

Although a template approach was applied, during coding it became apparent that a small number of additional dynamics also existed within the responses. In response, a smaller number of emergent codes were created in vivo to capture these.

Towards the end of the interview, respondents were asked directly if any of the dynamics they had discussed were thought to be particularly relevant to the type of company they worked for, i.e. Consultant, Main Contractor or Sub-Contractor, or to the size of company. These responses were analysed and relevant codes noted to suggest any variations in dynamics due to company type and size.

Finally, reflecting the suggestion that five key characteristics of any innovation "… help to explain their different rates of adoption" (Rogers, 2003, p15), the codes identified were applied to these characteristics and allocated nominal values of high, medium and low. In doing so, this enabled a number of observations to be made on how the adoption of BIM may be influenced by these.

4.5.6 Quantitative Analysis

To support the stated aims of the research, the same initial analyses of the quantitative data, were undertaken, again to establish the current level and any patterns of BIM usage and suggest the next category of BIM adopters against Rogers model.

Before discussing the testing of hypotheses, it is worth noting the current degree of debate within literature on the methods of analysis and reporting of individual Likert response variables. Discussion on the first point centres around the treatment of these variables as interval or ordinal scale items, with Jamieson (2004) arguing strongly for the latter, while Grace-Martin (2009) argue the application of parametric tests is appropriate in certain cases. On the second issue, Carifo & Perla (2007) argue against the analysis and reporting of individual Likert response variables, whereas Grace-Martin (2009) note this can be justified where a distinction is made between a “Likert scale” containing many items / responses, or an individual “Likert response variable”, as in this case.

Having weighed both sets of arguments, the researcher has chosen to treat the Likert response variables as interval data and will be reporting on the results of individual variables on the basis that: (i) Each item has 7 points with some indication that the intervals are approximately equal. (ii) The sample size is relatively large. (iii) These results form part of a wider qualitative analysis. (iv) Results are subject to methodological triangulation. (v) No major policy decisions are being made on the basis of the conclusions. (vi) The distinction between scales and variables has been made.

As an example within this study, this means that the response to Q1, the example question illustrated above, is treated as ordinal data with a value of 7 allocated to the response “Strongly Agree”, 1 allocated to the response “Strongly disagree” and intermediate integer values of 2 to 6 allocated to the respective intermediate responses. Parametric analysis in terms of calculation of mean value and ANOVA was then carried out on this variable, using on the data from all respondents to explore the particular dynamic, Industry Flexibility.

As the first stage in a more detailed statistical analysis of the quantitative data, the reliability of the scales used in the Likert responses variables were checked using Cronbach's alpha as a measure of internal consistency (Pallant, 2010) to ensure this value was adequate. Five initial hypotheses were then developed and tested to explore potential relationships between key variables and suggest any patterns of BIM usage and identify statistically significant dynamics.

The first hypothesis was set to test for any relationship between the size of company, as measured by turnover, and their usage of BIM.

The null hypothesis, $\mathbf{H_{o1}}$ was set as:

> There will be no relationship between the size of company and the percentage of work carried out using BIM.

The alternative hypothesis, $\mathbf{H_{A1}}$, was then set as:

> There will be a relationship between the size of company and the percentage of work carried out using BIM.

The second hypothesis was set to test for any relationship between the length of time BIM had been used and the percentage of work carried out using BIM.

The null hypothesis, $\mathbf{H_{o2}}$ was set as:

There will be no relationship between the length of time BIM has been used and the percentage of work carried out using BIM.

The alternative hypothesis, $\mathbf{H_{A2}}$, was then set as:

There will be a relationship between the length of time of BIM has been used and the percentage of work carried out using BIM.

The third hypothesis, was set to test any relationship between the length of time BIM has been used and the sharing of BIM data, with the null hypothesis $\mathbf{H_{o3}}$ being set as:

There will be no relationship between the length of time BIM has been used and the percentage of work carried out using BIM and the sharing of data with other companies.

The alternative $\mathbf{H_{A3}}$ hypothesis was then set as:

There will be a relationship between the length of time BIM has been used and the percentage of work carried out using BIM and the sharing of data with other companies.

To identify those dynamics of BIM adoption which were considered to be the most significant by respondents, the fourth hypothesis $\mathbf{H_{A4}}$, was set as:

The 95% lower confidence interval of the sample mean will be greater than the critical Likert response value (μ_0) for a neutral response.

The null hypothesis, $\mathbf{H_{o4}}$ was set as $\mu <= \mu_0$, with the alternative hypothesis $\mathbf{H_{A3}}$ of $\mu > \mu_0$. Where μ is the sample mean and μ_0 is the critical Likert rating. Given the 7 point Likert response used, with 4 representing the neutral response, μ_0 was given this value, such that a value >4 represented a perception of "somewhat agree", "agree" or "strongly agree".

To identify those dynamics of BIM adoption which were specifically not considered to be significant by respondents, the final hypothesis $\mathbf{H_{A5}}$, was set as:

> The 95% higher confidence interval of the sample mean will be lower than the critical Likert response value (μ_0) for a neutral response.

The null hypothesis, $\mathbf{H_{o5}}$ was set as $\mu => \mu_0$, with the alternative hypothesis $\mathbf{H_{A5}}$ of $\mu < \mu_0$. Where μ is the sample mean and μ_0 is the critical Likert rating. Given the 7 point Likert response used, with 4 representing the neutral response, μ_0 was given this value, such that a value <4 represented a perception of "somewhat disagree", "disagree" or "strongly disagree".

To establish if there was any variation in dynamics by company size or type, two one way between group analysis of variance (ANOVA) were carried out. To reduce the risk of a type 1 error[59] when carrying out multiple ANOVA, the researcher followed guidance by (Pallant, 2010), applying a Bonferroni adjustment which resulted in a more stringent alpha value as shown below.

Normal alpha value	(a):	0.05
Number of tests	(b):	2
New alpha value	(a / b):	0.025

To test for differences in population mean across each of these categories of respondents, the null hypotheses $\mathbf{H_{06}}$ (company size) and $\mathbf{H_{07}}$ (company type) stated that the sample means are equal across groups representing the company

[59] A type 1 error is the incorrect rejection of the null hypothesis. (Pallant, 2010)

characteristics, with the respective alternative hypotheses $\mathbf{H_{A6}}$ and $\mathbf{H_{A7}}$ stating there would be a statistically significant difference in the sample means across the groups.

Analysis of the Likert response data was undertaken using Exploratory Factor Analysis (EFA). This is a method available to reduce a large number of measured variables into a smaller number of related groups of variables, referred to as factors (Coakes, 2012) and was undertaken to test for any further potential underlying constructs which accounted for the results (Suhr, 2006) . This was undertaken using a three step technique (Pallant, 2010), starting with preliminary testing of the data to assess its suitability for EFA.

Finally, those Likert response variables with statistically significant results were mapped against the five key characteristics of innovation having the most influence on the rate of diffusion (Rogers, 2003) and as per the qualitative analysis, notional values of high, medium or low were applied to better suggest their impact on the rate of BIM adoption.

4.5.7 Triangulation

Within the field of social research, triangulation is a term with a variety of common uses. However, some of the earliest academics to apply the term describe how the application of multiple approaches can enable researchers to more accurately focus on the information they seek (Webb et al., 1966). More recently, triangulation is defined as “The use of more than one method or source of data in a study of social phenomenon …” (Bryman and Bell, 2007, p.733) enabling the findings to be “… cross checked”. Scott and Marshall (2009) build upon their description of triangulation as the use of multiple data sets or perspectives for research on a particular theme, to “complement and validate each other” (p.768) by arguing that triangulation is an approach often used to achieve “… more robust results”. Implicit within these definitions is the point that triangulation is more than just mixed methods, in that it also includes cross validation of two or more sets of results (Oppermann, 2000).

As an author who considered the problems of triangulation in social research, Blaikie (1991), notes that common themes in the application of triangulation are the desire to overcome issues of both validity and bias, as well as overcoming the deficiencies of a single research method. However, this author goes on to take a very strong anti-triangulation perspective, on the basis that different research methods have different ontological and epistemological underpinnings, which are fundamentally incompatible and should therefore not be mixed.

While Fielding and Fielding, are not against triangulation per se, they caution that:

> We should combine theories and methods carefully and purposefully with the intention of adding breadth and depth to our analysis but not for the purpose of pursuing “objective” truth (Fielding and Fielding, 1986, p.33).

All three of the above pro-triangulation arguments, were influential in the selection of this method as being appropriate to this research. In addition, the researchers stated position of pragmatism leads them to conclude Fielding and Fielding's statement above, supports the application of triangulation as used in this study. This position of pragmatism also negates, within the confines of this research, the arguments against triangulation noted above (Blaikie, 1991) on the basis that this is not to identify an objective "truth" per se, but to better understand the dynamics of BIM adoption, albeit in a way that applies more robust techniques than appear to have been applied in previous literature, where the vast majority have applied mono-methods. As a mixed methods study, this research applies methodological triangulation, which is described as the application of more than one research method to the subject of interest (Denzin, 1978), in this case qualitative and quantitative techniques.

To assist and provide a structure for the methodological triangulation of data, a conceptual model, illustrated at Figure 4.4, was developed which reflects the hypothetico deductive approach taken and identify the different categories of results that may arise from methodological triangulation.

The largest zone, labelled A and represented by the dashed line, contains the 104 suggested dynamics of BIM adoption identified within the literature review. In contrast, the smallest central zone, labelled B and shaded in orange represents convergent results which are supported by both the qualitative and quantitative methods, while zone C, shaded in blue represents those divergent results which are only supported within the quantitative analysis. Similarly, zone D, also shaded in blue, represents those divergent results which are only supported within the qualitative analysis. Finally, zone E, also shaded in blue indicates the final category of divergent results, those which lie outside the dynamics identified from literature, but have the potential to emerge from the qualitative analysis.

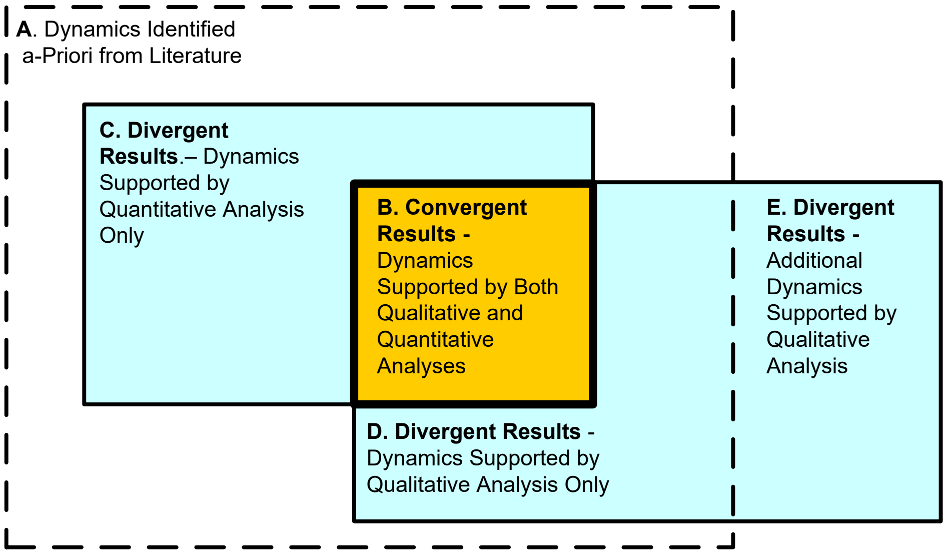

Figure 4.4 –Methodological Triangulation, Categories of Potential Results

4.6 Validity and Reliability

The importance of validity and reliability to research is succinctly captured by Morse et al. (2002, p.13), who note “Without rigor, research is worthless, becomes fiction and loses its utility”. This research has also been undertaken applying a positivist paradigm, with the aim of contributing to knowledge partially through addressing a lack of robustness perceived in previous literature.

Defined as “The effectiveness of a data collection instrument for taking accurate and consistent measurements of a concept” (Henn et al., 2009, p.336), reliability is a key criteria for positivist research and a pre-condition for validity. Within this study, reliability was critical in the development and testing of the questionnaire, semi structured interview guide and administration of both instruments, thus ensuring they are reliably measuring the concepts across the different respondents. Within the quantitative analysis, this was further confirmed through the calculation of Cronbach’s alpha.

Validity, defined by Scott & Marshall (2009, p.787) as "… a true reflection of attitudes, behaviours or characteristics", and Cook and Campbell (2000, p.37) as " … best available approximation to the truth or falsity of a given inference, proposition or conclusion," is a further key criteria for positivist research. For this study, validity is critical to the conclusions being an accurate representation of BIM adoption and is a measure of the degree to which the findings of this study can be generalised to the wider UKCI.

Therefore, throughout this research, a number of measures were applied to improve the validity and reliability, hence its credibility. Described throughout this thesis, these are collated and summarised for the convenience of the reader at Table 4.6.

<table>
<tr><th>Measure Applied</th><th>Location of Description</th><th>Rationale</th></tr>
<tr><td>Explanation of context to research.</td><td>Chapter 1, Section 1.4</td><td>Strengthens reliability by giving background which informed research and context within which the research is being undertaken.</td></tr>
<tr><td>Deductive approach.</td><td>Chapter 5, Section 5.4.1</td><td rowspan="2">Supports construct validity through application of theories relevant to the concepts.</td></tr>
<tr><td>Consideration of BIM as an innovation.</td><td>Chapter 1, Section 1.3.2</td></tr>
<tr><td>Declared insider researcher position.</td><td>Chapter 5, Section 5.3</td><td rowspan="2">Reduces perception of and potential for researcher bias by taking a neutral and balanced perspective.</td></tr>
<tr><td>Consideration of both supporting and inhibiting dynamic.</td><td>Chapter 5, Section 5.3</td></tr>
<tr><td>Mixed methods.</td><td>Chapter 5, Section 5.4.2</td><td>Overcomes issues associated with a single method and best supports the declared pragmatic paradigm.</td></tr>
<tr><td>Concurrent equal status mixed methods.</td><td>Chapter 5</td><td>Avoids bias from one method influencing the results of the other, thus improving validity.</td></tr>
<tr><td>Comprehensive description.</td><td>Chapter 5</td><td>Supports reliability by giving full and detailed visibility of the research methodology, sampling, data capture and analysis enabling a repeat study to be undertaken in future.</td></tr>
<tr><td>Sample size.</td><td>Chapter 5, Section 5.5.1</td><td>This was set in excess of literature recommendations for both two tailed hypothesis and saturation to increase the reliability of the results, with similar numbers of respondents within the three types of company type to support application of Anova and comparison of qualitative results.</td></tr>
</table>

Sample frame.	Chapter 5, Section 5.5.1	External validity strengthened by ensuring respondents are representative of the UKCI, as measured by output (£/pa)
Pre-testing of instruments.	Chapter 5, Section 5.5.4	Validity improved as feedback from expert peers was incorporated into the final instruments before application.
Qualitative analyses.	Chapter 5, Section 5.5.5	Issues of inter observer consistency were avoided as interviews, transcription and analysis were all undertaken by the researcher and a template coding frame was applied.
Quantitative analyses.	Chapter 5, Section 5.5.6	Chronbach's alpha was applied to test the internal reliability of the scales developed. Results were tested for statistical significance at 95% confidence level, a Bonferroni adjustment was applied and CFA undertaken.
Methodological triangulation.	Chapter 5, Section 5.5.7	Strengthens comparative reliability by cross checking results from two different sets of respondents gained using 2 different methods of data capture and analysis.

Table 4.6 – Methods Applied to Improve Research Validity and Reliability

While all of these are important to achieving validity and reliability, of particular significance to this study in terms of achieving this and setting it apart from previous literature are the sampling design, the application of concurrent equal status mixed methods and methodological triangulation. While the application of these were not without their issues, particularly in terms of meeting the sampling frame, developing knowledge of both qualitative and quantitative methods, plus the additional work required in comparison to a single method, they are in retrospect, justified in terms of the outcomes achieved.

4.7 Ethics

In developing a response to the ethical aspects of this study, the researcher has "… read and incorporated …" into the study " … the principles associated with at least one of the major professional associations mentioned" as recommended by Bryman & Bell (2007, p.148). This research has incorporated the Guidelines For Research (The Social Research Association, 2003), which provides a 14 point checklist. Prior to commencement, the researcher carried out a thorough evaluation of the proposed study against this list, which is shown at Appendix 3. The researcher also considered and incorporated the Key Principles of Good Practice (University of Huddersfield, 2011), as the host academic institution. Prior to data collection, the research proposal was also subject to formal scrutiny by the University of Huddersfield, Business School Ethics Committee using the prescribed process, and no ethical issues were raised.

Based on these evaluations and approval process, the researcher concluded that this research does not present any potential harm to respondents nor researcher, neither are there any particularly complex or contentious ethical issues.

4.8 Summary & Conclusion

This chapter provides detail of the research methodology and methods applied within this study, which was undertaken from a paradigm of pragmatism, an ontological position of objectivity and a positivist epistemological perspective. As a declared insider, the researcher applied concurrent equal status mixed methods along with methodological triangulation to ensure the results were robust. Stratified random sampling was applied to both methods to ensure respondents were representative of the UKCI, as measured by output, as well as being spread across large and small companies and roughly equal across the three main types of company: Main Contractors, Sub-Contractors and Consultants.

Qualitative data was captured using semi structured interviews held by phone , analysed using CAQAS (Nvivo) applying with the coding template developed from the 104 suggested dynamics of BIM adoption, arising from the literature review. Similarly, the suggested dynamics were used to develop an online and postal questionnaire to capture quantitative data, which included the use of 7 point Likert response items. This data was subject to graphical analysis followed by parametric statistical analysis using SPSS. Throughout the methodology section, a number of measures were described to ensure reliability and validity of the study. This was also subject to detailed ethical consideration and host institution approval, with no particularly complex or contentious ethical issues arising.

This study is significant in that it combines a range of techniques, which even when taken in isolation do not appear to be widely applied within previous studies, albeit they are applied within wider social research. Of particular note are the application of 2 dimensional stratified random sampling, robust sample sizes, concurrent equal status mixed methods and methodological triangulation. All of these support this study’s contribution to knowledge and differentiate it from much of the previous literature.

While one can only speculate on the apparent dearth of these methods within UKCI specific research, this may be related to the difficulty in achieving a representative sample in such a diverse sector, the technical (quantitative) focus of construction researchers which reflects their professional backgrounds and / or training, or the broader lack of value given to research within what remains a short term and cost focused industry. While these approaches were not without their practical challenges within this study, they strongly support the pragmatic approach applied, by means of the increased usefulness of the results and conclusions.

Chapter 5 - Results

5.1 Introduction

Following collection and analysis as described in the previous chapter, this is the first of the final three chapters covering the results, discussion of results, plus conclusion and contribution to knowledge.

While a detailed analysis of the qualitative data was undertaken and is presented at Appendix 10, with quantitative data as shown at Appendix 11, this chapter gives an overview of sampling accuracy and respondent profiles before presenting the outcome of methodological triangulation undertaken. This firstly examines the convergent results before moving onto a more limited number of divergent and contradictory results[60]. While the main aim of triangulation is to identify results supported by both methods, divergent and contradictory results are also reported for completeness.

Although both types of data capture were carried out concurrently and from the same positivist perspective, a decision was made such that the qualitative analysis was carried out before the quantitative analysis. This was to avoid the introduction of potential subjectivity and bias by the researcher, from the results of the latter to the former. Similarly, reflecting the positivist approach taking to this study, following coding and thematic analysis, the qualitative data was predominantly analysed and reported from a quantitative perspective to best support methodological triangulation.

[60] Convergent results are those supported by both methods, divergent results are only supported by a single method and in the case of contradictory results, the results of each method conflict.

5.2 Response Rate, Sampling Accuracy and Respondent Information

5.2.1 Qualitative Data

Between October 2013 and January 2014, 24 semi structured interviews were undertaken, a response rate of 17.6% of the 136 companies approached. A 93% match against the sampling frame was achieved, comprising 100% of consultants, 89% of main contractors and 88% of sub-contractors with detailed breakdowns illustrated within Appendix 8. The researcher does not view this as a significant variation from achieving a representative sample of the UKCI, given the small sample size and the large number of sampling categories containing a single respondent.

Interviews were recorded, generating just over 25 hours of spoken data, with an average interview duration of 64 minutes. Transcription by the researcher, using a combination of speech to text software followed by extensive cross checking and correction generated a significant amount of data, totalling some 188,923 words over 617 A4 pages.

5.2.2 Quantitative Data

During the same period and in parallel with the qualitative data capture, a total of 311 usable survey responses were obtained, resulting in a response rate of 15.4% of the 2109 companies approached. The respondents provided a close match to the sampling frame, as illustrated at Appendix 9, however, given the relatively large number of respondent (n=311) and small variance, the researcher does not consider this a significant deviation from a representative UKCI sample.

Despite the discarding of 15 postal questionnaires which were incorrectly completed, this resulted in the capture of a large quantitative dataset, comprising a 311 column x 112 row data matrix giving a total of 34,832 individual items of data, of which 32,344 were Likert response items relating to potential dynamics of BIM adoption.

However, following the preliminary testing described within Section A11.6 of the appendices, this data was found to be unsuitable for robust exploratory factor analysis and this analysis was therefore not carried out.

5.3 Convergent Results

5.3.1 BIM Usage

Reflecting the first research aim to establish the state of play of BIM in the UKCI, the analysis of the length of time BIM has been used for both methods are represented as line plots at Figure 5.1 below, with both sets of results showing a similar distribution of BIM usage. Circa 30% of respondents are currently not using BIM and the rate of BIM adoption has increased recently, with circa 40% of respondents adopting within the past 4 years and a smaller percentage of respondents, circa 20%, having used BIM for longer.

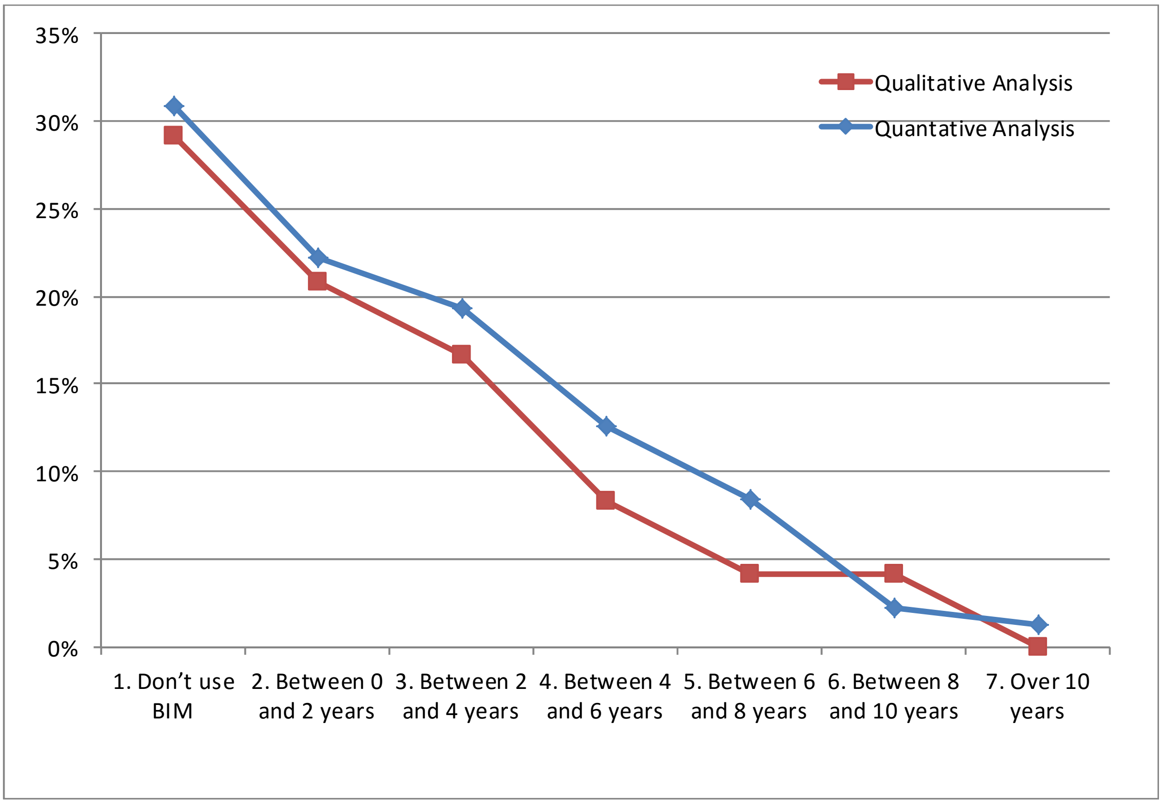

Figure 5.1 – Triangulation: Length of Time BIM has been Used

Similarly, the percentage of work undertaken using BIM, shown at Figure 5.2, indicates a similar distribution for both methods, albeit with a degree of variation between the analyses for the 1-25% range (Qualitative = 21%, Quantitative =14%) and 51% - 71% range (Qualitative = 8%, Quantitative = 15%) usage categories. These are convergent in terms of profile and distribution, with an overall trend that the number of respondents decreases as the percentage of work carried out using BIM increases.

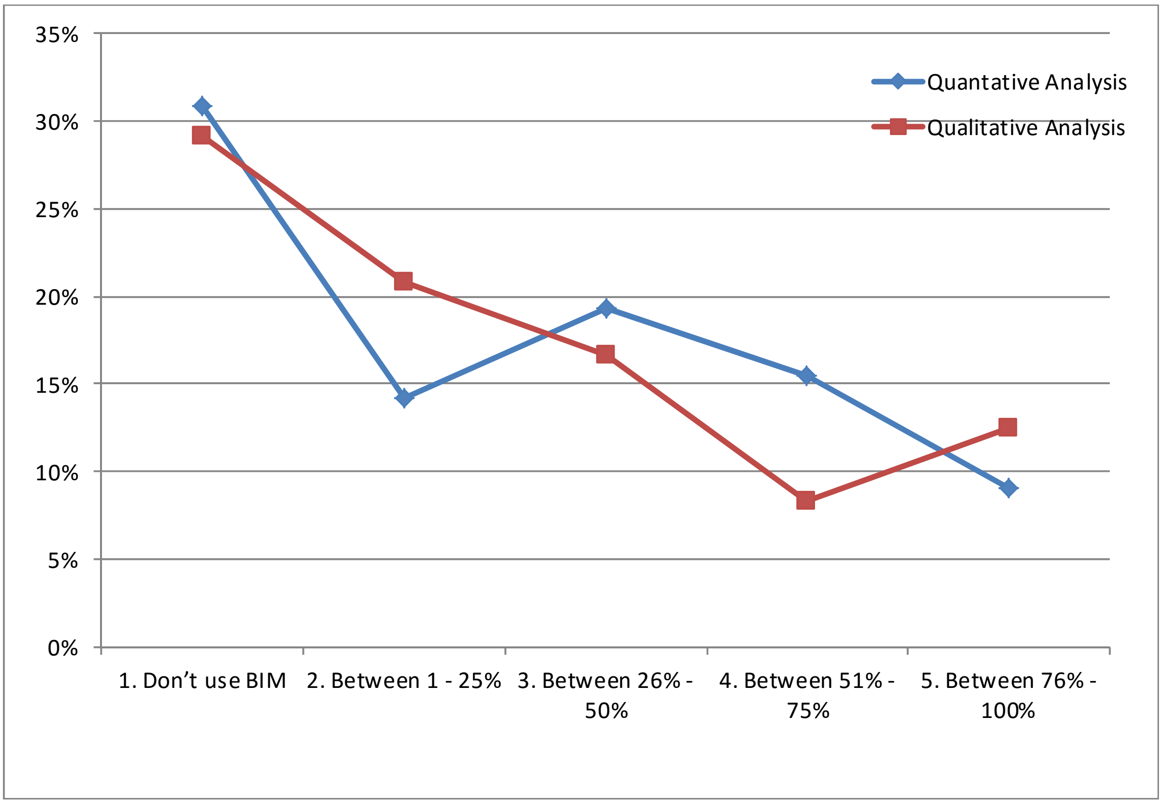

Figure 5.2 – Triangulation: Percentage Of Work Carried Out Using BIM

Figure 5.3 again illustrates convergent results across qualitative and quantitative results for the usage of BIM and transfer of data to 3rd parties, with closely matched profiles both indicating significant transfer of BIM data to other companies taking place, albeit with some difference in the 1-25% category (Qualitative=33%, quantitative = 27%) and scope for this to increase substantially.

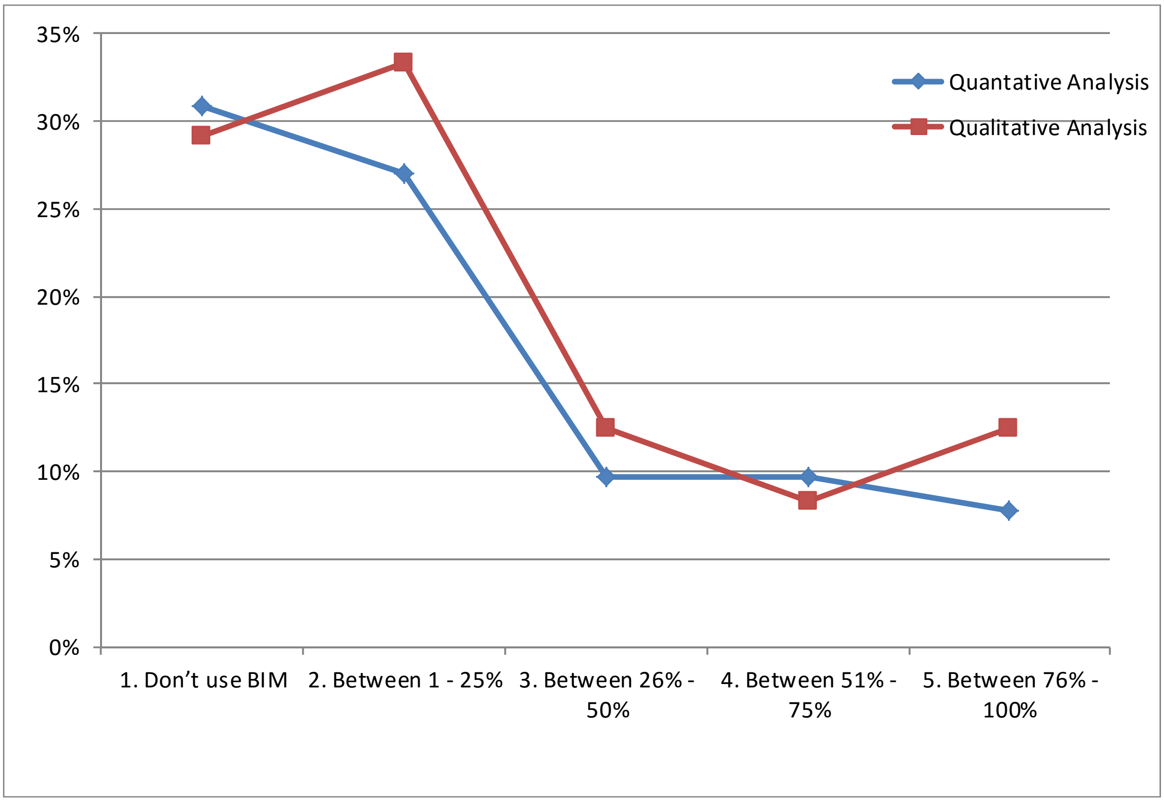

Figure 5.3 – Triangulation: Percentage Of Work Carried Out Using BIM and transfer of BIM data to other Companies

The final graphical analysis, examined the potential for work to be carried out using BIM, as illustrated at Figure 5.4 and again illustrates convergent results. When compared with existing usage statistics, this indicates the potential for a substantial increase in both the adoption of BIM per se and its utilisation. Nevertheless, there remain circa 10% of respondents who do not perceive any opportunity for the application of BIM.

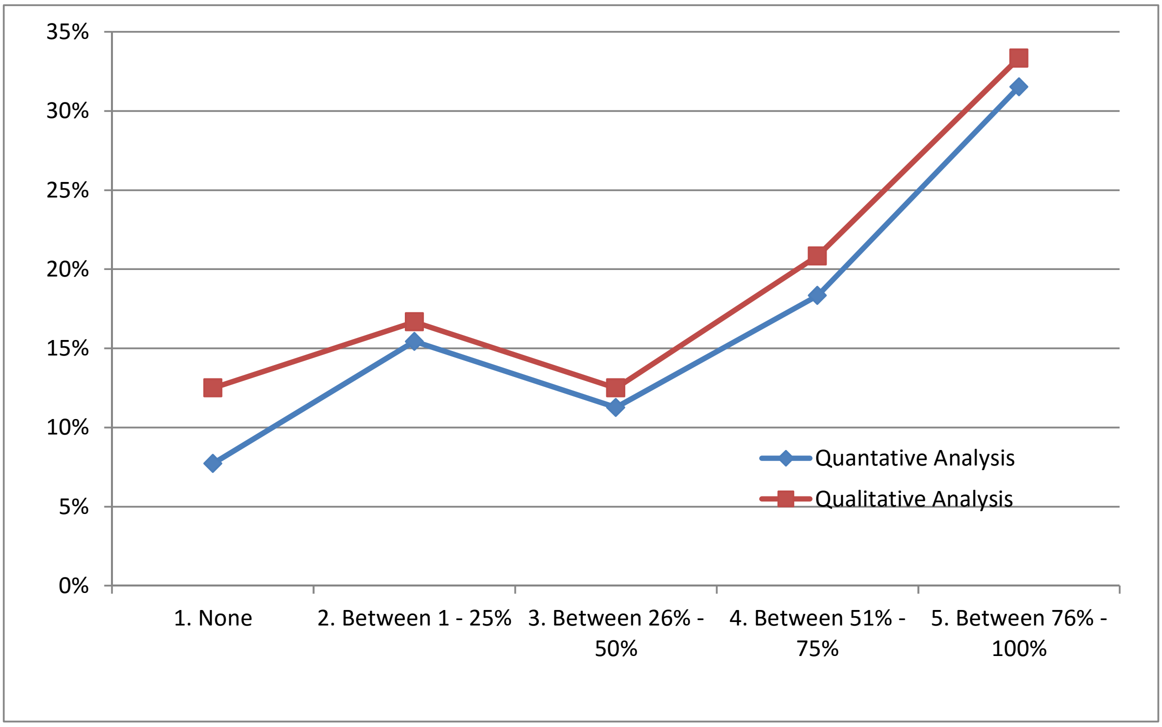

Figure 5.4 – Triangulation: Percentage of Work That Could Be Carried Out using BIM.

5.3.2 Company Size and BIM Usage

Both qualitative (inspection of tabular data) and quantitative (Chi-Square test) analyses indicated a positive relationship between the size of the company and their usage of BIM, with larger companies using BIM more than smaller companies.

5.3.3 Time Since Adoption and BIM Usage

When exploring any relationship between the time since adoption and BIM usage, both quantitative results (Chi-Square test) and qualitative results (examination of responses) suggest a positive relationship in which BIM usage (as a percentage of total work) tends to increase as time since initial adoption passes.

5.3.4 Time Since Adoption and Sharing of BIM Data

Finally, both analyses (Chi-square test and examination of responses) also indicated a positive relationship between the time since adoption and sharing of BIM data with other companies.

5.3.5 Mapping of BIM Usage against Innovation Adopter Categories

Using both quantitative and qualitative data, the current percentage of BIM adoption was analysed, with the results then applied to Rogers's (2003) innovation adopter categories. Both analyses, shown at Table 5.1, indicate all the next predicted adopters of BIM across the sample as a whole and the three categories of company being in the "Late Majority" category. Both analyses also showed a lower rate of BIM adoption for respondents employed by sub-contractors, approximately 10% below the sample average of 62%.

Category of Company	**Quantitative Analysis**		**Qualitative Analysis**	
	Current BIM Users (%age of potential BIM users).	**Innovation Adopter Category for next adopters.**	**Current BIM Users (%age of potential BIM users).**	**Innovation Adopter Category for next adopters.**
Whole Sample	62.7%	Late Majority	61.9%	Late Majority
Main Contractors	64.4%	Late Majority	66.7%	Late Majority
Sub-Contractors	53.8%	Late Majority	50%	Late Majority
Consultants	69.2%	Late Majority	66.7%	Late Majority

Table 5.1 – Triangulation: BIM Usage and Innovation Adopter Categories

5.3.6 Non-Adopters of BIM

The fact that 10% of respondents did not perceive any opportunity for BIM within their current company, was a surprise to the researcher and did not appear to align with Rogers's model as commonly presented. A decision was therefore made to vary the research from the planned design and explore this emergent result in more detail as it appeared significant. Respondents from both qualitative and quantitative methods who had given this answer were re-contacted by phone and e-mail and asked if they would be prepared to discuss this point further by telephone at a convenient time. A total of 3 respondents agreed to do so, and a very short semi structured interview was carried out with each to explore their reasons for this response. This followed the previous protocol in terms of timing, recording, transcription and checking. While not subject to methodological triangulation, their responses provide some interesting insights into this issue, with key aspects illustrated in responses below which fortunately were across all three categories of company:

> "For a typical job it'll be me, 2 lads and van –pen, paper, drawings if it's a bit complex, plus a mobile phone for urgent orders and queries …. That's just fine for us."
>
> Respondent **A** – Main Contractor

> "We have some lads working for us with years under their belt …. very good at their job, but I can't see em [sic] ever changing over to BIM."
>
> Respondent **K** – Sub Contractor

> "No need to … drawing by hand is so much a part of the design process and something I love …. we'll carry on doing that till we finish working."
>
> Responded **P** – Consultant

All of these reflect cultural aspects of the UKCI in terms of existing methods often being perceived as good enough and a resistance to change, irrespective of the potential benefits, both of which align with the researchers own professional experience. The third response illustrates the close, almost emotional link, felt by architects who see hand drawing as an inherent and enjoyable part of the creative design process, despite the availability of CAD and now BIM, which differ substantially from the way they may have been trained to work using pen and paper.

5.3.7 Dynamics of BIM Adoption

In reflection of the second stated aim of the research, to identify dynamics which support and inhibit the adoption of BIM, 45 dynamics of BIM adoption were identified during coding of the qualitative data. Analysis of the quantitative data, resulted in the identification of 38 significant dynamics of BIM adoption and 10 dynamics of BIM adoption, which respondents considered not relevant.

Convergent results were more limited, with 20 relevant dynamics and 3 dynamics considered not relevant, identified by both methods. To confirm the reliability between the different research instruments, a correlation analysis was undertaken for the 20 relevant dynamics, as shown at Table 5.2.

Correlations

		Quantitative	Qualitative
Quantitative	Pearson Correlation	1	.509*
	Sig. (2-tailed)		.022
	N	20	20
Qualitative	Pearson Correlation	.509*	1
	Sig. (2-tailed)	.022	
	N	20	20

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5.2 – Dynamics of BIM Adoption, Correlation of Convergent Results.

This revealed for the 20 relevant dynamics of BIM adoption, that the qualitative and quantitative results were significantly related, $r = .509, N = 20, p = 0.022$, indicating good validity between the two instruments used.

The dynamics are listed in order of statistical significance (quantitative analysis) at Tables 6.3 and 6.4, as well as being represented diagrammatically, organised around Rogers's model at Figure 5.5.

Dynamic	Quantitative Analysis – 95% confidence interval	Qualitative Analysis – no. of occurrences	Example Response	Impact on BIM Adoption (of results)
Government Mandate	5.79	8	"The industry needed a good kick up the arse [sic] …. it was only after the Government announcement [for use of BIM by 2016] that people started to take BIM seriously.. Respondent **E** - Main contractor	Support
Training Level	5.64	3	"…. the challenge is up-skilling [training] all our staff at a reasonable cost, while keeping the work rate up." Respondent **U** – Consultant	Inhibit
Staff Specialist	5.32	2	"We already struggle to find staff who are real specialists in our area [curtain walling: a type of cladding / glazing]. Good BIM skills as well is even more of a challenge." Respondent **L** – Sub Contractor	Inhibit
Cost Implementation	5.22	4	"It doesn't matter how good it [BIM] is ….. we struggle to provide our staff with a standard PC and Office software. Revit costs are out of our league." Respondent **M** - Sub Contactor	Inhibit
D&B Increase	5.17	4	"Doing a fully designed project is a real pain … D&B brings the design under our control much earlier … which is great for BIMing [sic]." Respondent **D** - Main Contractor	Support
Relationships Temporary	5.14	4	"Sharing our innovative design in a BIM format, to consultants who may be our competitors on the next projects, feels a bit like lending them our crown jewels." Respondent **S** – Consultant	Inhibit

Payback Short	5.1	2	"I'd love another BIM station but our FD [Financial Director] won't sign the PO [Purchase order] without proof of a quick return." Respondent **C** – Main Contractor	Inhibit
Competence Technical	5.05	1	"One of the hardest bits, I think….. um ….. is how to getting [sic] our supply chain up to speed …. and to our standard." Respondent **E** - Main Contractor	Inhibit
MacLeamy	4.95	4	"BIM's been great when we finally did it properly ….. up fronting the design effort meant we could look at radical options when it [The Design] was still fluid, and I hear we saved about £45K on the cladding as a result." Respondent **G** - Main Contractor	Support
Cost Plans Duration	4.89	2	"A pukka [sic] model means we can do an estimate take-off in days rather than weeks." Respondent **W** – Consultant	Support
Short Term Focus	4.87	1	"I'd love to implement BIM more, but it's all about the profit this quarter, forget the longer term." Respondent **E** - Main Contractor	Inhibit
Complexity	4.86	3	As specialists in a niche market, we've seen a few presentations and been to some big seminars, but it just looks, erm really difficult …. almost byzantine." Respondent **P** – Consultant	Inhibit
Construction Cost	4.85	4	See quotation above from Respondent G.	Support
Co-ordination Different Companies	4.85	2	"One of the hardest bits, I think….. um ….. is how to getting [sic] our supply chain up to speed, all linked up …." Respondent **E** - Main Contractor	Inhibit
Design Change Cost Effective	4.81	3	See quotation above from Respondent G.	Support

Cash Flow	4.81	2	“The main difficulty for us is financial. Increasing the number of BIM seats to what we’d like would cost a bomb. At the moment we’re still struggling to pay the staff every month.” Respondent **Q** – Consultant	Inhibit
Construction Duration	4.73	2	“The job with the cladding I mentioned earlier ….. the PM [project manager] told me that one change shaved 4 weeks off the site time.” Respondent **G** - Main Contractor	Support
Industry Practices Robust	4.65	4	“I’m working for a company that can trace its origins to the 1880’s. It does OK but is always very measured when making any changes in the way it does things.” Respondent **E** – Main contractor.	Inhibit
Company Survival.	4.23	3	“It [BIM] all sounds great, but our priority is keeping our heads above water. So many of our competitors have come to grief in the past year.” Respondent **K** - Sub Contractor	Inhibit
Separation Traditional Procurement	4.15	1	“On one traditionally tendered job, we had to pay an extra 25 thou [Thousand] for the design team to BIM up all the work the client’s design team had done to date on CAD and in word documents.” Respondent **F** - Main Contractor	Inhibit

Table 5.3 – Convergent Results, Relevant Dynamics of BIM Adoption

Dynamics	Quantitative Analysis – 95% confidence interval	Qualitative Analysis – no. of occurrences	Example Response	Impact on BIM Adoption (of results)
Trialability	3.26	2	“It all looks good on paper, but not really being able to ‘try before you buy’ [sic] put back our first purchase of BIM for about a year.” Respondent **T** - Consultant	Inhibit
Design Team Size	3.18	2	“Not from our perspective … we’re just expected to do more work, more detail …. all for less fee.” Respondent **W** - Consultant	Inhibit
Demand Uncertain	3.07	2	“Anyone in main contracting who hasn’t been asked to do BIM must have had their head … where the sun don’t shine [sic].” Respondent **F** – Main Contractor	Support

Table 5.4 – Convergent Results, Dynamics of BIM Adoption – Not Relevant

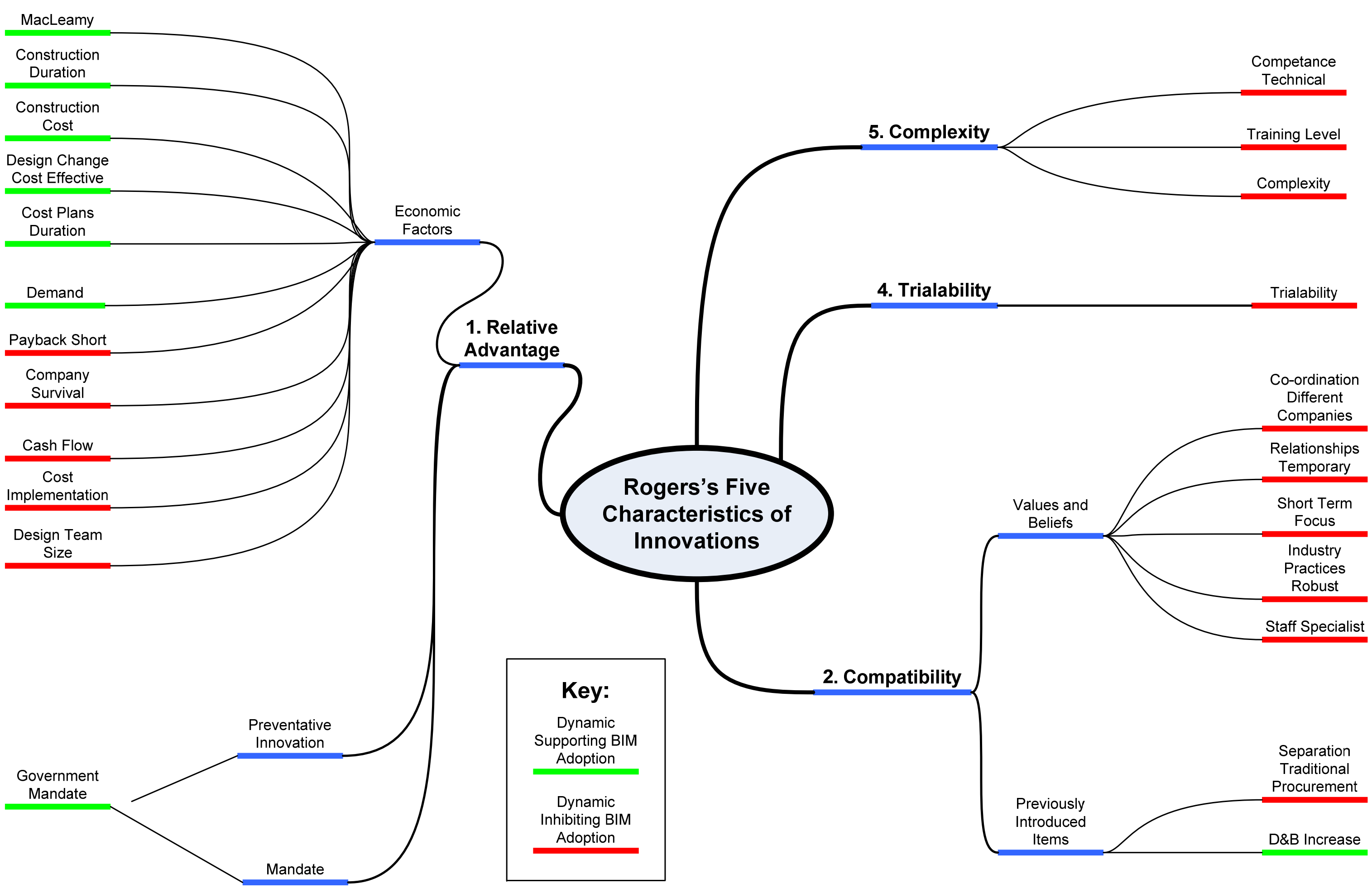

Figure 5.5 – Convergent Results, Dynamics of BIM Adoption

For the three dynamics identified as not being relevant to BIM adoption, the fact that these have a mean Likert scale value below 4, the level set for “Neither agree nor disagree”, plus the content of the qualitative responses cited have lead the researcher to categorise Trialability and Design Team Size as inhibiting dynamics and Demand Uncertain as a supporting dynamic. Therefore from the triangulated results, a total of 23 dynamics of BIM adoption were identified and are discussed in detail in the next chapter.

5.3.8 Variations in Dynamics by Company Size

To support the third research aim, the identification of any variation in dynamics by different company sizes and types, triangulation of the results for the effect of company size, identified limited convergent results with only 3 dynamics supported by both analyses, shown at Table 5.5.

Dynamic	Category of Turnover Most Relevant To	Impact on BIM Adoption (of results)	Other Notes
Cost Implementation	Lower Turnover	Inhibit	(Mean Likert response = 6.252 against 4.695 for Higher Turnover). "It's all right for the big boys, as an SME at the sharp end there's no spare cash for more BIM." Respondent **J** – Sub contractor.
Collaboration Platform	Higher Turnover	Support	Mean quantitative results for Lower Turnover respondents were below critical Likert threshold of 4.0 (3.086 - indicating disagreement) and above for Higher Turnover (4.475 - indicating agreement). "As a large practice, all using BIM we can co-ordinate complex 3D designs almost in real time with our engineers." Respondent **X** – Consultant
Government Mandate	Higher Turnover	Support	(Mean Likert Response = 6.505 against 5.581 for Lower Turnover). "For us and the other tier ones, the … erm. 2016 deadline has been by far the biggest driver." Respondent **F** – Main Contractor

Table 5.5 – Convergent Results, Effect of Company Size on Dynamics

5.3.9 Variations in Dynamics by Company Type

Again supporting the third research aim, the identification of any variation in dynamics by different company sizes and types, triangulation of the results for the effect of company size, identified limited convergent results, with only 4 dynamics supported by both analyses, shown at Table 5.6.

Dynamic	Category of companies most relevant to.	Impact on BIM Adoption (of results)	Quantitative results and qualitative response.
Industry Practices Robust	Main Contractors	Inhibit	Mean Likert response for Main Contractors was **5.469** against **4.159** for Sub Contractors. "I'm working for a company that can trace its origins to the 1880's. It does OK but is always very measured when making any changes in the way it does things." Respondent **E** – Main contractor
Cost Implementation	Sub-Contractors	Inhibit	Mean Likert response for Sub contractors was **6.029** against **4.700** for Main Contractors. "Small subbies like us don't have the dosh [sic]… not like the big boys." Respondent **J** – Sub contractor
Company Survival	Sub-Contractors	Inhibit	Mean Likert response for Sub Contractors was **4.955** (indicating **agreement**) against **3.274** for Main Contractors (indicating **disagreement**) ""… but our priority is keeping our heads above water. So many of our competitors have come to grief in the past year … us subbies are having it really tough." Respondent **K** – Sub contractor
Complexity	Sub-Contractors	Inhibit	Mean Likert response for Sub Contractors was **5.519** against **4.555** for Consultants. "Our staff are already highly specialist in our area.... BIM is really problematic…. I mean it's just seems so much more complicated." Respondent **L** – Sub contractor

Table 5.6 – Convergent Results, Effect of Company Type on Dynamics

The number of convergent results for the effect of company type or size on dynamics was lower than the researcher expected, but may have arisen for a number of reasons. The UKCI is a large sector with many different types and sizes of company and it may be that the highly varied circumstances of individual companies means the limited number of categories, 3 in terms of company type and 2 in terms of company size, were insufficient from a methodological perspective. An alternative explanation, is that the process of methodological triangulation generated a Type II error, i.e. a false negative, resulting in the discarding of valid variations which occurred in either the qualitative or quantitative results, but not both.

5.3.10 Suggested Characteristics of BIM

Both analyses of Rogers's five characteristics of innovations, indicate convergent results. As illustrated at Table 5.7, the rate of diffusion is supported by high (quantitative analysis) and medium (quantitative analysis) levels of relative advantage, however, it is inhibited by only a medium level (qualitative analysis) and low (quantitative analysis) of observability and low levels of trialability and compatibility, plus a high level of complexity (both analyses).

Characteristic of BIM	Relative Advantage	Compatibility	Complexity	Trialability	Observability
Allocated Notional Value – Qualitative Results	Medium	Low	High	Low	Not applicable
Allocated Notional Value – Quantitative Results	High	Low	High	Low	Low

Table 5.7 – Triangulation, Characteristics of BIM

The convergent dynamics illustrated above, also support the categorisation of BIM (Table 5.8) by the researcher under the following frameworks, introduced above in the literature review.

Author	Category	Rationale for Categorisation.
(Slaughter, 1998)	System Innovation.	Presence of dynamics: • A degree of technical competence across the whole project. • A high degree of co-ordination across different companies.
(Lim and Ofori, 2007)	Innovations that reduce contractors' construction costs.	Presence of dynamic: • Reduced construction costs of projects.

Table 5.8 – Triangulation, Categorisation of BIM

Surprisingly, the results did not indicate that BIM was an unbounded innovation (Harty, 2005), where the implications are likely to be outside the sphere of influence of any one party on project, although this does appear as a divergent result below.

5.4 Divergent Results

Inherent to the application of methodological triangulation are the identification of results supported by both methods. For completeness, the divergent results illustrated within the model at Figure 5.4 are also reported below.

5.4.1 Dynamics of BIM Adoption

22 dynamics occurred within the qualitative analysis only, including the 5 dynamics created in-vivo, and are shown at Table 5.9.

Dynamics	Qualitative Analysis – no. of occurrences.	Impact on BIM Adoption (of results)
Relationships Within Industry	5	Inhibit
Collaboration Culture	4	Inhibit
Industry Recession	3	Inhibit
Collaboration Platform	3	Support
Design Time	3	Support
Intellectual Property	3	Inhibit
Project Focus	2	Inhibit
Hardware New Specialist	2	Inhibit
Management Supportive	2	Support
Design Team Novation	2	Support
Design Team Focus	2	Support
Life Cycle Information	2	Support
Systems Open	2	Support
Exchange Formats Neutral	2	Contradictory Quotes
Relationships Supply Chain	2	Support
Legal Issues	2	Inhibit
Adoption Risk	1	Support
Company Nature	1	Support
Life Cycle Cost	1	Inhibit
Projects Sustainable	1	Support
Existing Methods Sufficient	1	Inhibit
Industry Initiatives	1	Inhibit

Table 5.9 - Divergent Results, Dynamics of BIM Adoption, Qualitative Analysis only.

Provided below are responses relevant to three of these dynamics:

Collaboration culture:

> "Working as a team is all well and good, but at the first hint of any problems, you know you're going to be wasting time chasing that next payment."
>
> Respondent **O** - Sub-Contractor

Management Supportive:

> “No if, no buts …. management made the choice [to use BIM] and are driving 100% adoption …. right from the top.”

Respondent **V** - Consultant

Industry Initiatives:

> “CAD, Partnering, Health and Safety, Project Management and now BIM. All of these so called initiatives promise results, but as an industry we still struggle to deliver what our clients are demanding.”

Respondent D – Main Contractor

Similarly, 18 relevant and 7 non relevant dynamics were supported by the quantitative analysis only, as shown below at Tables 5.10 and 5.11.

Dynamics	Quantitative Analysis – 95% confidence interval	Impact on BIM Adoption (of results)
Change Resistant	5.39	Inhibit
Decision Start Project	5.29	Inhibit
Use Benefit Level	5.21	Support
Design Information Quality	5.09	Support
Influence Client Requirements	5.07	Support
Early Client Mandate	4.96	Inhibit
Relationships Cross Project	4.96	Support
Lowest Cost Focus	4.94	Inhibit
Software Investment	4.87	Inhibit
Infrastructure High Speed	4.83	Support
Site Variations	4.81	Support
Industry Fragmentation	4.76	Inhibit
Control Span Of	4.76	Inhibit
Quality of Design	4.72	Support
Contract Prescriptive	4.68	Inhibit
Company Stability	4.52	Inhibit
Traditional Procurement Decline	4.39	Support
Company Leadership	4.21	Inhibit

Table 5.10 – Divergent Results, Dynamics of BIM Adoption, Quantitative Analysis only.

Dynamics	Quantitative Analysis – 95% confidence interval	Impact on BIM Adoption (of results)
Management Supportive	3.55	Inhibit
Research Academic	3.47	Inhibit
Observability	3.36	Inhibit
Industry Improvement Recognition	3.31	Inhibit
Project Focus	3.3	Inhibit
Use Benefit Level	3.26	Inhibit
Relationships Within Industry	3.21	Inhibit

Table 5.11 – Divergent Results, Dynamics of BIM Adoption - Not Relevant, Quantitative Analysis only.

The researchers suggestion above that a Type II error may have occurred as a result of methodological triangulation is supported by the fact that 5 of the dynamics from the quantitative results only had a mean Likert scale value of greater than 5, which represented somewhat agree, while 6 of the dynamics from the qualitative results only had more than 2 occurrences. Alternatively, these may have arisen due to differences in the two research instruments used, albeit the correlation analysis for the 20 significant dynamics from the convergent results, indicated validity was good. However given the researchers stated aim of providing robust results, these may simply be the consequence of robust methodological triangulation and as the impact of Type II errors (false negatives) are more limited than those of Type I errors (false positives) on the research outcomes, the researcher does not consider these detract significantly from the aims of this study.

5.4.2 Variations in Dynamics by Company Size

Divergent results were obtained for 22 dynamics, with 9 of these being indicated only by the quantitative results, Table 5.12, and 13 only by the qualitative results, Table 5.13.

Dynamic	Category of Turnover Most Relevant To	Impact on BIM Adoption (of results)	Other Notes
Lowest Cost Focus	Lower Turnover	Inhibit	(Mean Likert Response = 4.571 against 5.722 for higher Turnover)
Supply Chain Risk Transfer	Lower Turnover	Inhibit	Mean quantitative results for lower turnover respondents were above the critical threshold of 4.0 (4.492 - indicating **agreement**) and below for higher turnover (3.790 - indicating **disagreement**)
Systems Bespoke	Lower Turnover	Inhibit	Mean quantitative results for lower turnover respondents were below above threshold of 4.0 (4.336 - indicating **agreement**) and below for higher turnover (3.682 - indicating **disagreement**)
Relationships Cross Project	Lower Turnover	Support	(Mean Likert Response = 4.651 against 5.719 for Higher Turnover)
Trialability	Lower Turnover	Inhibit	(Mean Likert Response = 2.471 against 3.567 for Higher Turnover)
Collaboration Company Types	Higher Turnover	Support	Mean quantitative results for lower turnover respondents were below critical threshold of 4.0 (3.403 - indicating **disagreement**) and above for higher turnover (4.471 - indicating **agreement**)
Request For Information	Higher Turnover	Support	Mean quantitative results for lower turnover respondents were below critical threshold of 4.0 (3.086 - indicating **disagreement**) and above for higher turnover (4.475 - indicating **agreement**)
Effort can be concentrated to when it has the most impact on the project	Higher Turnover	Support	(Mean Likert Response = 5.694 against 4.305 for Lower Turnover)
Tangible financial benefits	Higher Turnover	Support	Mean quantitative results for lower turnover respondents were below critical threshold of 4.0 (3.272 - indicating **disagreement**) and above for higher turnover (4.517 - indicating **agreement**)

Table 5.12 – Divergent Results, Effect of Company Size on Dynamics, Quantitative Analysis only

Dynamic	Category of Turnover Most Relevant To	Impact on BIM Adoption (of results)	Other Notes
Industry Recession	Lower Turnover	Inhibit	Cited as relevant by one or more respondents within each category.
Capital Availability	Lower Turnover	Inhibit	
Design Team Novation	Lower Turnover	Support	
Design Team Focus	Lower Turnover	Support	
Complexity	Lower Turnover	Inhibit	
Training Level	Lower Turnover	Inhibit	
Staff Specialist	Lower Turnover	Inhibit	
Management Supportive	Higher Turnover	Support	Cited as relevant by one or more respondents within each category.
MacLeamy	Higher Turnover	Support	
Construction Cost	Higher Turnover	Support	
Construction Duration	Higher Turnover	Support	
Company Policies	Higher Turnover	Support	
Intellectual Property	Higher Turnover	Inhibit	

Table 5.13 – Divergent Results, Effect of Company Size on Dynamics, Qualitative Analysis only.

As examples, the relevance of the dynamic, Lack of Capital to smaller companies is illustrated by the following response:

“Small subbies like us don’t have the dosh [sic]… not like the big boys.”

Respondent **J** – Sub contractor

While the dynamic, Company Policies being more relevant to larger companies is illustrated by:

“Like many tier one [indicating the largest companies within the UKCI] main contractors, BIM is now completely integrated into our policies and QA [Quality Assurance] system.”

Respondent **F** – Main Contractor

5.4.3 Variations in Dynamics by Company Type

Divergent results were obtained for 17 dynamics, with 5 of these being indicated solely by the quantitative results and 12 solely by the qualitative results, shown at Tables 5.14 and 5.15 respectively.

Dynamic	Category of companies most relevant to.	Impact on BIM Adoption (of results)	Other Notes
Reduced site led change orders	Main Contractors	Support	Mean Likert response for Main Contractors was **5.711** against **4.978** for Consultants.
Benefits reflect investment	Sub-Contractors	Inhibit	Mean Likert response for Sub Contractors was **2.406** against **3.235** for Consultants and **3.637** for Main Contractors.
Smaller design team.	Consultants	Inhibit	Mean Likert response for Consultants was **2.546** against **3.511** for Main contractors.
Multiple project relationships	Consultants	Inhibit	Mean Likert response for Consultants was **2.670** against **2.981** for Sub Contractors and **3.812** for main contractors.
Designing at risk for tender.	Consultants	Inhibit	Mean Likert response for Consultants was **4.432** (indicating **agreement**) against **3.530** for main contractors (indicating **disagreement**).

Table 5.14 – Divergent Results, Effect of Company Size on Dynamics, Quantitative Analysis only.

Dynamic	Category of companies most relevant to.	Impact on BIM Adoption (of results)	Other Notes
Demand Uncertain	Main Contractors	Support	Cited as relevant by one or more respondents within each category.
Design Team Focus	Main Contractors	Support	
Company Policies	Main Contractors	Support	
Industry Recession.	Sub-Contractors	Inhibit	
Cost Plans Duration	Sub-Contractors	Support	
Collaboration Culture	Sub-Contractors	Inhibit	
Exchange Formats Neutral	Consultants	Support	
Intellectual Property	Consultants	Inhibit	
Collaboration Platform	Consultants	Support	
Project Duration	Consultants	Support	
Training Level	Consultants	Inhibit	
Staff Specialist	Consultants	Inhibit	

Table 5.15 – Divergent Results, Effect of Company Size on Dynamics, Qualitative Analysis only.

As examples, the relevance of the dynamic, Neutral Exchange Formats to Consultants, is illustrated by the following response:

> "For us designers, definitely the use of IFC [a vendor neutral exchange format] …. this means we can swap data with most of [the] systems out there."

Respondent **U** - Consultant

While the dynamic, Design Team Focus, being most applicable to Main Contractors, is supported by the response:

> “With all three contractors [Main Contractors] I’ve worked for ….. I’ve seen the designers using it [BIM} ….. and knuckle down to design rather than wasting time co-ordinating documents”.
>
> Respondent **E** – Main Contactor

5.5 Contradictory Results

Although not represented in the categories of triangulation illustrated in the previous chapter, a small number of contradictory results arose from the two results and are reported below for completeness.

5.5.1 Variations in Dynamics by Company Size

Contradictory results were obtained for a single dynamic: Existing Industry Practices Robust, where the quantitative analysis indicated this was more relevant to companies in the lower turnover category[61], but was felt to be relevant to respondents in both categories within the qualitative analysis.

5.5.2 Variations in Dynamics by Company Type

Contradictory results were obtained for a single dynamic, Project Focus where this was indicated as being most relevant to main contractors within the quantitative analysis, but to consultants[62] within the qualitative analysis, as illustrated in the following response:

> “Our [main] contractor clients’ can call the shots and the rest of the team …. has to fall into line if …. erm [sic] they want the work …. for us, each new project ends up on a learning curve.”

[61] Mean difference between categories of 1.389 at $p=0.008$.
[62] $\mu=3.812$, $SD=1.631$.

Respondent **Q** - Consultant

5.6 Summary of Results

Analysis of the data combined with the application of methodological triangulation has produced a range of empirically supported insights into the adoption of BIM within the UKCI. These appear to be robust from a methodological perspective, albeit from divergent results, the researcher acknowledges the risk of Type II (false negatives) errors taking place. These results are summarised below in order of their suggested importance. Given the large amount of data generated, the researcher acknowledges that this analysis has been limited to that which supports the original aims and objectives of the study. There is clearly scope for further analysis of this dataset, including from a positivist perspective, the manual cross correlation of dynamics[63] to identify any further patterns in the data. The researcher plans to undertake these as part of their subsequent research activities.

The research has identified a total of 23 dynamics of BIM adoption within the UKCI, with supporting dynamics[64] appearing mostly within the characteristic Economic Factors, with a lower number of inhibiting dynamics relating to adoption costs and financing[65] also present in this characteristic. Dynamics within the characteristics Complexity and Compatibility were all inhibiting, as was the single dynamic within Trialability. The most significant supporting dynamic was the Government's mandate for BIM use by 2016[66] and the most significant inhibiting dynamic was the level of training required to implement BIM[67].

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[63] As the quantitative data was found to be unsuitable for EFA.
[64] Dynamics: MacLeamy, Construction Cost, Design Change Cost Effective, Construction Duration and Cost Plans Duration.
[65] Dynamics: Cost Implementation, Payback Short, Company Survival and Cash Flow.
[66] Dynamic: Government Mandate.
[67] Dynamic: Training Level.

Based on current level of BIM adoption (circa 62% of the sample), the next adopters of BIM are likely to be in Rogers's (2003) "late majority" category of innovation adopters. Interestingly and surprisingly to the researcher, circa 10% of respondents do not see BIM as relevant for their work at all, indicating they may never adopt it.

Applying Rogers's generic characteristics of innovations, the adoption of BIM is supported by a medium / high relative advantage, but impeded by a low level of compatibility, low level of trialability, medium / low levels of trialability and a high level of complexity. Under the framework developed by Slaughter (1998), the results support the categorisation of BIM as a System Innovation, and, using the framework developed by Lim and Ofori (2007), as an innovation that reduces contractors construction costs.

Differences in the results for different sizes of company, demonstrate the cost of BIM is a more significant inhibiting dynamic for smaller companies, while the supporting dynamics Government Mandate and advantages of BIM are more significant to larger companies. Similarly, differences between results for different types of company show that the robustness of existing practices is a more significant inhibiting dynamic to Main Contractors, while the cost of BIM, company survival and complexity of BIM are more significant to sub-contractors.

A total of 22 relevant dynamics of BIM adoption were identified within the qualitative analysis only, with 18 found within the quantitative results only. Also, within the quantitative only results were 7 dynamics found to be not relevant. A single contradictory result occurred with the variation of dynamics by company size and one within the variations in dynamics by company type. Returning to the different categories of results illustrated at Figure 5.4 within the Methodology chapter, this distribution of dynamics within this model, following methodological triangulation are illustrated at Figure 5.6.

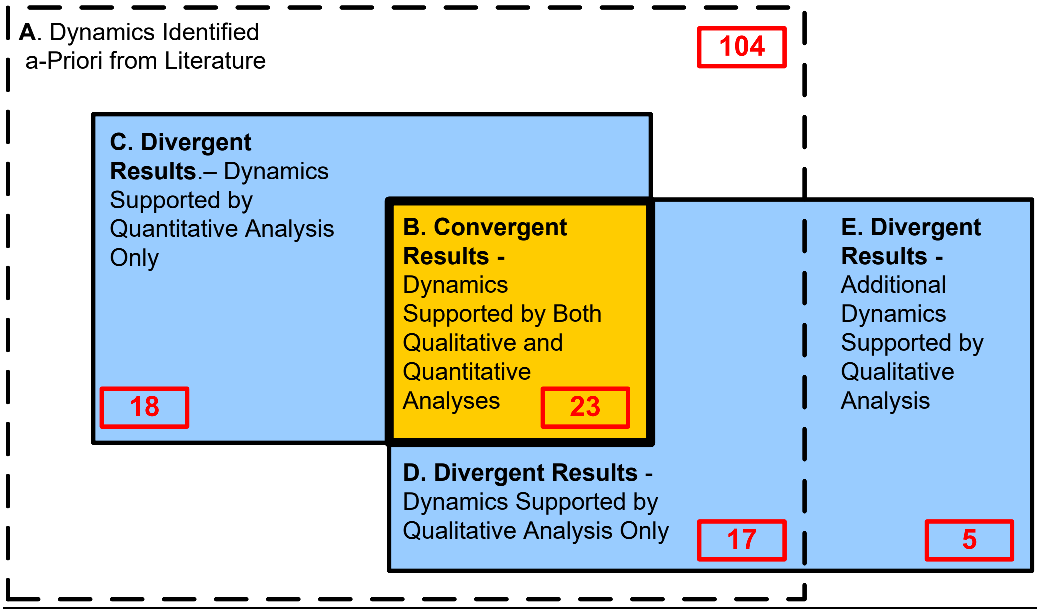

Figure 5.6 - Triangulation, Distribution of Results

Chapter 6 – Discussion of Results

While the previous chapter summarised the results of this research, this chapter presents a debate and discussion of these, including areas of particular interest. Results are related to literature, theory and practice, as well as identifying limitations of this research and suggesting ways in which others may research BIM in future.

6.1 Current Levels and Patterns of BIM Adoption

Although considered an innovation for the purposes of this research, following direct questioning of respondents, the results indicate BIM adoption has been significant, with circa 60% of respondents currently using it. Adoption rates have increased substantially in the past four years, with 40% of respondents (circa 65% of those who use BIM) having adopted within this period. This may be a reflection of the Government's announcement on the use of BIM by 2016, which in turn is reflected in the dynamic: Government Mandate, being the most significant supporting dynamic within the results. This announcement resulted in a large amount of publicity within the UKCI about BIM, raising awareness and from the researcher's own experience, has led to a number of companies adopting BIM, not because they believe in the benefits, but because they do not wish to be prevented from delivering public sector projects as illustrated in the following from respondent **F**, a Main Contractor.

> "Are we doing BIM because it brings benefits, I dunno [sic] …. what I do know is that if we don't do BIM in 2016 we can say bye-bye to most of our market [Public Sector Projects]."

While this dynamic has been categorised by the researcher as a preventative innovation, which are noted by Rogers as generally having a slow rate of adoption these results illustrate this is not the case for BIM. Potential reasons for this include the importance of public sector work to the UKCI, the importance of this work to construction companies during a significant recession and the relatively short timescale for the introduction of BIM.

For those who have adopted BIM, the results demonstrate scope for an increase in utilisation in terms of the percentage of total work carried out using BIM. While around 10% of respondents use BIM for between 75% - 100% of their work, 17% only use it for between 1% - 25% of their work. This may be due to the relatively recent adoption of BIM within the company, as discussed above, meaning that its application is currently limited by a lack of skills, realisation of the benefits or a lack of integration into wider processes. This may also be influenced by the cost of BIM, identified as a significant dynamic below, which may lead companies to phase implementation over a number of years, as a way to spread the cost, and change in processes, as well as reducing any disruption to day to day activities. The level of training required and need for specialist staff, also identified below, may also inhibit the wider application of BIM within a company, following its initial adoption.

Finally, although untested within this study, it is worth considering that certain specialist activities within the UKCI may remain unsuited to BIM. These could include legacy computer controlled manufacturing systems used by sub-contractors or highly specialised analysis packages used by disciplines such as acousticians or fire engineers, which do not yet allow the import of BIM data.

Similarly, the results indicate the potential for an increase in sharing of BIM data with only 10% of respondents using BIM and sharing data for 75% - 100% of their work, increasing to 30% in the 1% - 25% category. From this, the researcher concludes that the full benefits of BIM as a collaboration tool are not yet being realised, because data is not being shared fully, possibly as a result of concerns about legal issues and intellectual property, along with issues with data transfer between different systems, all of which are discussed below.

6.2 Innovation Adopter Categories

Applying adoption results on BIM usage with the 5 categories of innovation adopters (Rogers, 2003) indicates the next adopters of BIM across all three company categories will be in the Late Majority category. This author notes these as being a significant portion of a population (33%), who are generally sceptical of innovations. They tend to adopt when it becomes an economic necessity, i.e. the cost / benefits of BIM become acceptable. Adoption also tends to take place when peer pressure forces them to do so, i.e. when BIM becomes the norm within their network. Although, within a highly localised UKCI, the network of a particular company may be subject to distinct dynamics in comparison to the wider sector. Late adopters also tend to have relatively scarce resources, linking to the inhibiting dynamics of cost, and require most of the uncertainty about an innovation to be removed before they adopt. Irrespective of the benefits of BIM, it goes without saying that without sufficient resources, those in the late majority will not adopt BIM. Despite the cost focus of the UKCI, the highly localised market for SMEs and potentially self-limiting company networks which exist locally means some companies can often survive without the benefits and efficiencies, innovations such as CAD or BIM can bring. This again reflects the maturity of the UKCI, the presence of long established roles and processes and the robustness of existing, long standing practices.

Rogers also notes as the adopters start to fall into the late adopter category, the rate of adoption as shown previously on the ‘S’ curve at Figure 3.9, starts to slow.

Although Rogers describes a number of innovations where not all of the population adopt, this author’s model of innovation adopters does not include this. Although the author acknowledges this shortcoming in their adopter classification model and describes this as “incomplete adoption” (Rogers, 2003, p.281), the model as presented does not therefore reflect the circa 10% of respondents who do not currently see any opportunity for the use of BIM in their company. These results mirror the incomplete adoption of CAD, which despite its initial introduction in the late 1980s, followed by low cost software in the 1990s, was recently still not being used by 42% of respondents (NBS, 2011b).

This illustrates the resistance of certain, hard to reach sections of the UKCI to the adoption of innovations, despite their low cost and almost universally recognised advantages. While this may be explained by a lack of awareness of BIM by these respondents, leading them to this conclusion at the current time, it may be that as with CAD, these respondents remain non-adopters of BIM. This being on the basis that they remain relatively isolated from the wider sector, are members of a small network with a similar perspective, i.e. one that existing methods are sufficient and that their resources are insufficient to adopt, irrespective of the benefits.

While differences in sampling methods mean that a like for like comparison is not possible, the potential non-adoption rate for BIM of 10% is significantly lower than the non-adoption rate of CAD, despite the latter being much lower in cost, less complex and requiring less change. Potential explanations for this include the Governments mandate for BIM use, leading to a high level of publicity within the UKCI. Both of these may also have led to a degree of social desirability bias among respondents, who may have overstated their intended use of BIM.

6.3 Dynamics of BIM Adoption

The convergent results identify 23 dynamics of BIM adoption, illustrated at Figure 5.5 in the previous chapter, organised around the five generic characteristics of innovations suggested by Rogers (2003).

6.3.1 Relative Advantage

The first of these, Relative Advantage is noted having a positive relationship with the rate of adoption and as one of the most important characteristics. Within this characteristic, there are number of sub characteristics including Economic Factors, into which a number of the identified dynamics of BIM adoption fall.

The convergent results highlight a number of the benefits of BIM in terms of improvements to cost and time. The reduced time taken to deliver a construction project is one such advantage[68], illustrated by the following response from respondent **V**, a Consultant:

> “Once we’d ironed out the issue, on the third job we did with [X[69]] was bid and delivered with a 10% reduction in programme.”

The suggested benefit of a reduction in construction costs (Autodesk, 2006, Barlish and Sullivan, 2012, Riese, 2009) is also supported by the convergent results[70] and highlighted in the following response by **F**, a main contractor:

> “It’s hard to prove, but I reckon that one major error picked up before it got to site saved us at least £150K.”

This is reinforced by recent data from MHYOI Cookham Wood, a pilot BIM project recently undertaken by the researcher’s employer for the Ministry of Justice. This achieved a 20% reduction in construction costs against a comparable non-BIM project (Interserve, 2014). In contrast, within this research a reduction in the overall cost of a project (including design fees and life cycle costs) does not appear as a significant dynamic.

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[68] Dynamic: Construction Duration, mean = 4.73 + noted by 2 respondents.
[69] Contractors’ name removed to maintain confidentiality.
[70] Dynamic: Construction Cost, mean = 4.85 + noted by 4 respondents.

The BIM enabled focus of effort to where it has the most impact, suggested by the MacLeamy Curve (Light, 2011a) is a supporting dynamic identified in both sets of results[71], reflected in the following response, again from respondent F, a Main Contractor.

> "Done properly, BIM is great for ensuring our designers and us [sic] find and sort out issues before we get to site …. that's where they used to end up, often costing us big money to sort [out]".

Interestingly, the potential negative combination of this, combined with up front work at risk, although suggested by the researcher, is not indicated within either set of results.

The convergent results[72] and quotation below from **O**, a Sub-Contractor, demonstrates a further suggested advantage of BIM, (Autodesk, 2006, Riese, 2009).

> "It used to take us days to price a job. With the right data in the model and a few sense checks, this can now be done with a few clicks of the mouse."

While this is a recognised and logical application of the addition of cost data to a BIM model (5D BIM) to add value, this has the potential to directly impact on the role of Quantity Survey (QS), a particular type of Consultant, who traditionally "took off" quantities and estimated costs manually, using their professional skills to interpret the often incomplete data provided, especially at the early stages of the project. While it may seem that BIM may reduce the role of the QS, a recent trade article notes that this has the potential to enhance their role within the UKCI

[71] Dynamic: MacLeamy, mean = 4.95 + noted by 4 respondents.
[72] Dynamic: Cost Plans Duration, mean = 4.89 + noted by 2 respondents.

(Withers, 2014). A further trade article (Pryke, 2014) however, notes that relationships within the UKCI along with fragmentation, manifesting as a reluctance to share cost data, may lead to the full value of costing from the BIM model not being realised.

Building upon the MacLeamy Curve, noted above, the cost effective exploration of potential changes was also noted as a benefit of BIM[73] and is exemplified by the following quotation from **W**, a Consultant.

> "We got caught out by planners who needed the building height reducing by 900 mil [mm]. Working in BIM with the engineer alongside us meant we could check this out and confirm it could be done in 2 hours and knock out [sic] revised drawings in a day."

However, arguably reflecting the short term perspective if the UKCI, also noted as an inhibitor, the dynamic: Life Cycle Cost (Autodesk, 2006) arising from the 5:20:75 ratio of costs of design, construction and operation of a building (Boussabaine et al., 2012, p.43) did not appear as a significant dynamic.

The potential downside for the consultants, who undertake this exploration of changes, is that this may simply become an expected part of their service, eating into any reduction in man hours and therefore cost or time savings they would otherwise realise from using BIM. This is reflected in the discussion below, where Smaller Design Team, was identified as a non-significant dynamic of BIM. In addition, despite benefits to the project, the researchers own experience is that continued cost pressure within the UKCI means there is little opportunity for consultants to charge higher fees to reflect the higher value they can bring by using BIM.

[73] Dynamic: Design Change Cost Effective: mean = 4.81 + noted by 3 respondents.

The convergent results also highlight a variety of inhibiting dynamics of BIM, which can be also considered to be Economic Factors under Rogers's model.

The first of these, the high cost of BIM[74], is supported by a quotation from respondent **R**, a consultant:

> "….. we'd have to splash around eight K [sic] a pop on each new BIM seat".

Despite the recent introduction of pay as you go BIM, the typical direct costs of a BIM seat remain in the region of £10,000, including training and an initial reduction in productivity (Miller, 2013), and appears to represent a significant hurdle to adoption to many as discussed further below. Linked to this in the inhibiting effect of short repayment / payback of investments (Loewe and Dominiquini, 2006), identified within the convergent results[75] and which is a potential reflection of the short-term focus of the UKCI.

Also related to the costs of BIM is the need to maintain cashflow[76] (Abbott et al., 2006), which effects many industries but is arguably more relevant to this sector given the poor payment practices within the UKCI noted in recent trade articles (Hayman, 2014b, Pitt, 2014). The following response from **J**, a sub-contractor,not only illustrates the effect that poor payment practice can have on a company's ability to survive, but also demonstrates a further barrier, that of the need for continued company survival[77].

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[74] Dynamic: Cost Implementation, mean = 5.22 + noted by 4 respondents.
[75] Dynamic: Payback Short, mean = 5.1 + noted by 2 respondents.
[76] Dynamic: Cash Flow, mean = 4.81 + noted by 2 respondents.
[77] Dynamic: Company Survival, mean = 4.23 + noted by 3 respondents.

> “Earlier this year, a large late payment nearly took us out …. we were a gnat’s c**k [sic] from going under. ….. our focus is surviving, not BIM, … we’re being squeezed harder and harder.”

This is despite some indication in improvement within the UKCI since the depth of the recession (Office of National Statistics, 2014) and a reduction in construction insolvencies (Dennis, 2013) highlighted in a recent trade article. For some companies their ability to continue to trade is rightly more of a priority than BIM, with some large and well-known names within the UKCI suffering from poor financial performance, as illustrated in trade articles on Miller Construction (Pitt, 2013) and Balfour Beatty (Hayman, 2014a).

Within these results, two further barriers to adoption fall within the Economic Advantage sub-category. The first of these, that BIM enables the use of a smaller design team, was specifically considered to be irrelevant within the convergent results[78]and is illustrated within the following quotation from **X**, a Consultant:

> “Nay [sic] … the time’s soaked up on doing more detailing and 3D co-ordination.”

This may be a result of any time saving from BIM, being utilised to explore possible changes, supporting the reduction in construction costs and time above, as suggested in the MacLeamy Curve.

Identified as an emergent code within the qualitative analysis, the barrier presented by the perceived adequacy of existing methods[79], is illustrated by a quotation from **A**, a main contractor.

[78] Dynamic: Design Team Size mean = 3.18 + noted by 2 respondents.
[79] Dynamic: Existing Methods Sufficient, noted by 1 respondent.

> “All of our work is domestic ….. mostly small extensions and the odd house, all off paper drawings. For our small size, BIM isn’t on our radar”.

This supports the conclusion above that the next adopters of BIM are likely to be in the laggards category, as well as the modifications to Rogers’s models suggested by the researcher in the conclusion.

Two further sub categories suggested by Rogers, Mandate and Preventative Innovation are represented by the most significant driver within these results[80], the Government mandate for BIM use by 2016, captured in the following response from **E**, a main contractor.

> “Public sector contracts have kept us going through the bad times …. although things are picking up, we can’t afford not to do BIM and lose a big chunk of our workload.”

Although Rogers (2003) notes that preventative Innovations tend to have a low rate of adoption, this mandate appears to have had a significant supportive effect on the adoption of BIM. Interestingly, within the private sector, there appears to be less pro-active client support for BIM with this noted in a trade article as a barrier to BIM (Wilding, 2013), but appearing as neither a supporting nor inhibiting dynamic within this research.

None of the dynamics identified within the convergent results fall within the final three sub categories suggested by Rogers; Status Aspects, Effect of Incentives and Overadoption. This reflects what appears to be a change from the early adoption of BIM and the initial marketing advantages (Autodesk, 2006, Withers, 2011). The researcher’s own experience of the early introduction of BIM within the UKCI included aspects of the first of these, with those adopting BIM using this

[80] Dynamic: Government Mandate, mean = 5.79 + noted by 8 respondents.

as a marketing tool to differentiate themselves from non-BIM companies. This contrasts with the current UKCI, where BIM now appears as a pre-requisite rather than a differentiator.

6.3.2 Compatibility

The second key characteristic of an innovation suggested by Rogers is that of Compatibility, described as:

> … the degree to which an innovation is perceived as consistent with the [1] existing values, [2] past experiences and [3] needs of potential adopters. (Rogers, 2003, p.240).

Within the third sub category: Needs, and the convergent results, uncertain demand was specifically considered not to be relevant[81] and therefore it can be argued that demand for BIM is a supporting dynamic. This appears to be the result of the Government Mandate noted above and is illustrated by the following response from **S**, a Consultant:

> "Most of our contractor clients won't even consider non-BIM practices …"

A further supporting issues that falls within sub category of Past Experiences, is the increase in the use of Design and Build Contracts[82]. Under this procurement route, the activities and construction are brought closer together, enabling greater collaboration across the team. While this is demonstrated by the following quotation, from respondent **W**, it is interesting to note that the novation of designers (consultants) under Design and Build contracts, was not noted within the results.

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[81] Dynamic: Demand Uncertain, mean = 3.07 + noted by 2 respondents.
[82] Dynamic: D&B Increase, mean = 5.17 + noted by 4 respondents.

"…… as designers, D&B has been a great driver for BIM …. "

The maturity of the UKCI, it's well established processes and degree of change required for BIM is reflected with all seven dynamics in the Value and Beliefs sub category of Compatibility, being inhibiting dynamics. The first of these, the short term focus of the UKCI[83],is an issue that affects a wide range of sectors outside the industry (Loewe and Dominiquini, 2006) and is illustrated by the following response from **O**, a Sub-Contractor:

> "We concentrate on the immediate future, winning the next project and improving profits from the last one."

The temporary nature of relationships within the UKCI is noted as a key weakness of construction (Egan, 1998, Slaughter, 1998, Doubois and Gadde, 2002, Yitmen, 2007) and as one that differentiates it from other production industries. Within the convergent results this appears as an inhibiting dynamic[84], illustrated by the following reply from **L**, a Sub-Contractor:

> "Being asked to use and invest in Tekla [a BIM package] for this project is all well and good, but that may only be good for this job. What if our new client demands we use Revit [a different BIM package] ?"

Despite this being a well-recognised issue, from the researcher's own 26 year experience within the UKCI, there appears to be little evidence of systemic changes to address this.

The need for co-ordination across different companies during innovation (Slaughter, 1998, Andrews, 2006, Tovstiga and Birchall, 2008) is a further

[83] Dynamic: Short Term Focus, mean = 4.87 + noted by 1 respondents.
[84] Dynamic: Relationship Temporary, mean = 5.14 + noted by 4 respondents.

inhibitor to BIM[85]. This is a reflection of the large number of companies noted as likely to be involved in a typical project and short term focus of the UKCI and is illustrated in the quotation below by **E**, a main contractor.

> "Leaping in on our first BIM project in 2011, we expected everyone to just use it …. That was before we realised most of the sixty companies involved hadn't used BIM before".

A further potential issue is the negative effect on the value to the overall project that BIM can bring, by the failure of a single key supplier within the wider project supply chain to use it. This single weakest link can break the information and value chains, which flow from design through to completion, reducing many of the potential benefits to others involved, the client or the project as a whole.

The difficulties presented by the separation of design and construction in traditional procurement are also reflected in the convergent results[86] and are related to the co-ordination issue above. Under this procurement route, design and construction remain the responsibility of different organisations, are separated by a formal and inherently adversarial contractual relationship, which reduces the opportunity for BIM enabled collaboration. Despite being highlighted as an issue in many of the Government initiated reviews of the performance of the UKCI, this procurement route still accounts for 55% of contracts used (NBS, 2013), with the issue being illustrated by the response from **G**, a main contractor:

> "… we had to pay an extra 25 thou [Thousand] for the design team to 'BIM up' all the work the client's design team had done to date on CAD and in word documents".

[85] Dynamic: Co-ordination Different Companies, mean = 4.85 + noted by 2 respondents,
[86] Dynamic: Separation Traditional Procurement, mean = 4.15 + noted by 1 respondent.

All four of these dynamics adversely impact on BIM, noted earlier as a systemic process innovation that spans the timescale of individual projects, organisational boundaries and the one off relationships so prevalent within the UKCI.

Illustrated by the quotation below from **E**, a main contractor, a further issue from the convergent results is the robustness of industry practices[87].

> "Our best suppliers are good and relatively cheap, however they're not really up for change …. they've always done it their [non-BIM] way."

This is again, arguably a reflection of the maturity of the UKCI with many of the key roles and processes having being established a long time ago. This history is illustrated by the formation of the Royal Institute of British Architects in 1837, the Royal Institute of Chartered Surveyors in 1881 and the Chartered Institute of Building in 1834. Further influences may also include the highly specialised and geographically localised nature of the UKCI, particularly for SMEs, plus from the researchers own experience, deep rooted cultural issues such as an inherent resistance to change, often arising from a strongly held conviction that current ways of working are good enough. Given the potential broad scope of this dynamic, which in hindsight leads the researcher to consider it a theme in itself, the robustness of existing practice and cultural issues within the UKCI are an area worthy of further study by themselves.

This robustness in the case of BIM links closely to the inhibiting dynamic Training Level, noted below, with Sexton et al. commenting that:

> Any technology that is too far removed from this 'comfort zone' is seen to require too much investment and too contain too much risk, and thus tends to be intuitively and swiftly sifted out.(Sexton et al., 2006, p.11).

[87] Dynamic: Industry Practices Robust, mean = 4.65 + noted by 4 respondents.

The final three inhibiting dynamics, were emergent from the qualitative data only and provide further perspectives on some of the issues presented by BIM, over and above those identified deductively by the researcher within the literature review and that appear within the convergent results.

The nature of the changes in contracts, processes and roles required for BIM enabled collaboration to take place fully, is reflected in the emergent inhibiting dynamic, Legal Issues[88]. This is noted as a barrier in a recent trade article by Pinsent Masons (2014), who note a lack of collaboration on most construction contracts due to a lack of alignment of parties interests, plus 66% of respondents to their survey expressing the view that current contracts were not fit for purpose for BIM. This is further illustrated in the following quotation from **L**, a sub-contractor:

> "… what happens if 14 months down the line, someone re-uses or miss uses our data and finds an error which causes [them] major problem?"

While the collaborative use of BIM should reduce the number of issues arising on a project, where such problems do occur, it may be more difficult to determine exactly who is responsible for the error. In contrast, this is less of an issue in traditional UKCI practices, with each working in their own silo with clearly defined boundaries.

So far the response of the UKCI to this has been twofold. Firstly, rather than addressing the fundamental nature of the relationships between parties enshrined within contracts, a number of BIM protocols which sit above the contract documents have been introduced. Secondly, within the construction insurance market, a small number of project based insurance policies are being introduced.

[88] Noted by 1 SSI respondent.

These insure risk on a project rather than individual company level and seek to overcome the problems in accurate allocation of liability between the many companies involved on a typical project.

A related inhibiting emergent dynamic is that of Intellectual Property[89], illustrated by the following from respondent **N**, a Sub-Contractor.

> "…. or the contractor simply says thank you, then uses it [our BIM data] to get cheaper prices from a competitor".

BIM data is arguably a richer and more valuable format of information than 2D CAD or soft digital formats such as PDF. Despite some companies applying their intellect and processes to add value to their services, there appears to be little opportunity within what remains a cost focused UKCI, for them to increase prices to reflect an increase in the value of their information. With BIM, this information also becomes easier for others to use or re-use in an unauthorised way, either deliberately or accidentally. This is highlighted by a recent trade article (Bright, 2012) who cautions, that in relatively unregulated markets such as China, local manufacturers may miss-use BIM data to produce low cost copies of components designed by others.

Although BIM data can be covered by copyright law, this is an expensive legal recourse to any issues and may be out of reach of many companies within the UKCI. Furthermore, the imbalance of some contracts between large clients or contractors and their supply chain also means that to secure the work, smaller companies are effectively forced to waive their rights to their intellectual property.

The failure of the UKCI to effectively improve its performance despite a number of Government commissioned reviews and formal initiatives, is reflected in the final

[89] Noted by 1 SSI respondent.

emergent and inhibiting dynamic[90]. This is succinctly captured in the following response from respondent **P**, a consultant:

> "CAD, Partnering, CDM [a Health and Safety Initiative], Project Management and now BIM ….. all of these initiatives have promised great results in the past, but have they delivered [?]"

This reflects a degree of cynism among certain sections of the UKCI, some of whom from this response arguably fall within the Late Majority or Laggards categories noted by (Rogers, 2003). The response also reflects the perspective of (Drucker, 1985) noted earlier, on the high level of failure for complex industry wide innovations.

6.3.3 Complexity

The third key characteristic of innovations noted, is that of Complexity, which the author notes as being "…. negatively related to its rate of adoption." (Rogers, 2003, p257). The degree of potential change BIM brings to current practices within the UKCI, is reflected with these dynamics being predominantly inhibiting, including the complex nature of BIM[91] reflected in the following response from **D**, a main contractor:

> "I went to one of those Task Force seminars on BIM …. the more I heard, the more complicated it got".

Also identified is the inhibiting dynamic: Training Level[92], which supports the perception that BIM is a complex piece of software and requires a high degree of training to use fully. This is also supported by information from Excitech[93], who

[90] Dynamic: Industry Initiatives, noted by 1 respondent.
[91] Dynamic, Complexity: mean = 4.86 + noted by 3 respondents.
[92] Mean = 5.64 + noted by 3 respondents.
[93] One of the largest BIM software vendors, support and training organisations in the UK.

suggest new users of Revit, undertake a total of 3 separate courses, with practice in between, totalling 5 days intense training at a cost of £1850 (Excitech, 2014). While many undergraduate construction courses include an element of BIM training, the challenge for many companies is how to up-skill their existing workforce while continuing to operate their business, illustrated in the following quotation from **N**, a Sub-Contractor:

> "….. the challenge is training our existing staff at a reasonable cost, while keeping the work rate up."

The next issue, securing specialist staff to operate BIM[94] is closely related to the dynamic Level of Training and demonstrated by the following response from **L**, also a Sub-Contractor:

> "… It's a struggle to find staff who are specialists in our area [curtain walling and cladding] … good BIM skills as well is even more of a challenge."

Both of these dynamics demonstrate the need for those within the UKCI to possess not only good BIM skills, but also the technical skills relevant to their role. While those recently graduating from university may have good BIM skills but a lack of technical experience, those who have been in construction for some time are likely to have a wealth of technical experience but fewer BIM skills.

The final dynamics falling within the Complexity category are two contradictors items, both of which relate to the exchange of information between different BIM software packages. While the Dynamic: Systems Open[95], which forms a key part of the Governments BIM mandate, is noted as a supporting dynamic, Exchange

[94] Dynamic: Staff Specialist, mean = 5.32 + noted by 2 respondents.
[95] Noted as a supporting dynamic by 2 SSI respondents

Formats Neutral[96] is noted as an inhibiting dynamic. This reflects the practical issues with exchanging complex data between different software packages, in a constantly evolving market for BIM. Although standards such as Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie) have been developed to support the transfer of data, from a practical perspective there are a number of issues, such as the loss of fidelity of data (Autodesk User Group International, 2013, Dietzen, 2014).

6.3.4 Trialability

The fourth key characteristic is that of Trialability, “the degree to which an innovation can be experimented with on a limited basis” (Rogers, 2003, p258). Within the convergent results the Dynamic: Trialability[97], is noted as not being relevant and is therefore an inhibiting dynamic of BIM, with the following quotation from **R**, reflecting the high costs and complexity:

> “With the costs, training and changes required, it’s not something we could really dip our toe into …. It’s an all or nothing choice.”

6.3.5 Observability

The fifth and final characteristic is that of Observability, “… the degree to which the results of an innovation are visible to others” (Rogers, 2003, p258). Although this characteristic was tested directly within the questionnaire, it did not appear within the convergent results. The fact that the Government has felt necessary to mandate the use of BIM may indicate a low level of Observability. However, as noted above, there is a good recognition of a number of the key benefits of BIM, including savings in construction costs and time, within the convergent results.

[96] Noted as a supporting dynamic by 1 SSI respondent and an inhibiting dynamic by 1 SSI respondent.
[97] Mean = 3.26 + noted by 2 respondents.

There were a number of construction specific dynamics which appear to be widely recognised and supported by literature, but were notable to the researcher by their absence from the triangulated results. The negative impact of a focus on lowest cost was suggested as an inhibitor (Tatum, 1986, Egan, 1998, Davidson, 2001, Fairclough, 2002, Jones and Saad, 2003), but only arose in the qualitative results. Similarly, the project focus of construction was noted as an inhibitor (Egan, 1998, Slaughter, 1998, Gann and Salter, 2000, Davidson, 2001, Doubois and Gadde, 2002, Dulaimi et al., 2005, Yitmen, 2007) and only arose in the quantitative results. The fragmentation of the UKCI was noted as the final inhibitor (Nam and Tatum, 1988, Betts and Ofori, 1994, Fairclough, 2002, Brewer et al., 2006, Yitmen, 2007, Cabinet Office, 2011), but did not appear within the results at all. These omissions may be as a result of Type II errors arising from methodological triangulation, or perhaps as these are core characteristics of the UKCI, respondents did not consider them to be specifically applicable to BIM, thus reflecting a difference between perception of respondents and the dynamics really at play.

6.3.6 Differences to Rogers's Model

Although Rogers's model suggests that Relative Advantage is one of the most important supporting characteristics of an innovation, the results demonstrate in the case of BIM, that Compatibility is an equally significant but inhibiting characteristic, with many inhibiting dynamics occurring within the sub categories Values and Beliefs, and Previously Introduced Ideas.

Returning to Relative Advantage, the sub categories Status Aspects and Overadoption, are not relevant to BIM, perhaps reflecting the fact that decisions to adopt within the UKCI, tend to be made at a company rather than individual level and, in contrast to consumer markets, no value is now given to the status from, nor prestige that arises from adopting BIM. Surprisingly, Observability does not appear to be a relevant characteristic at all, although this is arguably as a result of contractual relationships within the UKCI, combined with a reluctance to share what may be highly sensitive cost data, in a cost focused competitive market.

6.4 Categorisation of BIM as an Innovation

Of the five researcher suggested categorisations of BIM as an innovation, made within Chapter 5, the results only support the categorisation of BIM as System Innovation under the framework developed by (Slaughter, 1998) and as an innovation that reduces contractor’s construction costs under the categorisations of Lim and Ofori (2007).

The first of these goes some way to explaining the relatively slow uptake of BIM prior to the Government mandate, with the data directly aligning with the authors suggestion that technical competence is required and the effective use of BIM as this type of innovation conflicting with current practice. While the second of these is also directly supported by the results, in the case of BIM, this appears to conflict with the interim findings of Lim and Ofori (2007) noted within the literature review, who found that none of the contractors they interviewed perceived innovation as being able to support competitive advantage by means of increased margins and lower costs than their competitors. However, an alternative perspective is that with the more widespread use of BIM, any competitive advantage is only temporary, as other competing companies within the UKCI also adopt and realise the benefits. Similarly, rather than increasing margins, the cost led nature of the UKCI may mean that BIM means companies simply reduce their price to continue to win work, at the expense of improved margins.

6.5 Variations in Dynamics and BIM Usage by Company Size

A key finding from this study was the identification of variation in dynamics and BIM usage by company size. This was determined through visual comparison within the qualitative method and ANOVA within the quantitative method. Within both analyses, a threshold of £10M was set, above which companies were noted as within the category: Higher Turnover and below which companies were noted as within the category: Lower Turnover.

Two dynamics, Government Mandate and Collaboration Platform appear as being more relevant to those in the higher turnover category. The first of these may be a reflection of the Government's role as the UKCI's largest client, with many Higher Turnover companies undertaking more public sector work and hence, being impacted by the requirement for BIM to be used. Similarly, Higher Turnover companies tend to undertake larger and inherently more complex projects, where the benefits of BIM as a collaboration platform may be more applicable and / or more visible.

For Lower Turnover companies, the results indicate the dynamic of Cost Implementation, is more significant. In a sector where 98% of companies are SMEs this may be a reflection of a lack of financial resources available, (Andrews, 2006, Loewe and Dominiquini, 2006, Myers, 1984) exacerbated by the recession or the higher relative cost of BIM adoption for a first single BIM seat. This is calculated as a percentage of company turnover applying figures from the research sample, and illustrated at Table 6.1, applying turnover figures from the research sample. This shows the relative cost of their first BIM seat is approximately 56 times greater on average from companies in the lower turnover category (<=£10M), when compared with companies in the higher turnover category (>=£10M)

Category of Company	Average Turnover within Sample (A)	Typical BIM Cost (B)	Implementation cost as a percentage of turnover (A) / (B).
Lower Turnover	£2.89M	£10,000	0.3469%
Higher Turnover	£163.89M		0.0061%

Table 6.1 – Relative Costs of BIM Seat

6.6 Variations in Dynamics and BIM Usage by Company Type

A further finding from this study was the identification of variation in dynamics and BIM usage by company type, which applied the same methods as for that of company size, i.e. visual comparison and hypothesis testing by ANOVA.

This identified one inhibiting dynamic of particular relevance to Main Contractors: Existing Industry Practices Robust. This group has one of the widest spans of involvement and relationships on construction project and also tends to be subject to the most financial risk. In response to this, Main Contractors have historically evolved highly rigorous and robust processes to manage risk, to which BIM introduces a high degree of change.

The results indicate three significant inhibiting dynamics of particular relevance to Sub-Contractors: Cost of BIM, Company Survival and Complexity of BIM. These reflect the nature of the input of Sub Contractors to a project, where they are rarely involved from the start and of the three categories of company, have the least opportunity to add value, mostly being selected purely on the basis of price. In addition, the costs of BIM in percentage terms of their input to a project, is arguably higher than the other two categories. Sub-Contractors frequently encountered issues with late or non-payment, often leading to insolvency (Tremark, 2013). According to UKCI data (Department for Business Innovation and Skills, 2014), they have also suffered the highest level of insolvencies in comparison to the other two categories, since the UKCI output peaked in 2008. Sub-Contractors also tend to be highly specialist, with a more limited interface with the wider project team and may not have a design role per-se, their scope being limited to deliver works designed and specified by others. These factors may also explain the higher perception of the Complexity of BIM as an inhibiting dynamic more relevant to Sub-Contractors.

Both qualitative (inspection of tabular data) and quantitative (Chi-Square test) analyses indicated a positive relationship between the size of the company and their usage of BIM, companies in the Higher Turnover category generally using BIM more than those in the Lower Turnover category. This may be a result of the variation in dynamics above, with larger companies able to overcome resource issues and more likely to be delivering large projects in public sector, which are subject to the Government's BIM mandate. In addition, smaller companies tend to be more specialist in their field, and may have limited internal ICT support, access to ICT infrastructure, supporting company policies although the last two of these did not appear within these results.

The most significant variation in BIM usage by company type was for Sub-Contractors whose adoption rate was approximately 10% below the population mean and circa 15% below that for Consultants. As well as the dynamics noted above, these may be a reflection of a number of characteristics of Sub Contractors noted at Table 2.2 within the Literature Review, namely their lower size, later involvement in a project, more limited input to influence others and being subject to high competitive forces and low switching costs.

Another potential explanation for the lower adoption rate for Sub Contractors can be found when analysing the cost of BIM against the benefits that accrue to each company type. Based on a synthesis of the literature review and quantitative results, both of these variables were allocated a notional value of between 1 (low) to 5 (high) and the overall ratio of benefits to perceived cost calculated. Shown at Table 6.2, applying notional values and graphically at Figure 6.1, these demonstrate the lower value of this ratio for Sub-Contractors against the other two categories of company, which is reflected in their lower BIM adoption rate.

Company Type	Notes	Cost of BIM Relative to Turnover from A Typical Project (1 - Low, 3 = high).	Benefits to Company (1 = low, 3 = high).	Ratio of Benefit to Relative Cost
Main Contractor	Under most procurement routes, 100% of project turnover will flow through the main contractor. Cost of BIM relative to turnover from a project is typically **Low.** Has potential to receive most benefit from BIM in terms of lower construction costs - **High.**	1	3	3
Consultant	Consulta+nts fees typically make up ~ 10% of the cost of a project. Cost of BIM relative to turnover from a project is therefore **Medium** and similar to cost of a fully kitted out CAD station. Receives some benefit from BIM, but less than Main Contractor - **Medium - High**	2	2.5	1.25
Sub Contractor	An individual sub contractors costs are only likely to form a small portion of the total costs. The cost of BIM is relatively high to this type of company, who are often competing purely on the basis of cost and typical have a lower turnover than main contractors. - **High.** Some benefit in terms of accellerated costing - **Medium to Low.**	3	1.5	0.5

Table 6.2 – Indicative Calculation of BIM Benefits vs. Relative Cost.

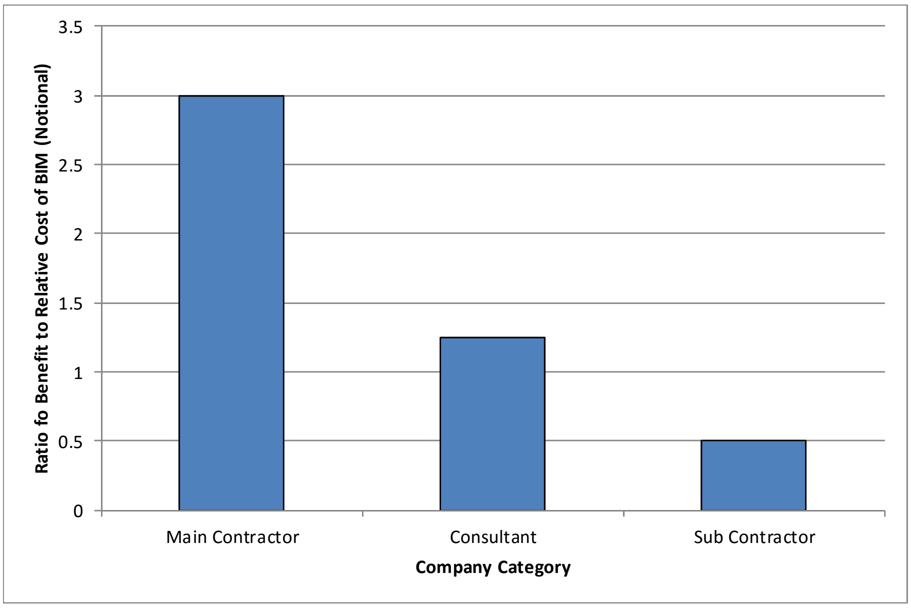

Figure 6.1 – Graphical Representation, Notional BIM Benefits vs Relative Cost of BIM by Company Type

6.7 Potential Consequences of BIM

Without the supporting measures suggested above, many small companies and Sub-Contractors may need to simply await the further maturity of BIM and wider availability of lower cost software, as full BIM functionality ceases to be sold as a premium product. Alternatively, they may decide, not to adopt BIM for the foreseeable future and become the "non-adopters" discussed above. A consequence of this, is that they would be locked-out from public sector contracts and resulting in a two tier, BIM and Non-BIM UKCI. For those who do not adopt, this may not be perceived as an issue in the short term, however, if larger companies adopt, successfully lever the benefits and start to deliver smaller projects cost effectively, then non BIM users may come under increasing cost based competition in the long term.

Although both the European Commission (2000) and Government (Curren, 2000) recognise the importance of SME's to the wider economy, with the latter actively encouraging SME's to be successful in delivering public sector construction projects (Muse, 2014), the 2016 mandate may have the opposite effect. While SME's are unlikely to be acting as the Main Contractors on large projects, they form an important part of the supply chain either as Consultants or Sub-Contractors. With BIM becoming a pre-requisite by many, before SME's can even be considered for involvement on a project, those that fail to adopt BIM may find themselves locked out of a major part of the UK construction market, contrary to the Government's stated objectives for SME's in the UKCI (Cabinet Office, 2011). Non BIM companies may also find themselves increasingly uncompetitive against similar sized companies who are using BIM, in what is noted as a predominantly cost focused UKCI (Tatum, 1986, Egan, 1998, Fairclough, 2002), with rivals realising the benefits and choosing to pass these on to their clients by means of lower prices. One final observation, is that any stimulus to the economy or support to SMEs, the Government may seek to provide through increased construction and infrastructure spending, may have a more limited effect in future as SMEs are less able to secure this work.

Although larger companies tend to have higher overheads and cannot compete on small projects on the basis of price, the cost advantage that BIM brings to the former may change this. This may allow larger companies to expand at the expense of smaller companies, either organically or through acquisition and vertical integration, resulting in consolidation within the UKCI and a corresponding reduction in both the fragmentation and high number of small construction companies. A further effect of this, would be to effectively raise the barriers to entry within the UKCI, which have traditionally been very low, leading in the longer term to a reduction in the high number of small construction companies.

A further potential consequence of BIM arises from the high number of temporary relationships and difficulties in effective collaboration across robust and legally mediated organisational boundaries. Given its advantages, BIM may incentivise consolidation among different companies as the most effective way of overcoming these issues and fully realise these benefits. This also suggests a move towards further consolidation with a smaller number of larger companies, who are able to successfully integrate different design, construction and sub-contracting functions within a single organisation. Increased benefits of BIM could then be realised through closer integration under Design and Build, with a continued increase in the use of this procurement route at the expense of traditional procurement.

Alternatively, BIM may result in an improvement in the duration and nature of relationships, co-ordination and collaboration across companies involved in projects, described within the literature review as “tight couplings” (Doubois and Gadde, 2002, p621). Based on the evidence from Literature Review and the researcher’s own experience within the UKCI, this appears unlikely to happen, given a sector that sadly has been successful in the de-facto resistance of real change, despite well publicised and acknowledged performance issues and multiple Government initiatives.

As well as increasing integration during the design and construction stage of a project, BIM also has the opportunity to deliver value through the complex transition from construction to occupation and the operation of a building itself. The first of these has been reflected in the publication of guidance for this process such as Government Soft Landings (Mueller et al., 2013), which incorporates requirements for BIM data. The latter of these, which is noted earlier as being the most expensive phase of a buildings life, also has the potential to benefit from BIM through lower asset and life cycle costs, supported by better information. Wider client recognition of these may therefore encourage a more pro-active requirement by clients for BIM usage in the earlier design and construction stages, or alternatively lead more Main Contractors to realise this benefit through further expansion beyond construction, into the longer term operational phase of buildings.

6.8 Questions Arising from the Results

While the study has been successful in achieving the stated objectives, there are a number of further questions which, with the benefit of hindsight, arise from the results.

Although the adoption of BIM has increased rapidly within the past 4 years, the granularity of the data means it is not possible to accurately map the rate of adoption against Rogers's diffusion 'S' curve to see if this adoption profile is applicable to BIM. For example, has the adoption of BIM followed this profile and what effect has the Government mandate had? Longitudinal research, carried out over a longer period of time, but using the same tools, would overcome this issue and allow the accurate development of what Lewin (1951) described as social fields and capture any variation in the dynamics of BIM adoption over a period of time.

Having been undertaken using a positivist and deductive approach, this study provides a valuable perspective on the "what" of BIM adoption. Despite the application of a robust methodological approach, the researcher is only able to infer the reasons behind these results. Therefore, what are the causal relationships relevant to BIM adoption? On a similar vein, while the researcher suggests reasons for the lower rate of adoption among Sub Contractors and those who have no plans to adopt BIM, it would be of value to drill down into these particular areas to better understand the reasoning and circumstances of both groups to understand why?

Finally, the researcher is of the view that further valuable perspectives on the adoption of BIM, as well as reflective feedback to theories, can be achieved through the application of alternative theoretical lenses to this topic. What further understanding could be achieved by the application of theories of change management or inter-organisational systems to the adoption of BIM and what would the results tell us about these theories?

These and the limitations noted above are both reflected in the suggestions for future research section of the Conclusion chapter.

6.9 Supporting BIM Adoption

By providing an improved understanding of BIM adoption, the results enable the researcher to discuss ways in which the many different UKCI stakeholders can better support adoption.

The fact that the Government has felt it necessary to mandate the use of BIM from 2016 onwards, is a reflection that it's relative advantage has not been sufficient to overcome some of the other characteristics of BIM as an innovation and the inhibiting dynamics identified. This is also mirrored within these results, with the dynamic: Benefits Financial Tangible, conspicuous in its absence from the results. Although the mandate has increased BIM adoption, for those who have yet to adopt, in particular companies in the Lower Turnover Category and Sub-contractors, the results indicate key inhibiting dynamics remain, particularly around the cost and complexity of BIM. To do so, the researcher is of the opinion that further Government measures are required to increase awareness of the benefits of BIM and support both groups.

Although a BIM4SME subgroup of the Governments BIM Task Force has been established specifically to target smaller companies, there remain a number of further steps that could be taken to support this important sector of both the UKCI and wider economy. As a major client, the Government could contractually require Main Contractors to provide support BIM related to both smaller companies and Sub-Contractors on public sector projects. This may include secondment of specialist staff to develop BIM skills, along with the provision of long term IT and technical support by the Main Contractor to their supply chain. Direct financial incentives from the Government, such as tax breaks for BIM start-up and support costs, could also help overcome some of the financial barriers small companies and Sub-Contractors face, as well as incentivising Main Contractors to provide better support to their supply chain.

There is a potential mismatch between the needs of the UKCI and those of BIM vendors. For BIM adoption to be maximised, the cost and perceived complexity of BIM needs to be reduced and issues of interoperability overcome. However, from a BIM vendor's perspective, the high price, feature rich nature and complexity of the product, along with sub-optimum interoperability can support them in maintaining competitive advantage and high switching costs among users within the BIM software marketplace and thus maximise their own margins. While it is highly unlikely the Government would go so far as to intervene on the pricing of BIM, it could go further and take a more prominent role in ensuring an accurate information exchange standard is developed and indirectly incentivise vendors to support this, through mandating its application on public sector and potentially large private sector projects.

The large number of parties who should be collaborating using BIM also introduces a higher degree of complexity of company interfaces and relationships, hence the need for improved leadership, management and co-ordination. Within the design and build procurement route, these can be provided by Main Contractors. However, there remains an important role for private sector clients, within the early stages of all projects and in particular on traditional procurement, where contractual roles and the separation of design and construction, preclude either the lead Consultant or Main Contractor taking such a role. As one of the major potential beneficiaries of BIM, private sector clients have a role to play in providing better and early leadership to their supply chains and follow the example of BAA for Heathrow T5 discussed within the Literature Review.

Chapter 7 – Conclusion and Contribution to Knowledge

As recap, the key objectives of this study were to establish:

- The state of play of BIM adoption in the UKCI.
- The perceived dynamics which support and inhibit the adoption of BIM.
- In a sector which is characterised by companies of many different sizes and types, any variations in these across different types and sizes of company.

Following the application of concurrent mixed methods and methodological triangulation, the results have met these objectives. The results the researcher allow, within this chapter, to contribute to knowledge through the articulation of models of BIM adoption and suggest amendments to Rogers's diffusion of innovation models. A contribution to practice, is made through the suggestions of ways in which the adoption of BIM can be better supported, discussed in the previous chapter and the potential impact of BIM on the structure of the UKCI suggested below. This study has also enabled the researcher to improve their understanding of the UKCI and enhance their research and professional skills, described within the accompanying Personal Impact Statement.

7.1 Patterns of BIM Adoption

This study shows that an average of 62% of respondents are using BIM, with 40% of all respondents (approximately 2/3rds of current BIM users) having adopted in the past four years. Combined with the fact that the most significant supporting dynamic of BIM adoption is Government Mandate, this suggests the announcement for mandatory BIM use on public sector projects by 2016, made in early 2011 has had a significant effect in increasing BIM adoption, despite the deadline for implementation being some time away.

While both Consultants and Main Contractors have similar levels of BIM adoption, at approximately 68% and 65% respectively, the adoption rate for Sub-Contractors was lower at approximately 52%. This is a reflection of the identification of three inhibiting dynamics: Cost Implementation, Complexity and Company Survival, which are more relevant to this company type than the others, plus the researcher's suggestion that the benefit to cost ratio of BIM for Sub - Contractors is lower.

There is a positive relationship between the size of company and BIM adoption, with larger companies (turnover > £10M) having adopted BIM more than smaller companies (turnover <£10M). The dynamic: Cost Implementation being more relevant to smaller companies, provides one potential explanation for this.

While the rate of adoption has increased in the past four years, the study shows there remains scope for adoption by those who have not done so, along with scope for increased utilisation, following adoption and increased sharing of BIM data across different companies. Surprisingly, 10% of respondents do not see BIM as being relevant to their work at all and by implication do not have any plans to adopt.

7.2 Categories of Adopters

While Rogers's indicates many cases where innovations are not adopted by all of a population, the finding that 10% of respondents do not see any opportunity for BIM to be used within their company, have led the researcher to suggest two modifications are required to Rogers's model, illustrated at Figure 7.4 below. Firstly, the cumulative adoption profile may flatten out and never reach the 100% level, leaving what the researcher has termed an **"Adoption Gap"**. This is made up of non-adopters who share many of the characteristics of laggards, plus those noted above, but never adopt BIM. Despite the advantages of BIM, this decision is perfectly rational from their own perspective due to their particular characteristics, network and circumstance.

7.3 Characteristics of BIM as an Innovation

As with the categories of innovation adopters, these results do not align with Rogers's model of the innovation characteristics across a number of areas, leading the researcher to again suggest a number of modifications to this model, as illustrated at Figure 7.3 below, to better reflect these results and the adoption of BIM within the UKCI. This shows the characteristic Observability, which was directly tested within the study, was not significant and is irrelevant to BIM. This leaves four main characteristics within the model, of which both Relative Advantage and Compatibility are of equal status in this case, with the former both supporting and inhibiting the adoption of BIM and the latter significantly inhibiting adoption.

Examination of the inhibiting dynamics within Compatibility, led to the creation of two new sub-categories. The first of these, Production Structure (4.5), reflects the degree to which BIM appears not to align within the existing production methods, company specialisms and roles within the UKCI, described within the literature review and directly supported by the dynamics: Co-ordination Different Companies and Relationships Temporary. The second, Legal / Risk Profiles

(4.6), manifests the mismatch between BIM and existing procurement, contracts and insurance arrangements within the UKCI, supported by the dynamic: Separation Traditional Procurement and suggested by the dynamics: Legal Issues and Intellectual Property.

7.4 Models: Dynamics of BIM Adoption

The 23 dynamics of BIM adoption identified by this study along with variations to these by company type and size have enabled the researcher to represent these as a model. Shown at Figure 7.1, this utilises force field analysis, a simplified version of field theory developed by Lewin (1951) and introduced within the literature review.

The 9 supporting dynamics are shown on the left hand side of the model, with the length of the arrow indicating the approximate relevance to this dynamic on BIM adoption, from largest (Government Mandate) at the top, to smallest (Demand) at the bottom. Similarly, the 13 inhibiting dynamics are shown on the left hand side, with those having most relevance (Training level) at the top, to least relevance (Design Team Size) at the bottom. Also on the right hand size, two supporting dynamics, Government Mandate and Collaboration Platform are identified as being more relevant to larger companies (turnover > £10M) and shown with yellow infill and one inhibiting dynamic: Cost Implementation is shown with blue infill to reflect this as more significant to smaller companies (turnover <£10M). Within the centre of the model, the two rectangles contain inhibiting dynamics specific to different types of company, with UKCI Practices Robust being more relevant to Main Contractors and three dynamics: Cost Implementation, Complexity and Company Survival and being more relevant to Sub-Contractors.

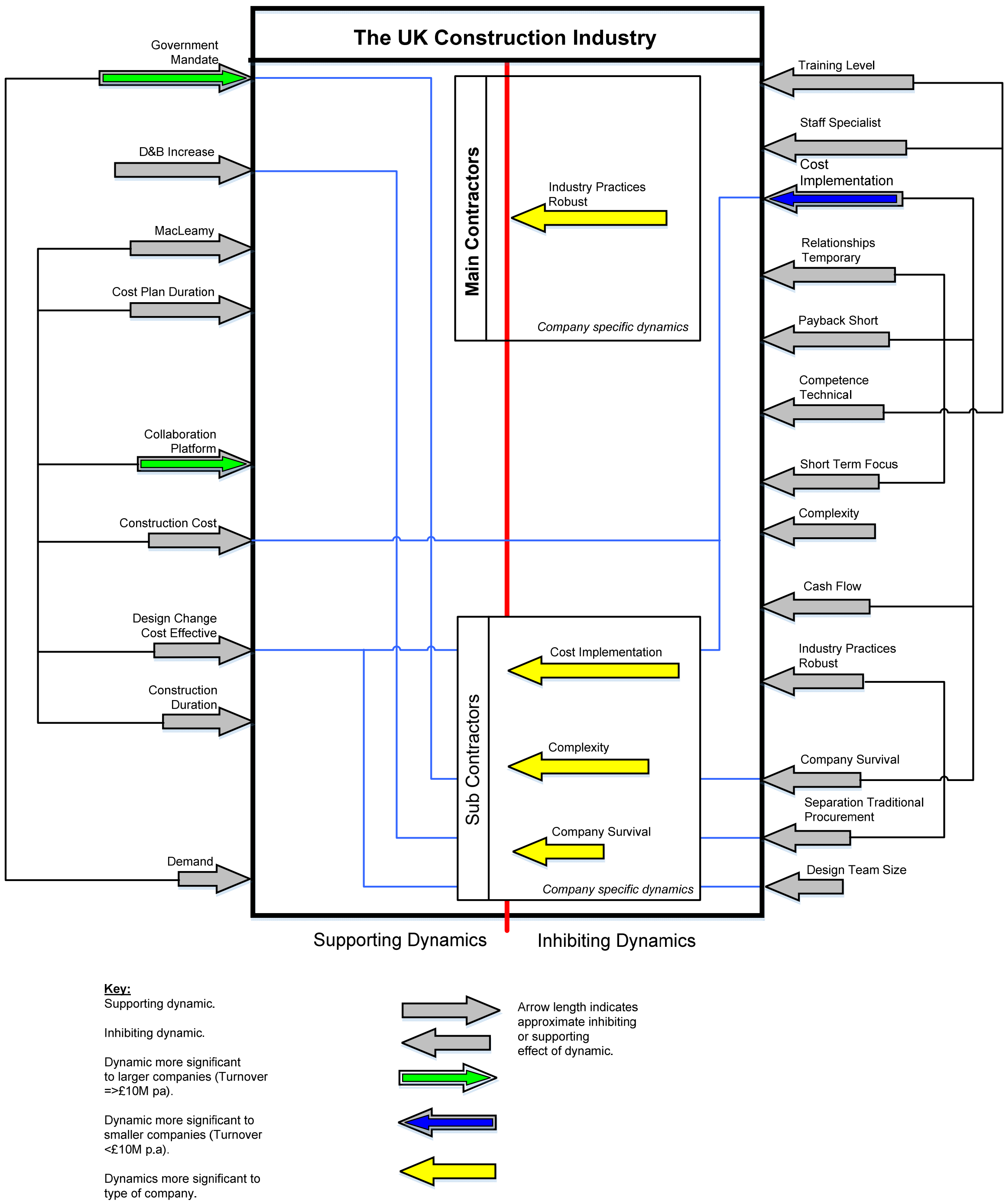

Figure 7.1 – Model of BIM Adoption

Also indicated are a selection of the suggested interrelationships between dynamics, albeit, these are shown on a thematic / logical basis, rather than statistical basis from the results.

Within the supporting dynamics, the dynamic, Government Mandate has increased demand for BIM within the UKCI and is therefore linked to the dynamic: Demand. From a process perspective, the benefits reflected in the dynamics: MacLeamy and Collaboration Platform, enable and are linked to process benefits such as Cost Plan Duration and Design Change Cost Effective, which in turn enable and link to the tangible benefits represented by Construction Cost and Construction Duration.

Within the inhibiting dynamics, the technical skills require for BIM reflected in the dynamic: Competence Technical, is reflected and links to the dynamics Training Level and Staff Specialist. From a financial perspective, the dynamic: Cost Implementation, links to those of Payback Short, Cash Flow and Company Survival, in what remains a challenging trading environment. From a time perspective, the project focused nature of the UKCI is captured by linked dynamics: Relationships Temporary and Short Term Focus. Finally, one of the clearest manifestations of the resistance to change captured by Industry Practices Robust is the linked dynamic, Separation Traditional Procurement, reflecting the ongoing use of this long standing approach, despite the separation between the activities of design and construction and the issues this brings.

Within the model, a number of logical links are also suggested between dynamics which support the adoption of BIM and those which inhibit adoption, with these being shown as blue lines between the opposing dynamics. From a cost perspective, the supporting dynamics Design Change Cost Effective and Construction Cost are both linked to the inhibiting dynamic Cost Implementation, reflecting the upfront investment in BIM required and the suggestion that there is scope for asymmetry between those who invest in BIM and those who accrue the benefits, particularly lower construction costs. The most significant supporting dynamic, Government Mandate links to Company Survival, with those companies active within the public sector, but who fail to adopt BIM, facing potential exclusion from a significant part of the UKCI. From a procurement perspective, the supporting dynamic, D&B Increase links to the inhibiting dynamic Separation Traditional Procurement, a long standing alternative procurement route. Finally, the lack of reduction in manpower reflected in the inhibiting dynamic, Design Team Size appears to related to and is therefore linked to the dynamic Design Change Cost Effective, where teams may be expected to do more design exploration rather than reducing the amount of work required.

Returning back to Lewin’s original application of topology as a means of representing forces within a life space for a particular group, these results allow the researcher to illustrate the dynamics of BIM at Figure 7.2, in a way which better indicates the complex relationships and interactions between these dynamics.

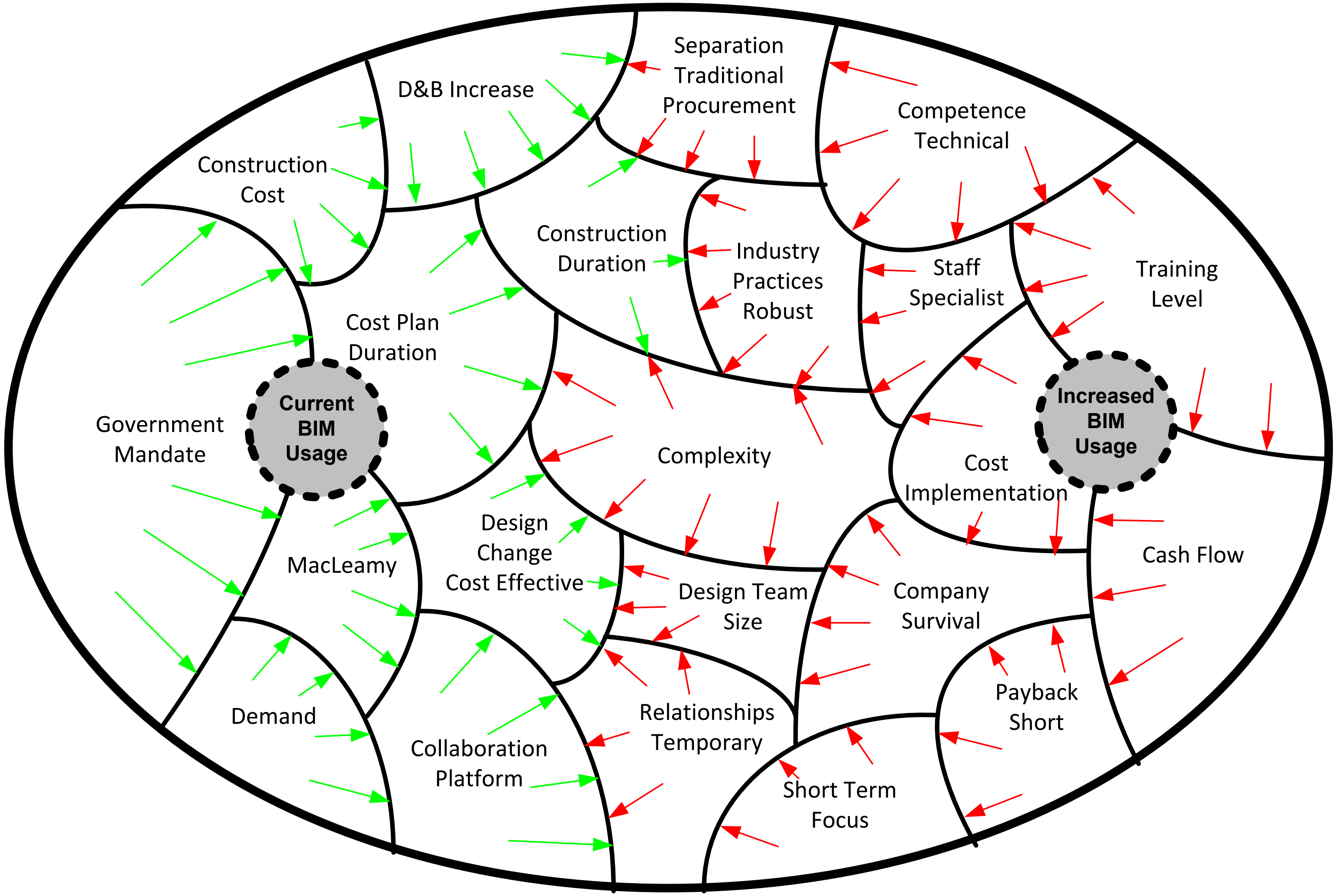

Figure 7.2 – Life Space: Dynamics of BIM Adoption

Here, the bounding oval represents the life space of companies within the UKCI, with current BIM usage shown as a point to the left and increased BIM usage as a point to the right. Within this life space are shown zones representing the dynamics of BIM adoption (forces) identified by the study, with those which support adoption are to the left with green arrows and those which inhibit to the right with red arrows. This life space diagram better illustrates the interrelationships between forces, demonstrating that increasing or reducing the size or pressure of one force, will not only affect immediately adjacent forces, but also the composition of the overall life space. In doing so, this negates the criticisms levelled against force field analysis (Goethals, 2008), including it's over simplification of complex influences.

Presenting the results in this way, validates the researcher's earlier observation that while the majority of supporting dynamics tend to be based on economic issues, the majority of inhibiting dynamics tend to represent organisational issues, aligning with Beer and Nohria (2000), who suggest change, in this case the adoption of BIM, is best supported by a combination of Theory E and Theory O. This further reinforces Lewin's suggestion, that to support change, not only do the supporting forces (dynamics) need to be strengthened, but also the inhibiting forces (dynamics) reduced.

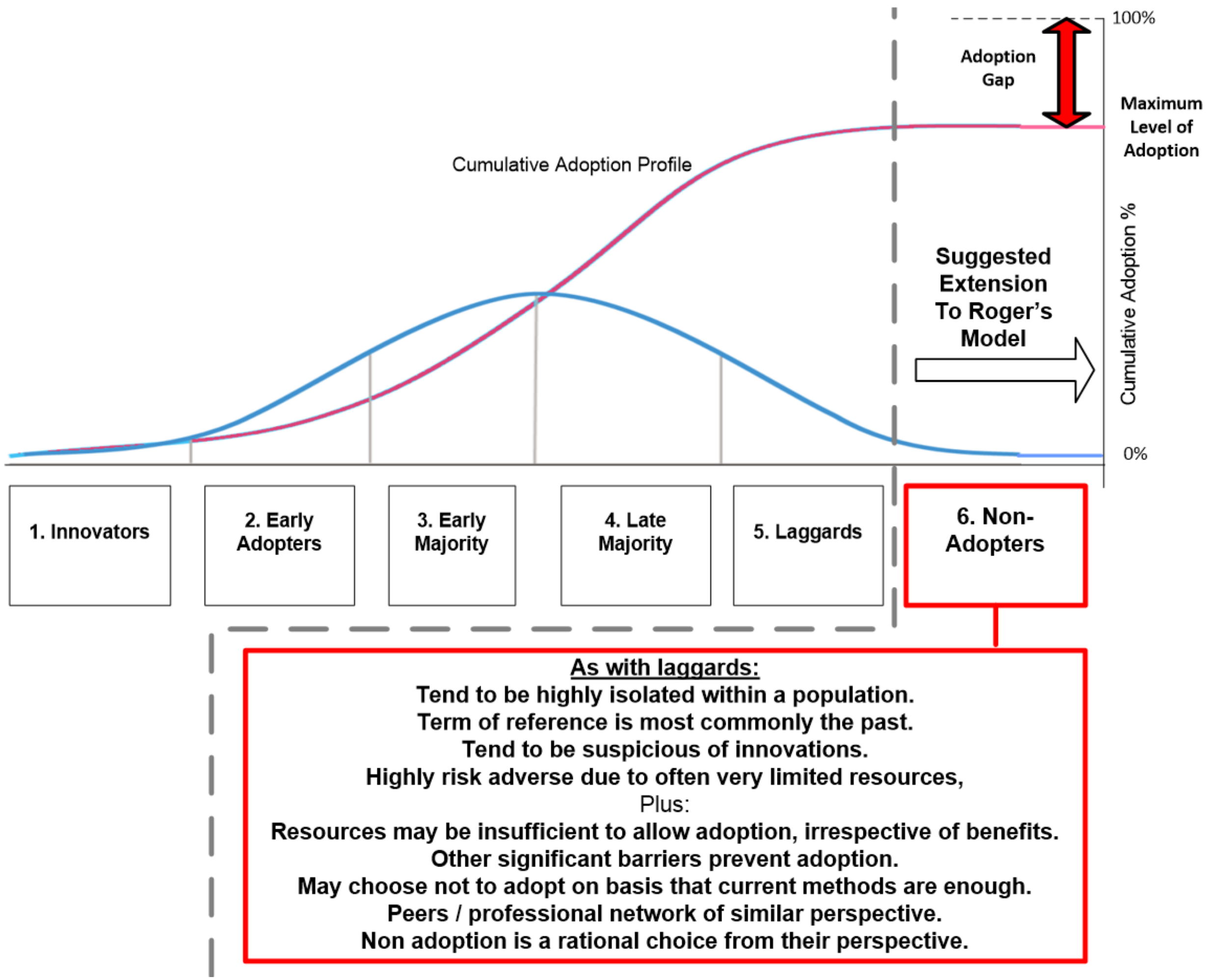

Figure 7.3 – Suggested Modifications to Rogers Categories of Innovation Adopters.

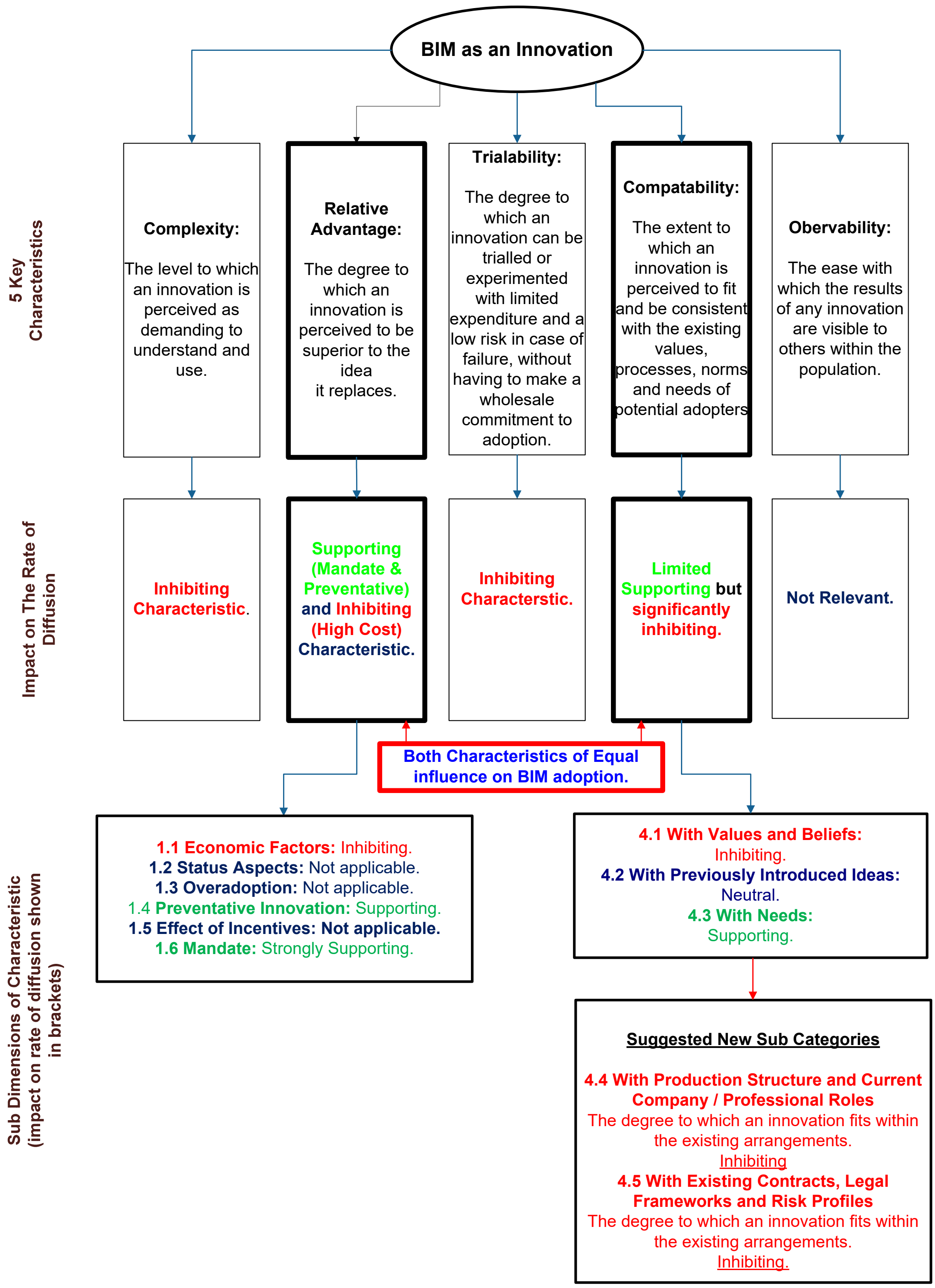

Figure 7.4 – Rogers Generic Characteristics of Innovations, Modified for BIM

7.5 Potential Changes to the UKCI

Given the advantages of BIM and the structural difficulties in collaborating effectively across company boundaries during temporary relationships, the potential for consolidation within the UKCI is highlighted as a possible consequence of BIM within the previous chapter. If this occurs, then the make up of the UKCI will change, as shown at Figure 7.5. This illustrates the potential transition from the current situation where smaller companies, who make up the vast majority of the UKCI by number, but only 40% of the UKCI by value, reduce in both number and market share and are locked out of larger public sector contracts. This is due to a small increase in the number of larger companies and their market share, due to BIM enabled cost benefits and their domination of larger public sector projects, which require the application of BIM.

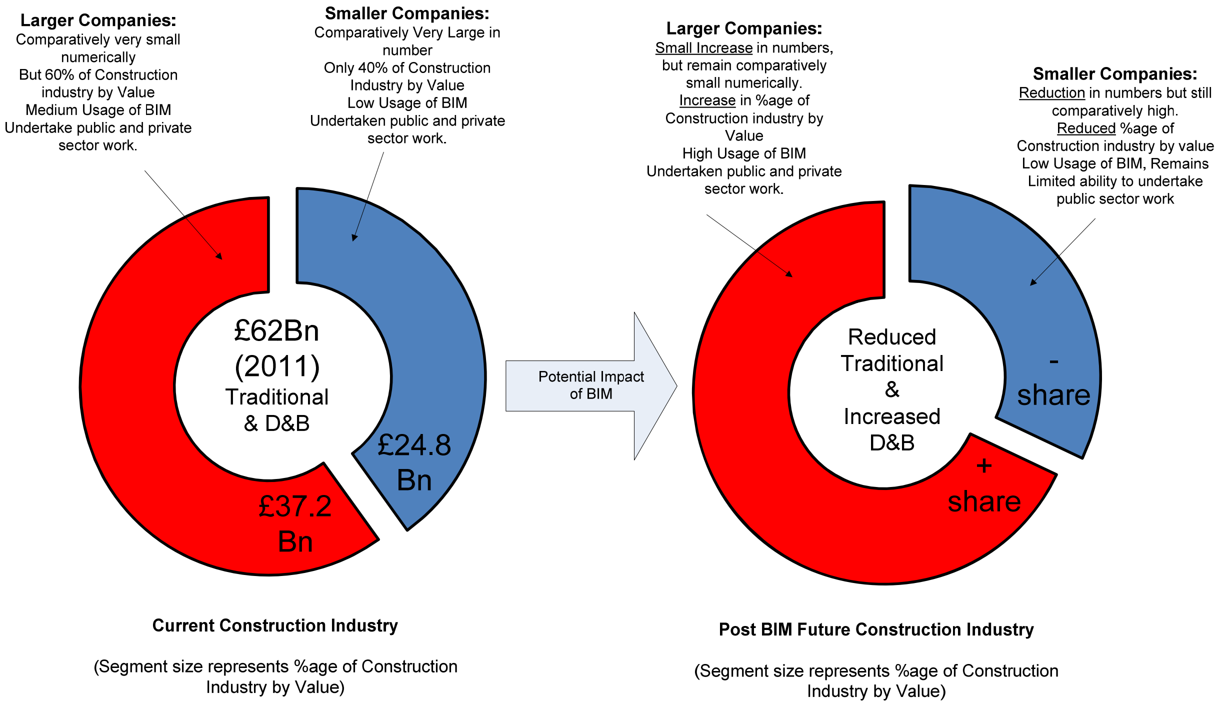

Figure 7.5 – Potential Changes to the Industry

7.6 Researcher's Observations

7.6.1 Results

While this study has been undertaken from a primarily positivist perspective, it is worth noting researchers own significant thoughts and observations on these results, as an insider researcher with extensive experience of the UKCI.

BIM is a complex innovation within a complex sector that uses unique methods of production. This is reflected in the high number of different dynamics suggested by the literature, the dynamics resulting from triangulation and by those emergent from the qualitative results. Although not directly identified within the results, from the researchers own experience, the wider culture of the UKCI reflected in its short term focus, resistance to change from established ways of working and focus on individual company rather than project benefits, also inhibit the adoption of BIM.

As the UKCI moves forward, it may be that the usage of BIM reaches such a level that a rigorous measurement of its benefits becomes impossible, due to the difficulty in separating out the impact of other issues. Social pressure within UKCI networks, may also mean the network effect becomes dominant and BIM simply becomes "the norm" irrespective of actual benefits, in the same way the mobile telephony and e-mail have in the business world.

While the lower adoption rates for smaller companies (turnover <£10M) and Sub-Contractors were not unexpected, it was of particular interest to explore the issue of benefits accrual. The researcher had been previously of the view that all who adopted BIM would see a direct benefit which reflects the amount of investment they have made. However, within the Discussion chapter, there appears to be some uncertainty as to whether this is happening, given an apparent asymmetry of investment vs. benefits accrual, the absence of the dynamic: Tangible Financial Benefits from the results and the benefit of reduced construction cost potentially being realised by Main Contractors, or being passed through to clients.

7.6.2 Comparing the Adoption of BIM with CAD

Although not specifically tested within this research, from the researchers own experience, Table 8.1 shows a number of noticeable parallels and differences in the recent adoption of BIM and that of its predecessor CAD, the adoption of which spanned the late 1980's, 1990's and early 2000's.

Characteristic	**CAD**	**BIM**
Speed of Adoption	Low – circa 15-20 years from initial introduction to widespread use.	High – large increase in adoption in the past 4 years.
Interoperability	Medium – Problems were present in the early days when vendor neutral formats were widely used. Issues were overcome by the effective dominance of the CAD market by AutoCAD.	Low – Problems remain with vendor neutral formats such as IFC and COBIE, although REVIT is the most widely used BIM application.
Technological Aspects	Low – ICT was immature, complex and relatively expensive.	High – ICT is mature, robust and relatively inexpensive.
Degree of change	Low – CAD replicated design activities undertaken manually using pen and paper.	Medium – BIM requires more fundamental change to processes and relationships.
Mandate	Low – No formal mandate for adoption was made.	High – Government has mandated all sector projects must use BIM by 2016.

Table 7.1 – Comparison of BIM and CAD

Firstly, the adoption of BIM appears to have been more rapid than CAD. This may be as a result of the Government Mandate combined with the fact that CAD has provided an interim step towards BIM from manual methods. In addition, more powerful and cost effective IT hardware and electronic communication via

Internet based collaboration tools are now established, whereas this was not the case during the adoption of CAD.

The BIM software market shows many similarities with the early CAD market, being dominated by a limited number of vendors who focus on selling feature rich high cost software. Early CAD adoption was also beset by issue of interoperability, which arguably only came close to being addressed by the domination of the market by Autodesk and their main product, AutoCAD, leading to their proprietary .DWG file format, rather than any vendor neutral file format, becoming the de-facto standard.

Early adopters of CAD tended to be larger organisations, a situation mirrored with BIM, reflecting the high initial costs. While the growth in design and build contracts lead some main contractors to adopt CAD, their adoption of BIM has been more rapid. This is probably as a result of the Government mandate, an increased applicability and benefits of BIM over CAD in construction activities and the desire to avoid “lock out”. While the last of these wasn’t an issue with CAD, overall, these have led to Main Contractors and Consultants having similar adoption rates. Eventually, lower cost CAD products enabled smaller companies to adopt, although its use is not universal and moving forward, a similar evolution in BIM may support its wider adoption.

From a process perspective, CAD often replicated tasks previously carried out using pen and paper and as such required little alteration to processes, inter-company interfaces or professional roles. In contrast, for the full benefits of BIM to be realised, a much wider raft of changes, some fundamental to the way the UKCI operates, need to take place.

7.7 Limitations of the Research

There are several limitations to the study that are worthy of attention, some of which relate to the research process. As cross sectional research, the results provide a snapshot of BIM within the UKCI at a single point in time. As a result, changes in the adoption and dynamics of BIM and whether adoption is following the ‘S’ curve suggested by Rogers are not covered by these results.

The research was undertaken a positivist perspective and applied mixed methods, which provided a high degree of validity and reliability and gave a good representation of the “what” of BIM within the UKCI, arguably at the expense of detail and the “why”. Similarly, taking a UKCI wide approach resulted in the achievement of “breadth” over “depth” of research. There were only 24 qualitative respondents, which aligned with literature recommendations to achieve saturation, but was much less than the circa 300 quantitative respondents. Finally, from a process perspective, the research method relied on individual respondents accurately representing both the status of BIM adoption within their employing company, as well as relevant dynamics of BIM adoption.

From a research outcome perspective, while the data captured was found to be unsuitable for exploratory factor analysis, it would have been useful to better understand any statistically robust cross correlation of the dynamics of BIM adoption, rather than relying on the thematic approach applied within the next chapter.

7.8 Future Research

In undertaking this study and approaching its completion, the researcher has become aware of potential future research, which may further contribute to our understanding and knowledge of BIM and its adoption within the UKCI.

As cross sectional research, these results provide a snapshot of BIM adoption and the associated dynamics at a single point in time, with the data capture being undertaken between October 2013 and January 2014. The research could be repeated longitudinally using the same instruments in 12, 24 and perhaps 36 months-time. This would enable any changes in BIM adoption and any patterns in these changes / or dynamics per se to be explored further.

To better understand the granularity and detail of BIM adoption, the substantial data captured from the semi structured interviews could be re-analysed qualitatively. The model of BIM adoption and life space diagram developed, provide a springboard from which future qualitative studies could be undertaken, focusing on a smaller number of Sub-Contractors or smaller companies, where this study highlights particular issues exist. An alternative but arguably more holistic perspective, which reflects the project based nature of the UKCI would be to again apply these models to qualitative studies of projects where BIM is being applied for the first time. This would enable examination of detailed issues such as the decision making process prior to BIM adoption, initial issues during implementation or the longer term effects of BIM within companies or to the project as a whole. These qualitative approaches would allow future researchers to better understand the “why” of BIM adoption from an individual company or individual project level.

The penultimate suggestion, reflects the pragmatic approach which pervades this research and seeks to better understand the key blockers to BIM adoption highlighted by this research. Future research could therefore consider “non-adopters”, the 10% of respondents who do not see any potential for the application of BIM within their company.

The now wide widespread use of BIM (average 62% of respondents) and the highest percentage (75%) of a building cost occurring during the operational and maintenance phase (Boussabaine et al., 2012, p.43), means there is potential for the cost of operations to be reduced and the benefits of BIM maximised. While this study has focused on the design and construction phases, future research may also consider the application of BIM and BIM data during the much longer and costlier operational phases of a building.

7.9 Concluding Remarks

BIM has the potential to offer significant benefits to the UKCI, but only if substantial changes are made to processes, roles and relationships across a mature sector. Despite the Government mandate, adoption remains inhibited by the current high cost of BIM, the inherent complexity of the means of production in the UKCI and BIM itself, combined with an asymmetry between those who adopt BIM and those who appear to receive the majority of the benefits, i.e. the Government, private sector clients and Main Contractors.

Despite the lack of fundamental change to the structure of the UKCI in the last century, when compared to other sectors, BIM has the potential to initiate more limited change within the confines of the existing structure in a number of ways. Firstly, there is the potential for division of the UKCI into two tiers: BIM and non BIM, with larger companies and those who are involved on larger projects using BIM. If these larger players are able to successfully overcome the inter-organisational issues of BIM, either through vertical integration or management practice, then they have the potential to achieve a significant competitive advantage over non BIM organisations. If applied to smaller projects, this advantage may lead to consolidation within the UKCI, along with improvements in performance and an increase in the barriers to entry.

Given the network rather than industry description of construction noted by the researcher above, combined with the lack of alignment of interests and the importance of full collaboration for BIM to fully succeed, one has to ask if the parties within the UKCI are capable of true collaboration focused around the benefits to the project. Based on the historically adversarial relationships, company rather than project specific focus, obsession with lowest cost and more recently the poor take up of partnering, highlighted within the literature review, regrettably this researcher has serious doubts. If this is in fact the case, then while BIM usage is likely to continue and grow, the benefits that it has to offer may never be fully realised. Notwithstanding this, the contribution this study brings can help the UKCI overcome these issues, through an understanding of the dynamics of BIM adoption along with the issues particular to Sub-Contractors and smaller companies, as well as informing future research.

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Appendix 1 – About the Researcher

Given Creswell's conclusion that "…. researchers approach their studies with a certain worldview that guides their inquiries" (1998, p.74) and the researchers own declared position as an insider researcher, it is worth exploring their background and experience within the UKCI, as this critical in controlling potential bias and ensuring validity and reliability is maintained.

The researcher is male, was born in 1967 and is married with 2 children. He has lived in the Huddersfield area of West Yorkshire, since 1984 and worked in the UKCI since 1988. He is currently employed by Interserve, a FTSE 250, £3Bn support services and construction company which is UK focused, but has a presence in about 40 other countries, with these contributing some 25% of revenue and 40% of group profits. While this company is not directly sponsoring the study, it is facilitating it by allowing the researcher time away from their duties and use of company IT equipment. The company is also adopting BIM and has expressed an interest in the outcome of the study, although it has not been involved in the choice of study or approach taken, both of which were entirely the choice of the researcher to avoid potential conflicts of interest.

From an early age the researcher has had a strong interest in science and technology and has been an avid user of computers since he was given a Sinclair ZX81 home computer in 1979, at the age of 11. After traditional O level and Maths / Science based A-level studies at sixth form, he originally studied Civil Engineering at Leeds University, however left this course after an academically successful first year. After a short spell working in retail banking and a 2 year break from studies, he joined the UKCI as a trainee architectural technician. Since then, the researcher has since undertaken 25 nearly continuous years of part time professional study while working full time. He is a Chartered Architect, qualified Project Manager and Fellow of the Chartered Institute of Building.

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Following on from an MBA completed at Huddersfield in 2004, this Doctorate is the next logical step in an on-going programme of lifelong learning.

During this career he has experienced two deep recessions within the UKCI and on reflection, some change, albeit much has stayed the same This change includes the introduction of new methods of procurement, different ways of working, some changes in roles and the wider use of technology. For the researcher, the 1990s were an interesting decade, which he spent learning about and implementing, what were then, cutting edge computer aided design (CAD) and specification systems in a medium sized local authority architects department. While the benefits of CAD were in his opinion clear to see and the rationale for its use has arguably been justified by its almost universal use today, at the time there were extensive resistance and many barriers to its implementation.

While the researcher’s current, more senior role is less hands on in terms of technology, there appear to be many parallels in this decade as the UKCI seeks to get to grips with the implementation of BIM. This is a technology enabled way of working that has been mandated for use by the UK Government on public sector projects by 2016. Although the adoption of BIM appears to have much in common with the adoption of CAD some twenty years beforehand, there are also differences. While CAD sought to replicate the design process previously undertaken on paper based media and transfer this to computer systems, the adoption of BIM is much wider in that it spans across the construction supply chain, has the potential to introduce a paradigm shift in roles, processes and even business models within the UKCI.

The researcher therefore brings to this research, a strong commitment to the personal and knowledge development, an interest in technology, extensive practical experience of the UKCI and finally, a sense of déjà vu in terms of some

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of the dynamics they perceive in relation to the implementation of BIM. Synthesising these with the opportunity to undertake Doctoral level research provides a valuable opportunity, not only for the researcher to develop further in a purely academic environment, but also from a practical perspective, in that any new knowledge can also be applied in their professional role.

This position and experience, have led the researcher to identify a number of possible areas of bias to the study. Firstly, as discussed above, the researchers own experience has inspired their decision select this research topic as well as a paradigm of pragmatism. In addition, the 27 years of experience within the UKCI, may lead to criticism of an insider-researcher role by others, as the researcher may be seen as an advocate of BIM rather than an objective and legitimate researcher. It is also important to declare, that from a professional perspective the researcher is broadly pro-technology and pro-BIM. A number of steps taken to overcome these issues are described within the methodology chapter.

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Appendix 2 – Suggested Dynamics of BIM Adoption

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Dynamic Title	Does the literature suggest a dynamic which supports or inhibits BIM adoption.	Suggested Size of Company Dynamic Most Applicable To (N /A, Higher or Lower Turnover)	Suggested Type of Company Dynamic Most Applicable To (N /A, Consultant, Sub-Contractor or Main Contractor)
Industry Flexibility	Supporting	N /A	N /A
Demand Uncertain	Inhibiting	Smaller	N /A
Companies Specialised	Inhibiting	N /A	N /A
Lowest Cost Focus	Inhibiting	Smaller	Sub-contractor
Supply Chain Risk Transfer	Inhibiting	Smaller	Sub-contractor
Industry Improvement Recognition	Supporting	N /A	N /A

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Project Focus	Supporting & Inhibitinging	N /A	Main contractor
Short Term Focus	Inhibiting	Smaller	N /A
Industry Fragmentation	Inhibiting	N /A	N /A
Industry Recession	Inhibiting	Smaller	N /A
Software Investment	Inhibiting	Smaller	N /A
Adoption Risk	Inhibiting	N /A	N /A
Time Implementation	Inhibiting	N /A	N /A
Cash Flow	Inhibiting	Smaller	N /A
Cost Implementation	Inhibiting	Smaller	N /A
Hardward New Specialist	Inhibiting	Smaller	N /A
Capital Availability	Inhibiting	Smaller	N /A

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Company Stability	Inhibiting	Smaller	N /A
Company Nature	Inhibiting	N /A	N /A
Innovation Processes	Inhibiting	N /A	N /A
Management Supportive	Inhibiting	N /A	N /A
Management Incentives	Inhibiting	N /A	N /A
Company Survival	Inhibiting	Smaller	N /A
Collaboration Company Types	Inhibiting	N /A	N /A
Company Leadership	Inhibiting	N /A	N /A
D&B Increase	Supporting	N /A	Main contractor

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Public Sector Procurement	Inhibiting	N /A	N /A
Traditional Procurement Decline	Supporting	N /A	N /A
Design Team Novation	Supporting	N /A	Consultant
Contract Prescriptive	Inhibiting	N /A	N /A
Design Change Cost Effective	Supporting	N /A	Consultant
Productivity Information Retrieval	Supporting	N /A	Consultant / Main Contractor
Design Team Focus	Supporting	N /A	Consultant
Quality of Build	Supporting	N /A	Main contractor
Quality of Design	Supporting	N /A	Consultant

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Carbon Emissions	Supporting	N /A	Consultant / Main Contractor
Construction Cost	Supporting	N /A	Main contractor
Life Cycle Information	Supporting	N /A	Consultant
Request For Information	Supporting	N /A	Main contractor
Life Cycle Cost	Supporting	N /A	Consultant
Main Contractor Costs	Supporting	N /A	Main contractor
Collaboration Platform	Supporting	Larger	N /A
Construction Duration	Supporting	N /A	Main contractor / Sub contractor
Tender Winning	Supporting	N /A	N /A
Payback Short	Inhibiting	Smaller	Sub-contractor

Formal Evaluations	Supporting	Larger	N /A
New Services	Supporting	N /A	Consultant / Main Contractor
Project Duration	Supporting	N /A	N /A
Value Added	Supporting	N /A	N /A
Site Variations	Supporting	N /A	N /A
Investment Benefits	Supporting	N /A	N /A
Projects Sustainable	Supporting	N /A	N /A
Design Information Quality	Supporting	N /A	Main contractor

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Site Delays	Supporting	N /A	Main contractor
Design Time	Supporting	N /A	Consultant
Project Cost	Supporting	N /A	N /A
Design Team Size	Supporting	N /A	N /A
MacLeamy	Supporting	N /A	Consultant / Main Contractor
Marketing	Supporting	N /A	N /A
Use Benefit Level	Supporting	Larger	N /A
Benefits Financial Tangible	Supporting	N /A	N /A

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Complexity	Inhibiting	Smaller	Sub-contractor
Staff Level	Supporting	N /A	N /A
Productivity Design Rework	Supporting	N /A	N /A
Observability	Inhibiting	N /A	N /A
Cost Plans Duration	Supporting	N /A	N /A
Projects Pilot	Supporting	N /A	N /A
Skills General Business	Inhibiting	Smaller	N /A
Competence Technical	Inhibiting	Smaller	Main-contractor
Training Level	Inhibiting	Smaller	Sub-contractor
Promotion Technology Access	Supporting	N /A	N /A

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Networks Knowledge	Supporting	N /A	N /A
Staff Specialist	Inhibiting	Smaller	N /A
Collaboration Promotion	Supporting	N /A	N /A
Compatibility Existing Systems	Inhibiting	Larger	Main contractor
Co-ordination Different Companies	Inhibiting	N /A	Main contractor
Change Resistant	Inhibiting	N /A	N /A
Systems Bespoke	Inhibiting	Smaller	Consultant / Sub contractor

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Systems Open	Support	N /A	N /A
Infrastructure High Speed	Inhibiting	Smaller	N /A
Research Academic	Supporting	N /A	N /A
Exchange Formats Neutral	Supporting	N /A	N /A
Clients	Supporting & Inhibitinging	N /A	N /A
Client Mandate Early	Supporting	N /A	Consultant
Influence Clients	Inhibiting	N /A	N /A
Government Mandate	Supporting	Larger	N /A
Client Policies	Supporting	Larger	N /A

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Relationships Supply Chain	Inhibiting	N /A	N /A
Relationships Temporary	Inhibiting	N /A	Consultant / Sub contractor
Relationships Cross Project	Inhibiting	N /A	Consultant / Sub contractor
Relationships Within Industry	Inhibiting	Smaller	Consultant / Sub contractor
Innovations Quicker	Inhibiting	N /A	N /A
Control Span Of	Inhibiting	N /A	Consultant / Sub contractor
Client Contractor Collaboration	Inhibiting	N /A	N /A

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Design Risk Tender	Inhibiting	Smaller	Consultant
Influence Client Requirements	Inhibiting	N /A	N /A
Decision Start Project	Inhibiting	N /A	Consultant
Company Policies	Supporting	Larger	N /A
Company Policies	Supporting	N /A	N /A
Trialability	Inhibiting	N /A	N /A
Project Team Composition	Inhibiting	N /A	N /A
Separation Traditional Procurement	Inhibiting	N /A	Main contractor

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Industry Practices Robust	Inhibiting	N /A	N /A
Working Environment	Inhibiting	N /A	N /A

Table A2.1 - Suggested Dynamics of BIM Adoption

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Appendix 3 – Ethical Considerations Checklist

A3.1 Project Title

This is covered by the introduction to the thesis.

A3.2 Expected Duration

The research is planned to be completed by May 2014. For respondents taking part in quantitative data capture, the researcher anticipates this will take between 20 to 30 minutes to complete. For respondents taking part in qualitative data capture, the researcher anticipates this will take between 30 to 45 minutes to complete.

A3.3 Identity of Organisational Base and Field Researchers

This research was carried out in order to meet the requirements of The Business School, University of Huddersfield to lead to the award to the researcher of a Doctorate of Business Administration. The research was carried out under the supervision of Dr. Annie Yeadon-Lee (DBA Course Leader), Steve Lawson and Dr. Leigh Morland (Academic Supervisors) and was carried out in strict accordance with the University Regulations. The research and all contact with respondents was carried out by the researcher, Lawrence Seed.

A3.4 Purpose of Study

Full detail can be found in Introduction chapter of this thesis.

A3.5 Sources of Funding

The research is being funded by the researcher. The researcher is being supported by non-financial support in terms of flexibility of working arrangement, time and use of company ICT resources by their employer, Interserve Investments Ltd. Although Interserve has not influenced the content, it should be noted that without this support to the researcher, this study would not be possible.

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A3.6 Scientific Background

This is covered in the Methodology chapter of the thesis.

A3.7 Design of Research

The research applied equal status concurrent mixed methods.
Detail is provided in the Methodology chapter of the thesis.

A3.8 Potential Benefits and Hazards

The benefits of this research are covered in the Introduction chapter of the thesis.

The researcher does not anticipate any hazards for individual respondents as all findings and any data published will be anonymous. The researcher does not anticipate any hazards for respondents' employers, given the wide dissemination of the research results outlined in item 3.14 below.

A3.9 Recruitment Procedures

All participants will be asked to take part in the research on a purely voluntary basis, with no implicit or explicit inducements.

A3.10 Informed Consent

All participants approached were briefed on the research, the purpose of the research and the ethical measures being taken. They were asked to give their informed consent prior to data collection. Any potential participants who do not give their informed consent did not form part of the data collection process.

All participants were able to withdraw their informed consent at any time prior to publication. This withdrawal resulted in the removal of the participants responses from the data set used for analysis and the deletion of the data. The granting, declining or withdrawal of informed consent was recorded by the researcher and confirmed in writing to the respondent by e-mail.

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All participants were asked if they would like to be provided with an electronic summary of the research findings on completion.

A3.11 Data Protection

All personal data was processed and held in accordance with the Data Protection Act 1998, under the University of Huddersfield's wider data protection registration.

A3.12 Confidentiality and Anonymity

To maintain respondent confidentiality, anonymity and data security, the researcher applied the following techniques and process:

Details of respondents, a record of their informed consent (or otherwise) and their responses (the primary data) were held securely.

Within the thesis itself, all data presented was anonymous, no names of individuals or their employing organisations was cited and the researcher took reasonable measures to ensure that it is not possible to use any anonymous data to identify individual respondents.

The personal details of each respondent and the data collected from each individual were held separately to ensure that security is maintained during the research process and that data within the thesis itself is anonymous.

Respondents' personal data was held in a Secure Personal Index File and data collected from each will be stored in a number of Anonymous Data Files as shown at Figure A3.1

`

Participant Index File

Name	Contact Details	Organisation	Unique Reference Number
Joe Bloggs	01-811-8055	A Builder	3454

1. Containing confidential personal and contact details of each participant

2. Secure data for authors use only in capturing data.

3. 128 Bit Encryped Micrsoft Excel .xlsx Spreadsheet.

4. Securely stored **K:\ drive** only and backed up as part of university system backups.

5. Access to this file required for identification of participant.

Link Between Partipant and Data Provided by URN

Anonymous Data Files

Unique Reference Number	Data 1	Data 2	Data 3	Data 4
3454	Strongly Agree	Disagree	No	Revit

Figure A3.1 - Storage of Respondents' Details and Data

Within this Participant Index File, a record was created for each participant approached which will include a Unique Reference Number (URN). This file was

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created in Microsoft Excel 2010, and provided with a strong password using the 128 bit encryption facility provided in this software package.

Qualitative and quantitative data collected from individual respondents will be identified by means of the URN above. Depending on the initial format and subsequent analysis, this data was stored in password protected Anonymous Data Files in Word, Excel, SPSS and Nvivo, all of which offer this facility.

This means that preparation, analysis and discussion are all carried out on anonymous data. Only by cross referencing the URN in both the secured Participant Index File and the Anonymous Data Files is it possible to identify individual respondents and the data they have provided.

In this way the possibility of data loss, deliberate or accidental unauthorised access to respondents personal details was minimised, in line with the requirements of the Data Protection Act and best practice.

A3.13 Monitoring of the Research

The research will be monitored by the three academic supervisors identified in point 4 above.

A3.14 Dissemination of Findings

Following submission and marking of the research by the University of Huddersfield and notification of its acceptance to the Researcher for the Doctorate, the research will be disseminated in the following order:

1. One copy retained by University of Huddersfield Library.
2. An electronic copy submitted to the British Library Thesis Repository.

3.= A summary of findings will be issued to all respondents who indicated at recruitment stage that they wished to receive a copy. Any respondent

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who wishes to receive a fully copy of the research will also be issued with an electronic copy.*

3. = A soft copy of the research will be issued to the researcher’s employer. *

5. = A number of journals will be approached for potential publication of the Journal Article.

* - The simultaneous release of the research to both the researcher’s employer and a summary of findings to respondents, is designed to overcome any conflict of interest issues that may arise due to early access to the data by organisations engaged a highly competitive construction environment.

`

Appendix 4 – Semi Structured Interview Informed Consent Form

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Dynamics of Building Information Modelling Adoption

Telephone Interview Consent Form

Firstly, a big **thank you** for expressing an interest in taking part in this research.

The purpose of the research is to explore your perceptions of the dynamics of Building Information Modelling in the UK construction industry.

The term Building Information Modelling can be used in many different ways.

For the purpose of this research, it is taken to mean:

> ***An information technology enabled approach that fully integrates people, systems, business structures and practices into a collaborative and highly automated process.***

The researcher will call you at the pre-arranged time on the agreed number, to take part in the telephone interview to discuss the dynamics of BIM adoption.

The interview to discuss your own perceptions of BIM will last between 30 – 60 minutes and will be recorded.

All responses will be treated confidentially and any published extracts, quotations or results will be cited anonymously. There are no trick questions and or "right" or "wrong" answers.

Consent

Please sign and date within the boxes to confirm your informed consent to take part in this research.

Signature:
Date:

You are free to withdraw from this research at any time prior to publication. If you wish to do so, please contact the researcher by phone on **XXXX YYYYYY.** Your data will then be withdrawn from the research, the recording deleted and any relevant transcriptions notes destroyed.

Results

If you would be interested in receiving a copy of the completed research or a summary of the results, please indicate this below.

Yes – please send me a summary of the results.	Yes – please send me a copy of the completed research.

Return

Thank you for agreeing to take part in this research– please use the stamped addressed envelope provided to return this consent form to the researcher.

IC.URN 0342

Page 1 of 1

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Appendix 5 – Semi Structured Interview Guide

Dynamics of BIM adoption
Semi Structured Interview Guide

Date: ____________________
Time: ____________________
Company: ____________________
Respondent: ____________________

Introduction and Interview Protocol

I'm ringing as per our earlier conversation to interview you about BIM.

Take ~ 30 / 40 min. Is it convenient ?

Recap on my role: Doctoral student at UoH, not employee of Interserve

Recap - You have given your consent to be interviewed.

You have the option to withdraw at any time – just let me know and the interview will stop.

As previously discussed, I will be recording the interview for later transcription. Is that still OK ?

Any information from the interview will be confidential.

To maintain confidentiality, all data will be kept securely and destroyed at the end of the study.

Finally, there are no right or wrong answers – its your opinion I'm interested in.

If theres anything you're unsure how to answer, just say and we can skip that part.

If that's all, Ok, lets get started !

Significant Dynamics of BIM Adoption Encountered

Compatibility

Degree of fit: Culture, Custom & Practice

Processes and System

Effort Profile

Your Company / Industry Level

Complexity

How demanding is BIM to use / adopt ?

Skills and knowledge

Training

Degree of change

Observability

Ease of assessment of benefits

How

To whom ?

Trialability

Ability to "try before you buy" or carry out a pilot before making large scale adoption decision.

Relative Advantage

Superiority to previous / current methods:

Clients

Demand

Benefits

Business case

Variation by Company Size and Type

Company Type Specifics – Main Cont, Subbie, Consultant.

Higher / Lower turnover related issues.

About Respondents & Usage Metrics

1. Designation ?
2. Employers Main Business ?
3. No of people who work for employer ?
4. Approx Turnover ?
5. How Long Used BIM ?
6. %age of work currently done on BIM ?
7. %age of work sharing BIM data ?
8. %age that could be carried out on BIM ?

Close Down

Is there anything else you'd like to add on your views / experience of BIM ?

Why is that ?

That's great – that concludes the formal part of the interview.

Its been great talking to you, thank you very much for your time.

Kvale's (1996) **Nine** Types of Questions in Qualitative Interviews

Introducing
"Why did you .." "Can you tell me about …"

Follow Up
"What did you mean by …" "Can you give me more detail of …"

Probing
"Do you have any examples …." "Could you say more about …"

Specifying
"What happened next"

Indirect Questions
"YYY is of the view that …."

Structuring Questions
"Moving on to …."

Silence
Indicating you wish further detail / answer the question.

Intepreting
"So do you mean that …"
"Is it correct that …"

Direct Questions
With a yes / no answer.
Best left till last

`

Appendix 6 – Coding Template

Ref:	Dynamic / Code	Brief Description of Code in terms of what the respondent says / mentions (including influence on BIM adoption / usage in all cases).
1	Industry Flexibility	Adaptability / flexibility / openness of industry / construction / or similar.
2	Demand Uncertainty	Presence or lack of demand / requirement / necessity or similar
3	Companies Specialised	Specialism / focus / dedicated or similar of companies or similar.
4	Lowest Cost Focus	Focus on lowest price / cost / fee / rate / charge / budget / outlay or similar
5	Supply Chain Risk Transfer	Risk transfer / allocation / assignment within supply chain / sub contracts or similar.
6	Industry Improvement Recognition	Recognition / perception / identification that industry needs to improve / get better or similar
7	Project Focus	One off / project / scheme / building focus / discontinuity or similar
8	Short Term Focus	Focus / attention or similar on short term.
9	Industry Fragmentation	Fragmentations / specialisation / large number of companies on a project or similar.

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10	Industry Recession	Recession /downturn / dearth of work / hard times or similar.
11	Software Investment	Investment / purchase or acquisition of new specialist / dedicated software or similar.
12	Adoption Risk	Risks / uncertainty / unpredictability in terms of adoption / use or similar.
13	Time Implementation	Lack or shortage of time / programme pressure / demands or similar.
14	Cash Flow	Keep / maintain / continue cashflow / income or similar.
15	Cost Implementation	High / excessive / price / cost / expenses.
16	Hardware New Specialist	Investment / purchase or acquisition of new specialist / dedicated ICT / hardware / computers or similar.
17	Capital Availability	Lack / absence / dearth of capital / cash / money for purchase / investment / acquisition or similar.
18	Company Stability	Company / or organisation stability / ongoing health is more important / priority or similar.
19	Company Nature	Nature / characteristic / disposition / make up of companies / firms or similar.
20	Innovation Processes	Lack / dearth / absence of innovation / adoption - process / systems / procedure or similar.
21	Management Supportive	Frim / Company management / supervision / are supportive / encouraging or similar.
22	Management Incentives	Inducements / incentives / motivations for managers / leaders / supervisors or similar.
23	Company Survival	Company / firm / organisation - ongoing existence / survival / being.
24	Collaboration Company Types	Collaboration / teamwork / partnership with different types / categories / specialisms of companies / firms and organisations or similar.

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25	Company Leadership	Lack / dearth / absence of firm / organisation / company leadership / guidance / direction or similar.
26	D&B Increase	D&B / single point of responsibility procurement / contracts or similar.
27	Public Sector Procurement	Public sector procurement / tender process / systems or similar.
28	Traditional Procurement Decline	Decline / reduction / fall in fully designed / traditional procurement / tender or similar.
29	Design Team Novation	Design team / consultant / designers transfer / novation client swap in D&B.
30	Contract Prescriptive	Prescriptive / rigid / narrow contract documents / requirements / processes.
31	Design Change Cost Effective	BIM allows cost effective exploration / consideration of changes / variations / design development or similar.
32	Productivity Information Retrieval	Easier / more rapid retrieval / finding / obtaining of information or similar.
33	Design Team Focus	The team can spend more time / effort / focus on design or mention of less time being spend on production of documentation or similar.
34	Quality of Build	Improved quality / superiority of finished / completed building / product / scheme or similar.
35	Quality of Design	Improved quality / superiority of design or similar.
36	Carbon Emissions	Reduced / smaller carbon / CO_2 emissions / releases, production or similar.
37	Construction Cost	Decline / reduction / fall in build / construction cost / price / bill or similar.
38	Life Cycle Information	Transfer / feed of information / data to life cycle / operations model / database or similar.

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39	Request For Information	RFI / requests for information / queries from site / construction / main contractors falls / reduced / minimised or similar.
40	Life Cycle Cost	Life cycle / operational / repair costs / price / budget of building / project / site reduced / minimised / decline or similar.
41	Main Contractor Costs	Costs / price for the main / lead contractor are reduced / lowered / minimised or similar.
42	Collaboration Platform	Platform / system / approach which supports / enhances / improves collaboration / teamwork / partnership or similar.
43	Construction Duration	Duration / timescale / programme for construction / site / build activities or similar.
44	Tender Winning	Improved tender / work / bid / win rate / success or similar.
45	Payback Short	Short / rapid / quick payback / return on investment / benefit realisation or similar.
46	Formal Evaluations	Formal / recognised / proper evaluations / appraisal / calculation of benefits / returns / advantages or similar.
47	New Services	New / enhanced / different services / offerings / deliverables to clients / customers / buyers / users or similar.
48	Project Duration	Reduction / decrease / shortening of time / programme / period to build / deliver a project / building / scheme.
49	Value Added	Add / increase / grow the value / worth / usefulness / benefit of activities / process / actions within the industry / construction / building or similar.
50	Site Variations	Site / construction / build led amendments / change orders / variations are reduced / decreased / occur less or similar.
51	Investment Benefits	Benefits / return / value / worth that companies / firms / organisations receive / accrue / gain reflect / mirror the level / amount of investment / spend / financial commitment or similar.

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52	Projects Sustainable	Buildings / projects / schemes increased / more sustainable / greener / environmentally friendly or similar.
53	Design Information Quality	Better / improved / enhanced quality / standard of design information / documentation / drawings or similar.
54	Site Delays	Build / construction / site delays / extensions due to / caused by / root cause by design issues / clashes / documentation minimised / reduced / less or similar.
55	Design Time	Design / creation time / programme / period reduced / minimised / shortened or similar.
56	Project Cost	Cost / price budget for whole / overall / entire project / building scheme reduced / minimised / savings or similar.
57	Design Team Size	Design / consultant team / group / number smaller / reduced / shrunk or similar.
58	MacLeamy	MacLeamy, effort / work / energy / endeavour focused / concentrated most / maximum impact / effect / influence or similar.
59	Marketing	Marketing / sales / advertisement / promotion supported / enhanced / increased or similar.
60	Use Benefit Level	More / increased / higher use / utilisation / application ….. benefits / rewards / return or similar.
61	Benefits Financial Tangible	Benefits / return / value / worth tangible / real / return on investment or similar.
62	Complexity	Issues with BIM being complex, complicated, intricate, convoluted or similar.
63	Staff Level	Scheme / project / building staff / team size / group reduced / shrunk / minimised / smaller or similar.
64	Productivity Design Rework	Increased / more / enhanced productivity / work rate via / through reduced / less design / re-work / abortive work or similar.

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65	Observability	Benefits / rewards / returns / advantages observable / easy to see / easy to determine / visible or similar.
66	Cost Plans Duration	Accelerated / faster / rapid take off / quantitates / costing / cost plans or similar.
67	Projects Pilot	Pilot / trial / test / preliminary projects / roll outs / adoptions or similar.
68	Skills General Business	Lack / dearth / shortage of general business / management / commercial / professional skills / knowledge / experience.
69	Competence Technical	Issues with BIM requiring a level of technical skills, knowledge, competence across the project or similar.
70	Training Level	Issues with BIM requiring a high level of training, learning, teaching, guidance, tutoring, skill, knowledge, ability, proficiency or similar.
71	Promotion Technology Access	Promotion / publicity of events / programmes / occasions for access / visibility of technology / ICT / software or similar.
72	Networks Knowledge	Knowledge / skill / learning networks / relationships / forums / connections or similar.
73	Staff Specialist	Specialist / trained / professional staff / human resource / capital / individuals or similar.
74	Collaboration Promotion	Promotion / publicity / events / programmes / occasions supporting / encouraging collaboration / teamwork / partnership or similar.
75	Compatibility Existing Systems	Incompatible / at odds with / unsuited / contrary to existing / current systems / processes / ways of working within the industry / construction / building or similar.
76	Co-ordination Different Companies	High / increase / more co-ordination / arrangement / order across different / many / multiple companies / firms / organisations or similar.
77	Change Resistant	Social / habitual / routine resistance / barrier to change / improvement / amendment / different process or similar.

`

78	Systems Bespoke	Bespoke / individual / customised company / form / organisations systems / processes / methods or similar.
79	Systems Open	Task Force / Government specified mandated open system / vendor neutral / neutral format / neutral file interface / software independent / COBie or similar.
80	Infrastructure High Speed	Lack / slow / inadequate high speed / fast / broadband / network / infrastructure or similar.
81	Research Academic	Stimulation / support formal / academic / proper / precise research / exploration / investigation or similar.
82	Exchange Formats Neutral	Task Force / Government specified mandated open system / vendor neutral / neutral format / neutral file interface / software independent / COBie / IFC or similar.
83	Clients	Clients / customers / consumers / patrons / buyers or similar.
84	Client Mandate Early	Early / start / beginning mandate / requirement / enforcement / instruction or similar.
85	Influencing Clients	Difficulty / problem / issue with influencing / persuading / swaying clients / customers / buyers or similar.
86	Government Mandate	Government mandate / requirement for BIM / Level 2 / usage / 2016 on large / public sector projects / tenders / schemes or similar.
87	Client Policies	Client / customer / buyer supportive / enhancing policies / mandate / instruction / requirement or similar.
88	Relationships Supply Chain	Links / networks / relationships supply chain / suppliers / providers / Sub-Contractors / Consultants or similar.
89	Relationships Temporary	Temporary / short term / transient relationships / arrangements / contacts / contracts within construction / industry / building or similar.

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90	Relationships Cross Project	Long term / multiple project / strategic relationships / networks / work streams / contracts or similar.
91	Relationships Within Industry	Nature / characteristic / type of relationships / contracts / networks / working arrangements within construction / industry / building or similar.
92	Innovations Quicker	Innovations / enhancements / new things / new ways of working faster / quicker / more rapid to adopt / implement / use / apply or similar.
93	Control Span Of	Control / oversight / authority / jurisdiction is outside / too much / impossible for any single party / company / business / organisation or similar.
94	Client Contractor Collaboration	Client / customer / buyer and contractor / supplier / provider / builder lack / absence / of collaborative / teamwork / partnership or similar.
95	Design Risk Tender	Design work / up front work at risk / unpaid in tender / competition or similar.
96	Influence Client Requirements / Process	Inability / impossible to influence / change clients / customer / buyers requirements / process / route / solution in a tender / competition or similar.
97	Decision Start of Project	Decision / mandate / requirement / instruction at start / early / beginning of project / scheme or similar.
98	Company Policies	Policies / protocols / guidelines / arrangements within my company / firm / organisation / builder / consultancy or similar.
99	Stimulation	Stimulating / supporting / encouraging / innovating regulations / requirements / standards within industry / construction / building or similar.
100	Trialability	Trial, try out, pilot, preliminary or similar.

`

101	Project Team Composition	Make up, composition, mix, membership of project / scheme team / organisation or similar.
102	Separation Traditional Procurement	Separation / segregation / divorce / split of design / development and construction / build / site activities under traditional / full design then build or similar.
103	Industry Practices Robust	Existing / current practices / methods / processes are too robust / resistant to change / entrenched / powerful or similar.
104	Working Environment	Supportive / complementary / backing working / employment environment / setting / situation or similar.

Table A6.1 - Coding Template

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Appendix 7 – Introductory Letter (Postal Version)

Lawrence Seed
[Home Address included
on original - omitted for
confidentiality in thesis copy]

Respondents Name
Respondents Company Name
Respondents Address

Date XX / YY / 2013

Dear Dr / Mr / Mrs / Miss [Deleted as appropriate] XXXX,

Following our telephone conversation of XXXX, thank you for agreeing to take part in my Doctoral Research on BIM.

Please find attached a copy of the Questionnaire we discussed and a stamped addressed envelope for you to return this.

Many thanks for your participation and time.

Yours Sincerely

[Signatureincluded
on original - omitted for
confidentiality in thesis copy]

Lawrence Seed

`

Appendix 8 – Quantitative Questionnaire (Postal Version)

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Dynamics of Building Information Modelling

Consent Form and Questionnaire

Firstly, a big **thank you** for expressing an interest in taking part in this research.

The purpose of this research is to explore your perceptions about the dynamics of Building Information Modelling in the UK construction industry.

The term Building Information Modelling can be used in many different ways.

For the purpose of this research, it is taken to mean:

> ***An information technology enabled approach that fully integrates people, systems, business structures and practices into a collaborative and highly automated process.***

This questionnaire contains 113 questions and will take you around 30 minutes to complete.

Please answer all questions.

All responses will be treated confidentially and all published research results will be anonymous. There are no trick questions and or right or wrong answers.

Consent

Please sign and date within the boxes to confirm your informed consent to take part in this research.

Signature:
Date:

You are free to withdraw from this research at any time prior to publication. If you wish to do so, please contact the researcher by phone on **XXXX XXXXXX.** Your data will then be withdrawn from the research, your questionnaire destroyed and any results deleted.

The Dynamics of Building Information Modelling

In this main set of questions, you will be presented with statements about the potential dynamics of Building Information Modelling in the United Kingdom Construction Industry.

Based on your employers / company experience within the UK construction industry, please indicate your level of agreement or disagreement with each statement.

`

Q1. BIM is supported by the flexibility of the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q2. The demand for BIM within the current construction industry market is uncertain.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q3. The highly specialised nature of companies within construction is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q4. BIM is not supported by the focus on lowest cost within the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q5. BIM is inhibited by risk transfer down the supply chain.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q6. BIM is supported by a wider recognition that the construction industry needs to improve its performance.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q7. BIM is supported by a project by project focus within construction.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q8. The short term focus of the construction industry is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q9. Fragmentation within the construction industry is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q10. BIM is being hindered by the current recession within the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q11. Investment in new specialist software is required to adopt BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q12. The risks in adoption are a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q13. BIM is held back by a lack of time to implement.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q14. The need to maintain cash flow is a hindrance to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q15. BIM is expensive to implement.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q16. BIM requires investment in new specialist hardware.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q17. A Lack of capital to invest is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q18. Company stability is more of a priority than BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q19. The nature of companies within the construction industry is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q20. BIM is held back by a lack of innovation processes.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q21. Company management are supportive of BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q22. BIM is supported by incentives for managers.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q23. Company survival comes before implementing BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q24. Collaboration with different types of companies within the construction industry assists BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q25. BIM is held back by a lack of appropriate company leadership.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q26. BIM is supported by the increase in use of Design and Build contracts.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q27. BIM is aided by public sector procurement processes.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q28. BIM is supported by the historic decline in traditional procurement.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q29. BIM is supported by the novation of the Design Team within Design and Build Contracts.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q30. Prescriptive contract documents inhibit BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q31. BIM allows possible design changes to be more cost effectively explored.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q32. Productivity is improved through the easy retrieval of information from BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q33. BIM allows the design team to spend more time on design.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q34. BIM results in an improved quality of build.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q35. BIM results in improved design quality.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q36. Carbon emissions are reduced on projects designed using BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

Q37. BIM reduces the construction cost of projects.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

Q38. BIM information can be directly fed into a life cycle model / database.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

Q39. BIM results in a reduction in requests for information / queries from site.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

Q40. BIM enables a reduction in the life cycle costs of a project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

Q41. BIM reduces the costs of the main contractor.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

Q42. BIM provides an intelligent collaboration platform.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don’t know	Prefer not to say.

`

Q43. The duration of construction works on site is reduced when using BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q44. BIM supports winning more work in a formal tender process.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q45. The need for short paybacks on investment is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q46. The advantages of BIM are clearly illustrated by formal evaluations of the benefits.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q47. BIM enables the provision of new services to clients.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q48. BIM enables an overall reduction in the time taken to deliver a construction project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q49. BIM presents the opportunity to add value to activities within the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q50. Site led variations and change orders are reduced when using BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q51. The benefits that individual companies receive from BIM reflect the levels of investment they make.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q52. BIM enables the delivery of more sustainable projects.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q53. BIM is supported by an improved quality of design information.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q54. There are less site delays due to design issues when using BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q55. The time taken to design is reduced using BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q56. BIM reduces the overall cost of the project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q57. BIM enables design to be carried out by a smaller team.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q58. BIM enables effort to be concentrated to when it has the most impact on the project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q59. BIM supports company marketing.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q60. The more a company uses BIM, the more benefits it receives.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q61. Implementing BIM leads to tangible financial benefits.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q62. The complexity of BIM is an obstacle to its use.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q63. Across the whole project, staff can be reduced when using BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q64. BIM increases productivity through reduced design re-work.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q65. The benefits of BIM to those who adopt it are easy to observe.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q66. BIM enables the development of accelerated cost plans direct from the model.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q67. BIM is supported by the funding of pilot BIM projects.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q68. A lack of general business skills is an obstacle to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q69. BIM requires a degree of technical competence across the whole project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q70. BIM requires a high level of training.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q71. BIM is supported by programmes promoting access to technology.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q72. Knowledge networks (e.g. the CIC's BIM Hubs) support the adoption of BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q73. The ability to provide specialist staff to operate BIM is a barrier to its use.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q74. BIM is supported by programmes which promote collaboration.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q75. BIM is incompatible with existing systems within the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q76. BIM requires a high degree of co-ordination across different companies.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q77. A social / habitual resistance to change is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q78. Bespoke company specific systems are barriers to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q79. The open system (software independent) approach recommended by the BIM Task Group supports the adoption of BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q80. A lack of high speed ICT infrastructure is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q81. BIM is supported by a stimulation of formal / academic research.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q82. BIM is supported by the use of vendor / software neutral data exchange formats such as COBIE / IFC.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q83. Clients are a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q84. The early client mandate to use BIM assists its use.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q85. The difficulty in influencing clients is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q86. BIM is supported by the Government's mandate for its use on large projects by 2016.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q87. The development of top down supportive policies by the client supports BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q88. BIM is supported by links and relationships with the supply chain.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q89. The temporary nature of relationships within construction is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q90. BIM is assisted by developing relationships between companies across multiple projects rather than one off projects.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q91. BIM is supported by the nature of relationships between companies within the construction industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q92. Relationships within the construction industry tend to support innovations which are quicker to implement than BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q93. The level of control required to implement BIM is outside that of any single party to a project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q94. The lack of collaborative working between client and contractor teams is an obstacle to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q95. The development of design work at risk in a tender situation is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q96. The inability to influence the clients' requirements / process within a formal tender situation is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q97. The decision to use BIM should be made at the start of a project.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q98. The policies within my company support BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

Q99. BIM is supported by stimulating regulations / requirements / standards within the construction Industry.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q100. It is easy to undertake a trial before implementing BIM fully.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q101. The make-up of the project team is important to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.
				54				

Q102. The separation of design and construction under traditional procurement is a barrier to BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q103. Existing practices within the construction industry are too robust to enable the widespread use of BIM.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

Q104. BIM requires a supportive working environment.

Strongly Agree	Agree	Slightly agree	Neither agree nor disagree	Slightly Disagree	Disagree	Strongly Disagree	Don't know	Prefer not to say.

`

This final section is about you (if you are a sole trader) or your employer (if you are an employee):

Q105. What is your designation?

Upper Management e.g. Owner / Sole Trader / Director / Partner	**Middle Management** e.g. Project Manager, Associate, Senior Professional**.**	**Chartered Professional**	**Other – please state.**	**Prefer not to say.**

Q106. What is your employer's main business?

Consultant	**Main Contractor**	**Sub-Contractor**	**Other – please state**	**Prefer not to say.**

Q107. How many people work for your employer?

1 – 7	**8 – 34**	**35 – 79**	**80 – 299**	**300 – 1199**	**1200 or over**	**Don't know**	**Prefer not to say.**

Q108. What is the approximate turnover (in £ thousands) of your employer for the last complete financial year?

£0K – £199K	Between £200K - £999K	Between £1M to £9.99M	Between £10M to £99.9M	Over £100M	Don't know	Prefer not to say.

Q109. How long has your employer used BIM?

Don't use BIM.	0 – 1 Years	2 – 3 Years	4 – 5 Years	6 – 7 Years	8 – 9 years	10 Years and above.	Don't know	Prefer not to say.

`

Q110. On what percentage of the work your employer undertakes is currently carried out using BIM?

Don't use BIM.	1 – 25%	26% - 50%	51% - 75%	76% - 100%	Don't know	Prefer not to say.

Q111. What percentage of the work your employer undertakes currently involves the sharing of BIM data with other companies?

Don't use BIM.	1% – 25%	26% - 50%	51% - 75%	76% - 100%	Don't know	Prefer not to say.

Q112. What percentage of the work your employer undertakes could be carried out using BIM?

None	1 – 25%	26% - 50%	51% - 75%	76% - 100%	Don't know	Prefer not to say.

Results

If you would be interested in receiving a copy of the completed research or a summary of the results, please indicate this below.

Yes – please send me a summary of the results.	Yes – please send me a copy of the completed research.

`

<u>**Appendix 9 – Follow Up Letter (Postal Version)**</u>

Lawrence Seed
[Home Address included
on original - omitted for
confidentiality in thesis copy]

Respondents Name
Respondents Company Name
Respondents Address

Date XX / YY / 2013

Dear Mr / Mrs / Miss [Deleted as appropriate] XXXX,

Following our telephone conversation of XXXX, thank you for agreeing to take part in my Doctoral Research on BIM.

I would be very grateful if you could return a completed copy of the questionnaire originally issued on XX/YY/ZZ. A duplicate copy of this is enclosed, along with a SAE.

Yours Sincerely

[Signature included
on original omitted for
confidentiality in thesis copy]

Lawrence Seed

`

Appendix 10 – Detailed Qualitative Results

A10.1 Response Rate and Sampling Accuracy

After selecting and contacting 136 different companies, a total of 24 semi structured interviews were undertaken by the researcher over the period October 2013 to January 2014, a response rate of 17.6%. These were recorded digitally to .mp3 files at 128kps, which generated a total audio duration of 25 hours and 36 minutes of spoken data. The interviews ranged from between 29 to 93 minutes in length, with an average duration of 64 minutes. All interviews were transcribed by the researcher using Dragon Naturally Speaking software and cross checked against the recording, corrected in Microsoft Word and checked once again. This generated a total of 188,923 words over 617 pages at Arial 12 point, double spacing. This significant repository of qualitative data was fully therefore transcribed and validated before any qualitative analysis took place.

It was not possible to exactly match the stratified random sampling frame; however, 89% of Main Contractors, 88% of Sub-Contractors and 100% of consultants matched the sampling frame, giving an overall match of 93% of respondents to the frame. Detailed breakdowns of these respondents are shown at Figures A10.1, A10.2 and A10.3. Given the relatively small sample size (n=24), along with the large number of sampling categories containing only one target respondent, the researcher does not view this as a significant deviation from a representative sample of the UKCI for the purposes of qualitative analysis.

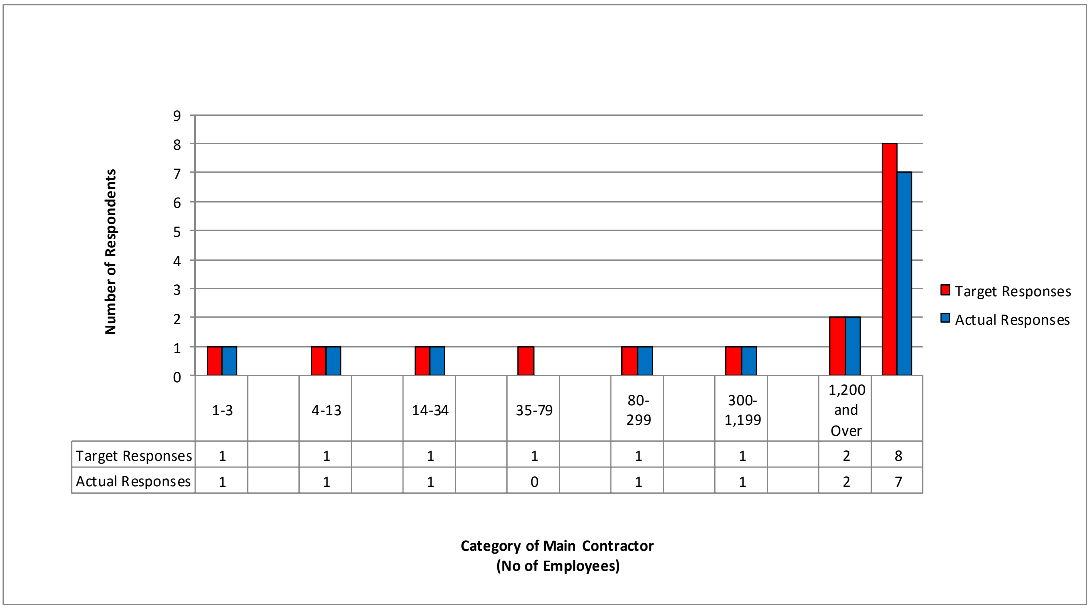

Figure A10.1 – Main Contractor, Stratified Random Sampling

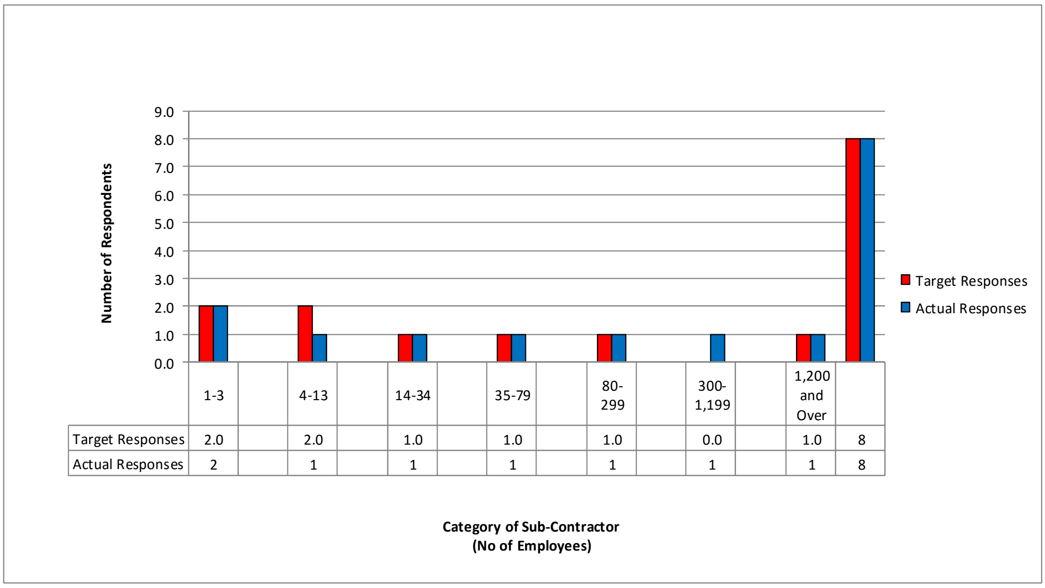

Figure A10.2 – Sub-Contractor, Stratified Random Sampling.

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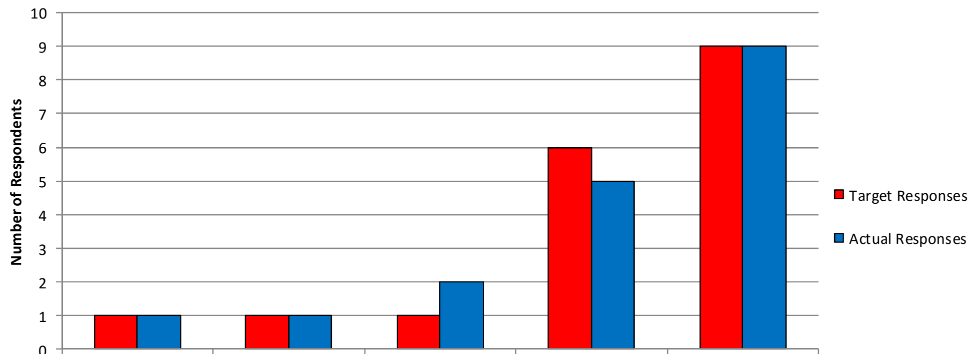

	<£200k	£200k-£1m	>£1m-£10m	>£10m	Total
Target Responses	1	1	1	6	9
Actual Responses	1	1	2	5	9

Figure A10.3 – Consultants, Stratified Random Sampling.

All 24 respondents fell within the three suggested categories of designation, namely upper management, middle management and chartered profession, with the distribution as shown at Figure A10.4. The 24 respondents achieved a good spread across the three main categories of company as reflected in the target sampling frame and shown at Figure A10.5.

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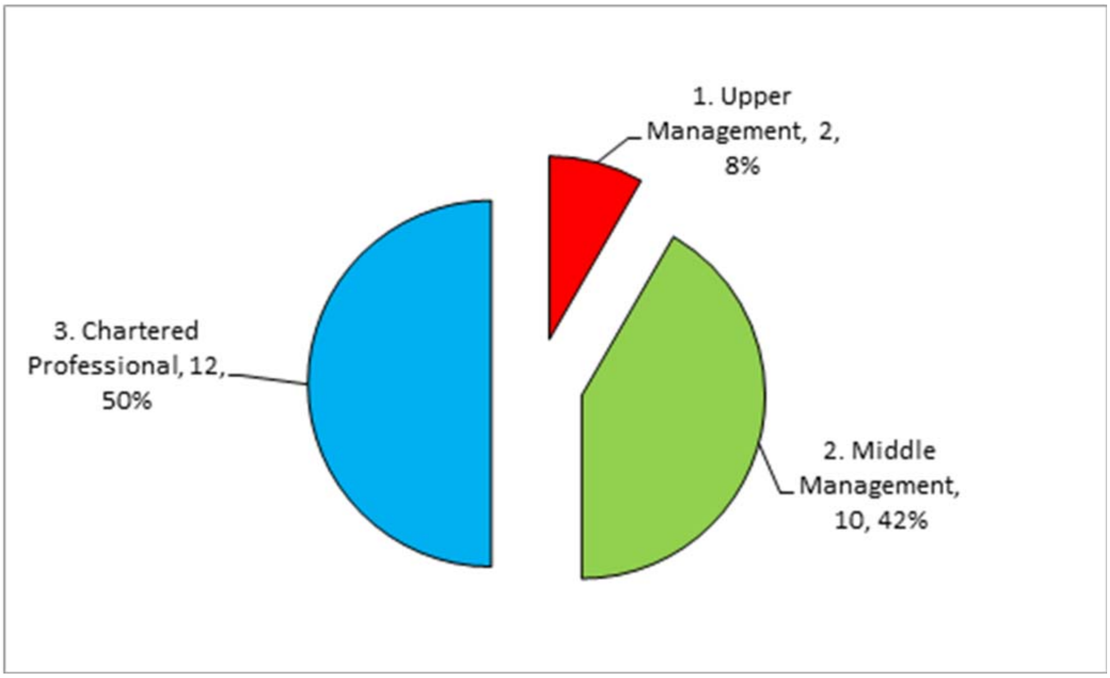

Figure A10.4 – Respondents Designation

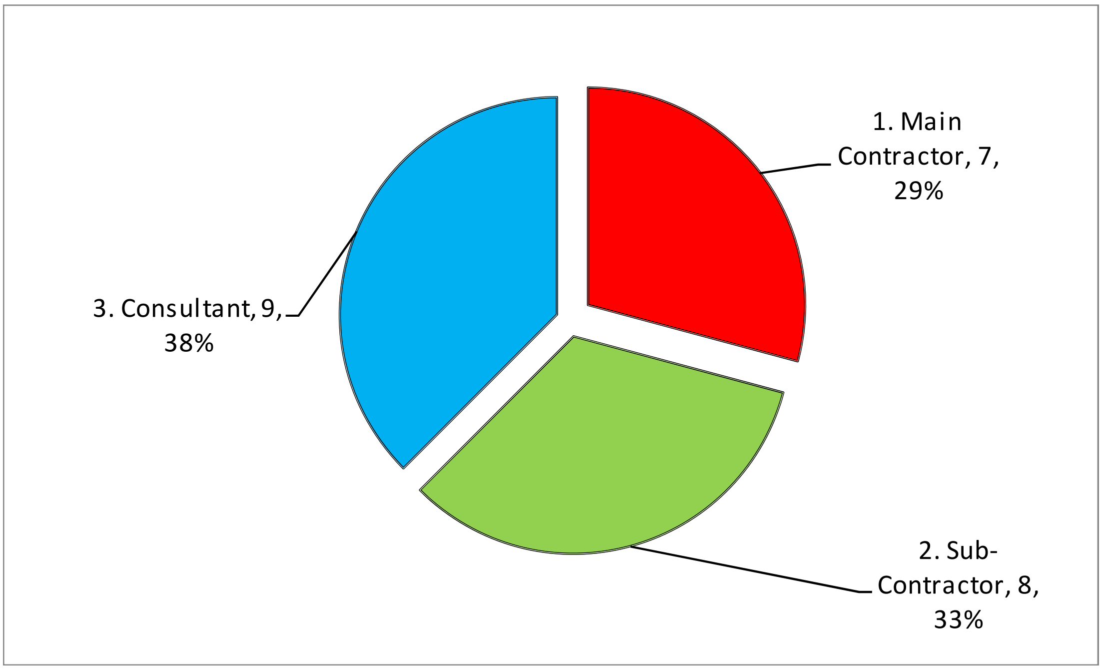

Figure A10.5 – Employers' Main Business

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A10.2 Respondent Information

As extensive reference is made below to quotations from individual respondents within the next section of the analysis, within Table A10.1 below, each is allocated a unique reference letter (**A** through to **X**). Each is also cross referenced to the respondents' main business, category of turnover and percentage work carried out using BIM. This is to enable the reader to develop a better insight into the respondents behind each quotation, while maintaining confidentiality.

Unique Reference	**Employers Main Business**	**No of Employees**	**Percentage of work carried out using BIM.**
A	Main Contractor	1-3	Don’t use BIM.
B	Main Contractor	4-13	1% – 25%
C	Main Contractor	14-34	1% – 25%
D	Main Contractor	80-299	Don’t know.
E	Main Contractor	300-1,199	Prefer not to say.
F	Main Contractor	1,200 and over	51% - 75%
G	Main Contractor	1,200 and over	76% - 100%
H	Sub-Contractor	1-3	Don’t use BIM
I	Sub-Contractor	1-3	Don’t use BIM
J	Sub-Contractor	4-13	Don’t use BIM
K	Sub-Contractor	14-34	Don’t use BIM
L	Sub-Contractor	35-79	1% -25%
M	Sub-Contractor	80-299	Don’t use BIM
N	Sub-Contractor	300-1,199	1% - 25%
O	Sub-Contractor	1,200 and over	26% - 50%
		Category of Turnover	
P	Consultant	<£200K	Don’t use BIM
Q	Consultant	£200 - £1m	26% - 50%
R	Consultant	> £1m - £10m	Don’t know
S	Consultant	> £1m - £10m	51% - 78%
T	Consultant	>£10m	1%-25%
U	Consultant	>£10m	26% - 50%
V	Consultant	>£10m	26% - 50%
W	Consultant	>£10m	76% - 100%
X	Consultant	>£10m	76% - 100%

Table A10.1 – Referencing and Categorisation of Qualitative Respondents

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Initial analysis of the qualitative data was undertaken to establish key metrics on the usage of BIM and an indicative categorisation was made of those next likely to adopt BIM adopters using Rogers's (2003) model. Following analysis of the usage of BIM and sharing of BIM data, the data was coded, applying the coding template as means of reducing the large amount of data collected (Miles and Huberman, 1994) and identifying dynamics occurring within the data. During this process, dynamics not identified a-priori became apparent within the data and therefore five codes were created in-vivo to reflect these. Echoing the positivist perspective applied and to support triangulation, the number of occurrences of each code was quantified for presentation below. Further analysis was then undertaken to establish variation in dynamics relating to company type and size, before establishing nominal values for the five generic characteristics of BIM as an innovation.

A10.3 BIM Usage

As part of the interview, respondents were asked a number of direct questions to establish a range of characteristics of any BIM usage. Of the 24 respondents, 7 (29%) stated that they did not use BIM with 13 respondent (54%) stating they did use it, 1 respondents (4%) declining to respond and 3 (13%) not knowing if BIM was used. Of those who did use BIM, the 9 respondents (38%) had used it for up to four years, 4 respondents (17%) had used BIM for between four and ten years, with no respondent having used BIM for more than 10 years, as shown in graphical form at Figure A10.6

Figure A10.7 shows that of those who use BIM, 9 respondents (38%) stated they undertake less than 50% of their work on BIM, with only 5 respondents (21%) using it for more than 50% of their work and 2 respondents (8%) declining to respond..

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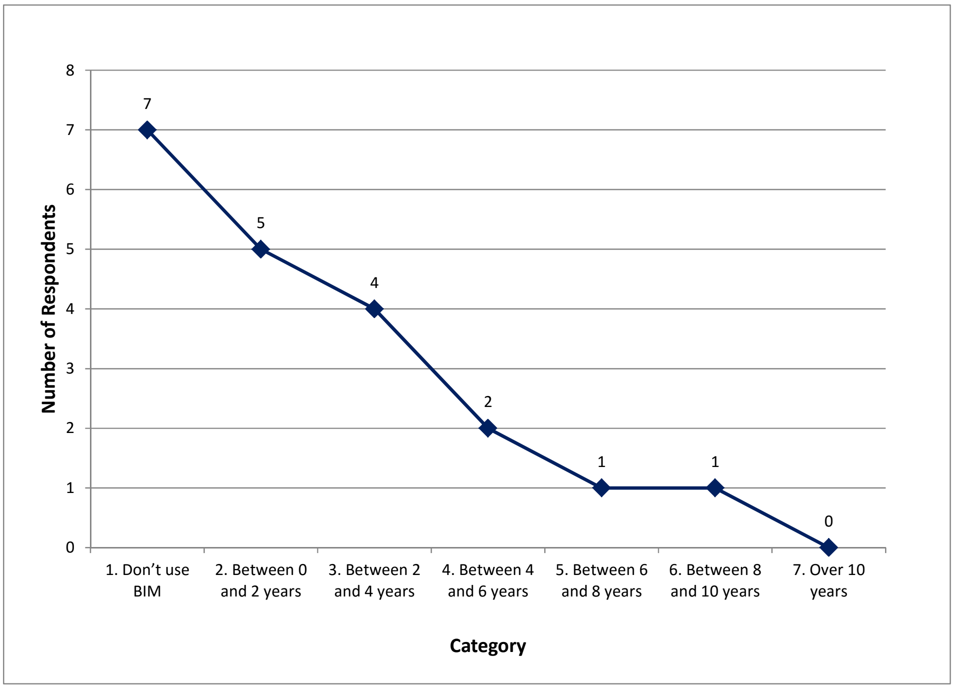

Figure A10.6 – Period BIM has been Used

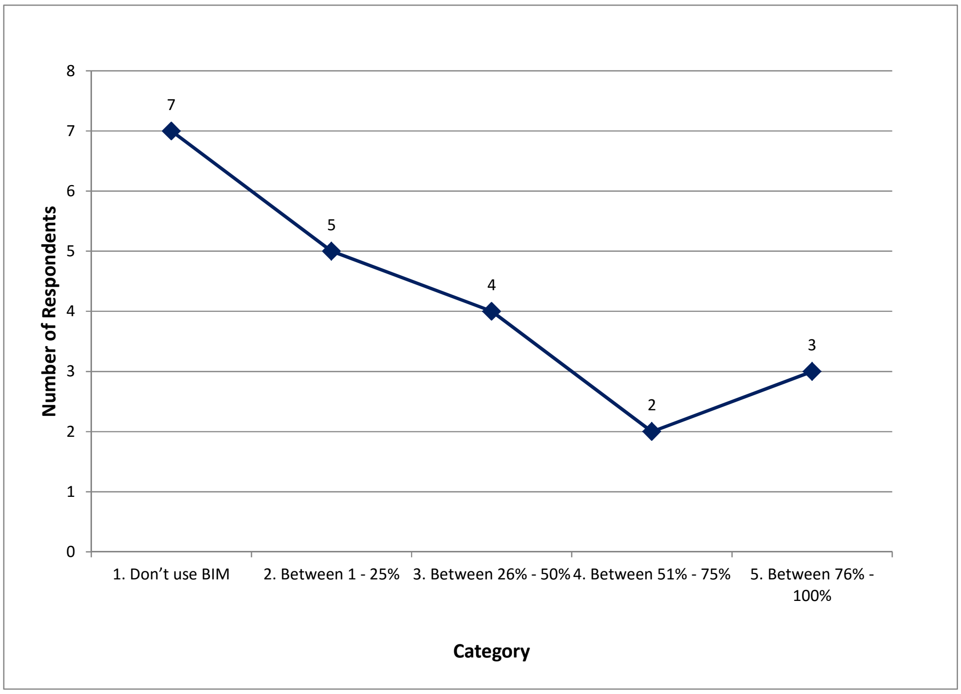

Figure A10.7 – Percentage of Work Carried out Using BIM

Again, only considering those respondents who use BIM, 11 respondents (46% of sample) stated that less than 50% of the work carried out using BIM involved the

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sharing of data with other companies, with 5 respondents (21%) noting a percentage greater than 50% and 2 respondents (8%) who did not know. These results are shown at Figure A10.8 In addition to the potential usage increases noted above, these results indicate a potential for the wider sharing of BIM data, as companies become more confident of both BIM itself as, well as the benefits of collaborating using shared data.

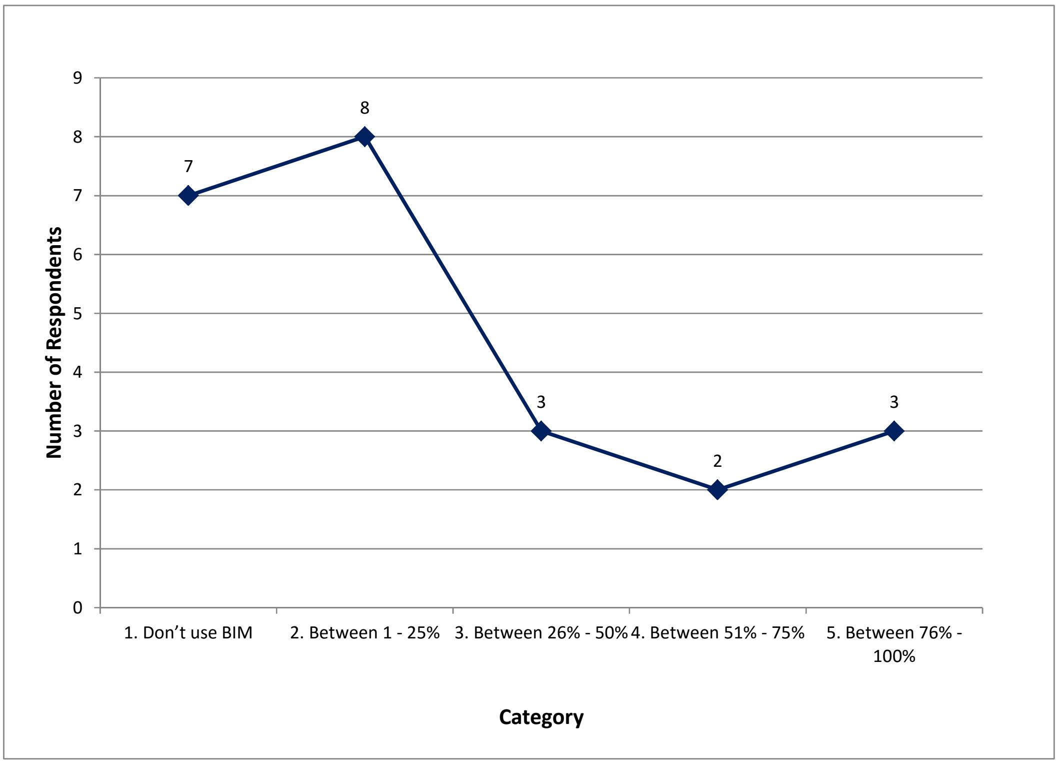

Figure A10.8 - Percentage of Work Carried out Using BIM and transfer of BIM Data to other Companies

To establish the potential for increased BIM utilisation, current categories of BIM usage were compared graphically with the categories for potential BIM usage at Figure A10.9. In terms of the potential for work to be carried out using BIM, 13 respondents (54%) were of the view that that more than 50% of their work could be carried out using BIM, with 7 respondents (30%) stating that BIM could be applied to less than 50% of their work, 3 (12%) respondents of the view that BIM

`

was not applicable to their work and 1 respondent (4%) who did not know. Taken together, these indicate both the scope for the further adoption of BIM by companies who currently do not use it, as well as the potential for an increase in utilisation (as measured by %age of work carried out using BIM) by those who already do.

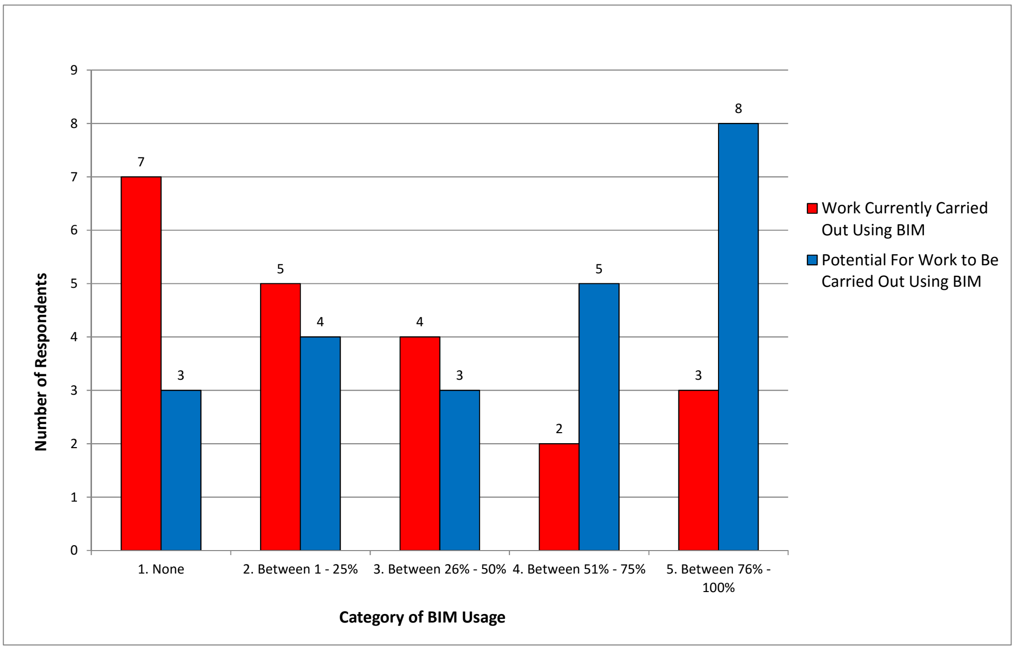

Figure A10.9 - Potential for work to be carried out using BIM

Although the qualitative data was such that a robust Chi-Square test could not be carried out, a visual inspection of data at A10.1 above indicates a positive relationship between the size of the company and its use of BIM. This is particularly noticeable in that six of the seven respondents who did not use BIM, were in the lower categories of size and that all three respondents in the 75% - 100% of work carried out using BIM category were in the highest category of size.

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A10.4 Mapping of BIM Usage Against Innovation Adopter Categories

The final initial analysis undertaken was based on the innovation diffusion model developed by Rogers (2003) and the five categories of innovation adopters noted within the literature review. By removing data for those respondents who state that 0% of their work could be carried using BIM, who by implication will never adopt it, the current percentage of BIM users for the remaining sample and within each group was calculated as shown at Table A10.2.

Group	Overall Sample	1. Main Contractors	2. Sub-Contractor	3. Consultants
Total Category Sample Size (A)	24	7	8	9
Respondents who state 0% of their work could be used for BIM (B)	3	1	2	0
Potential BIM Users Within Group (C) = (A-B)	21	6	6	9
Current BIM Users (D).	13	4	3	6
Current BIM Users as a Percentage of Potential BIM Users (E) = (D) / (C) * 100%.	61.9%	66.7%	50%	66.7%

Table A10.2 – Calculation of BIM Usage Percentages

Although the sample size is relatively small (n=24), the results of this analysis indicate that for the sample as a whole, 61.9% of respondents who are of the view that BIM is relevant to their work, have so far adopted it. Adoption rates are joint highest among consultants and contractors (66.7%) with Sub-Contractors having the lowest rate of adoption (50%). These percentage adoption rates were

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then applied to categories of innovation adopters developed by Rogers and shown at Figure A10.10. This indicates that the next adopters of BIM across the sample as a whole and all three categories of respondent are all likely to be in the late majority category.

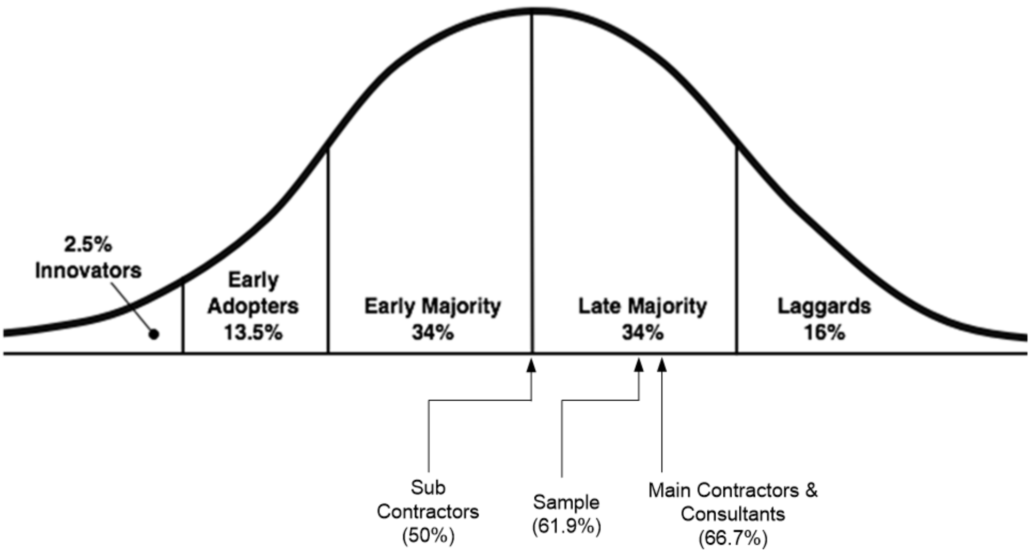

Figure A10.10 – BIM Usage Percentages (Qualitative Data) Applied to Innovation Adopter Categories (Rogers, 2003)

A10.5 Results of Coding

Following analysis against the coding template, a total of 41 codes were identified within the data, along with a further 5 codes developed in-vivo, as these appeared to represent additional significant dynamics. Of these 46 codes, there were a total of 113 occurrences within the data.

The codes allocated also included one of the following symbols to reflect weather the dynamic occurred in a supporting or inhibiting context.

[+] - Dynamic mentioned as supporting the adoption of BIM.

[-] - Dynamic mentioned as inhibiting the adoption of BIM.

`

A10.5.1 Complexity

Under this characteristic of innovations, 4 codes occurred, the majority of which related to inhibiting dynamics: Complexity [-] (3 occurrences), Training Level [-] (3 occurrences), Competence Technical [-] (1 occurrence). While Systems Open [+] (2 occurrences), illustrated in the data below, represented a supporting dynamic,

> "We were so relieved about the use of CoBIE [An open systems data standard] ... um we thought we may have backed the wrong horse ….. I mean selected the wrong system. It was squeaky bum time[98] [sic] for some I can tell you"

Respondent **T** - Consultant

A10.5.2 Relative Advantage

The second highest number of codes within the data (19 out of 43) occurred under this characteristic, offering partial sport to Rogers's suggestion that this is most important of the five generic characteristics of innovations.

A10.5.2.1 Relative Advantage – Economic Factors

Within this sub category 11 codes over 28 occurrences relating to supporting dynamics were present: Construction Cost [+] (4 occurrences), MacLeamy [+] (4 occurrences), Design Change Cost Effective [+] (3 occurrences), Collaboration Platform [+] (3 occurrences), Design Time [+] (3 occurrences), Demand Uncertainty [+] (4 occurrences),Design Team Focus [+] (2 occurrences), Project Duration [+] (2 occurrences), Design Team Size [+] (2 occurrences), Cost Plan

[98] Indicating a period of nervousness or stress

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Duration [+] (2 occurrences) and Projects Sustainable [+] (1 occurrences), with the first three dynamics captured in the following data:

> "BIM's been great when we finally did it properly ….. up fronting the design effort meant we could look at radical options when it [The Design] was still fluid, and I hear we saved about £45K on the cladding as a result"
>
> Respondent **G** *(Main Contractor)*

However these were somewhat balanced by the a total of 18 occurrences of 8 codes representing inhibiting dynamics: Cost Implementation [-] (4 occurrences), Industry Recession [-] (3 occurrences), Company Survival [-] (3 occurrences), Cash Flow [-] (2 occurrences), Hardware New Specialist [-] (2 occurrences), Payback Short [-] (2 occurrences), Life Cycle Cost [-] (1 occurrence) and Existing Methods Sufficient [-] (1 occurrence). The first of these codes is reflected in the following data:

> "It doesn't matter how good it [BIM] is ….. We struggle to provide our staff with a standard PC and Office software. Revit costs are out of our league"
>
> Respondent **M** - Sub Contactor

While the code: Company Survival [-] is demonstrated in the following data:

> "It [BIM] all sounds great, but our priority is keeping our heads above water. So many of our competitors have come to grief in the past year."
>
> Respondent **K** - Sub-Contractor

`

A10.5.2.2 Relative Advantage – Mandate

This sub category contained 9 occurrences of 2 codes reflecting supporting dynamics: Government Mandate [+], which with 8 occurrences appears the most significant of all codes and Client Mandate Early [+] (1 occurrence).

> "The industry needed a good kick up the arse [sic] …. it was only after the Government announcement [for use of BIM by 2016] that people started to take BIM seriously".

Respondent **E** - Main Contractor

A10.5.2.3 Relative Advantage – Other Sub Categories

There were no occurrences of codes representing dynamics from the other 4 sub-categories of relative advantage suggested by Rogers, i.e. Status Aspects, Overadoption, Preventative Innovation and Effect of Incentives.

A10.5.3 Trialability

A single code Trialability [-], associated with an inhibiting dynamic of BIM was the only code to arise, with 2 occurrences.

"It all looks good on paper, but not really being able to 'try before you buy' [sic] put back our first purchase of BIM for about a year"

Respondent **T** - Consultant

A10.5.4 Compatibility

The largest number of codes (20 across 47 occurrences) were found within this characteristic, with the majority of these (16) representing inhibiting dynamics, a smaller number (6) representing supporting dynamics and a single code being cited as both inhibiting and supportive by different respondents.

`

A10.5.4.1 Compatibility – Values and Beliefs

Within this sub category, 3 codes representing supporting dynamics of BIM were arose within the data: Management Supportive [+] (2 occurrences), Relationships Supply Chain [+] (2 occurrences) and Adoption Risk [+] (2 occurrences), with the supportive effect of the first of these illustrated in the following response:

> "No if, no buts …. management made the choice [to use BIM] and are driving 100% adoption …. right from the top"

Respondent **V** - Consultant

> "It doesn't matter how good it [BIM] is ….. we struggle to provide our staff with a standard PC and Office software. Revit costs are out of our league"

Respondent T - Consultant

However, 10 codes representing inhibiting dynamics were also identified: Relationships Within Industry [-] (5 occurrences), Relationships Temporary [-] (4 occurrences), Industry Practices Robust [-] (4 occurrences), Collaboration Culture [-] (4 occurrences), Companies Specialised [-] (2 occurrences), Project Focus [-] (2 occurrences), Staff Specialist [-] (2 occurrences), Co-ordination Different Companies [-] (2 occurrences), Short Term Focus [-] (1 occurrence) and Company Nature [-] (1 occurrence). The inhibiting effects of Short Term Focus and Collaboration Culture, being reflected in the following respective responses:

> "I'd love to implement BIM more, but it's all about the profit this quarter, forget the longer term."

Respondent **E** - Main Contractor

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> “Working as a team is all well and good, but at the first hint of any problems, you know you’re going to be wasting time chasing that next payment”
>
> Respondent **O** - Sub-Contractor

<u>A10.5.4.2 Compatibility – Previously Introduced Ideas</u>

Only 2 codes, representing supporting dynamics were identified within the data in this sub category: D&B Increase [+] (2 occurrences) and Design Team Novation [+] (2 occurrences). While 4 codes indicating inhibiting dynamics were also found: Intellectual Property [-] (3 occurrences – in vivo code), Legal Issues [-] (2 occurrences – in vivo code), Separation Traditional Procurement [-] (1 occurrence), Industry Initiatives [-] (1 occurrence – in vivo code). The two in-vivo codes highlight further arguably interrelated inhibiting dynamics, and are illustrated by the following respective examples from the data:

> “Once modelled and uploaded, compared with hard copy drawings we have little control over how others may choose to use our BIM data. This increases our risk of being sued if something major does go wrong down the line.”
>
> Respondent **V** - Consultant

> “Sharing our innovative design in a BIM format, to consultants who may be our competitors on the next projects, feels a bit like lending them our crown jewels”
>
> Respondent **S** - Consultant

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The final code Exchange Formats Neutral was found twice within the data, once representing and supporting dynamic and once representing an inhibiting dynamic of BIM.

A10.5.5 Observability.

There were no occurrences of codes representing dynamics within this remaining generic category of innovations.

A10.5.6 Summary of Coding Results

To provide a comprehensive but digestible summary of those that occurred, these are shown diagrammatically at Figure A10.11, mapped against Rogers's 5 categories.

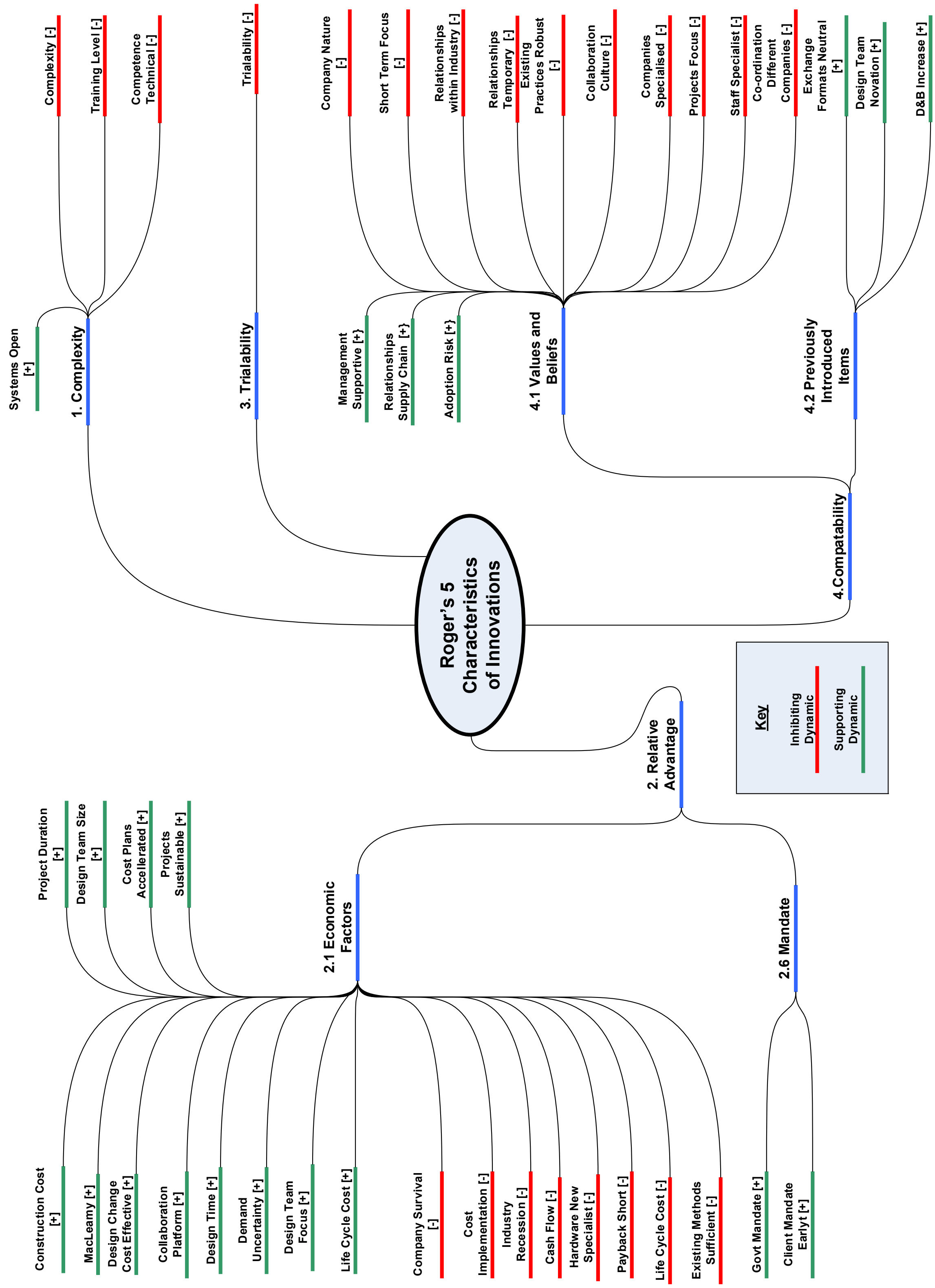

Figure A10.11 - Summary of Coding Results

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A10.6 Variation in Dynamics Linked to Company Type

Towards the end of the interview, respondents were asked directly if any of the dynamics they had discussed were thought to be particularly relevant to the type of company they worked for, i.e. Consultant, Contractor or Sub-Contractors. Respondents identified 18 individual dynamics, of which four were thought to be relevant to Main Contractors, six to consultants and seven to Sub-Contractors. One dynamic was also noted as being relevant to both man contractors and consultants by respondent each. The codes for these dynamics are shown at Table A10.3 below and illustrated in the quotations which follow:

Group	Code
Main Contractors	Demand Uncertain [-], (1 occurrence) Design Team Focus [+], (2 occurrences) Company Policies [+], (1 occurrence) Industry Practices Robust [-], (1 occurrence)
Consultants	Project Focus [-], (2 occurrence) Collaboration Platform [+], (2 occurrence) Project Duration [+], (1 occurrence) Training Level [-], (1 occurrence) Exchange Formats Neutral [+], (1 occurrence) Intellectual Property [-], (1 occurrence)
Sub-Contractors	Industry Recession [-], (3 occurrence) Cost Implementation [-], (2 occurrences) Company Survival [-], (2 occurrences) Complexity [-], (1 occurrence) Cost Plan Duration [+], (1 occurrence) Staff Specialist [-], (1 occurrence) Collaboration Culture [-], (1 occurrence)
Main Contractors and Consultants	Govt. Mandate [+], (4 occurrences)

Table A10.3 – Dynamics Related to Company Categories

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Industry Practices Robust [-]:

> “I’m working for a company that can trace its origins to the 1880’s. It does OK but is always very measured when making any changes in the way it does things”

Respondent **E** – Main Contractor

Training Level [-]:

> “…. the challenge is up-skilling [training] all our staff at a reasonable cost, while keeping the work rate up”

Respondent **U** – Consultant

Staff Specialist [-]

> “We already struggle to find staff who are real specialists in our area [curtain walling: a type of cladding / glazing]. Good BIM skills as well is even more of a challenge”

Respondent **L** – Sub-Contractor

This analysis indicates a balanced supporting and inhibiting set of dynamics of relevance to Main Contractors and consultants, however, six out of seven of the dynamics identified by respondents employed by Sub-Contractors inhibit BIM adoption. This indicates a perception by these respondents that there are higher challenges to their adoption of BIM.

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A10.7 Variation in Dynamics Linked to Company Size

Respondents were also asked directly to identify any dynamics raised which they thought were particularly applicable to their size of company, with the sample being divided into two categories. The category “lower turnover” was set to including those respondents having a turnover up to £9.99M (n= 11) and the category “higher turnover” as those having a turnover above this level (n= 13). Respondents identified a total of nineteen dynamics, with nine of these thought to be relevant to “lower turnover” and ten thought to be relevant to “higher turnover”. One dynamic industry practices robust was noted by two respondents as being relevant to “lower turnover” and one respondent as being relevant to “higher turnover”. The codes for these dynamics are shown at Table A10.4 below.

Group	Code for Dynamics of Particular Relevance
Lower Turnover	Industry Recession [-], (2 occurrences) Cost Implementation [-], (2 occurrences) Capital Availability [-], (1 occurrence) Design Team Novation [+], (1 occurrence) Design Team Focus [-], (1 occurrence) Complexity [-], (1 occurrence) Training Levels [-], (2 occurrences) Staff Specialist [-], (1 occurrence)
Higher Turnover	Management Supportive [+], (1 occurrence) Design Change Cost Effective [+], (1 occurrence) Construction Cost [+], (2 occurrences) Collaboration Platform [+], (2 occurrences) Project Duration [+], (1 occurrence) Design Time [+], (1 occurrence) MacLeamy [+], (2 occurrences) Govt. Mandate [+], (3 occurrences) Company Policies [+], (2 occurrence) Intellectual Property [-], (1 occurrence)
Lower Turnover and Higher Turnover	Industry Practices Robust [-], (1 occurrence)

Table A10.4 – Dynamics Related to Company Turnover

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Interestingly, seven of the eight dynamics of relevance identified by those within the “lower turnover” category are inhibitors of BIM adoption. Conversely nine of the ten dynamics felt to be relevant to those in the “higher turnover” category support the adoption of BIM. Finally, the inhibiting dynamic represented by Industry Practices Robust which was noted by respondents in both categories. These are illustrated by the following quotations across the three company categories:

Cost Implementation [-], Lower Turnover:

> “All of our work is domestic ….. mostly small extensions and the odd house, all done off paper drawings. For our small size, BIM isn’t on our radar”.

Respondent **A** - Main Contractor

> “The main difficulty for us is financial. Increasing the number of BIM seats to what we’d like would cost a bomb. At the moment we’re still struggling to pay the staff every month”.

Respondent **Q** – Consultant

Capital Availability [-]. Lower Turnover

> “While were aware of BIM, as a small specialist it’s … nor something we could justify. Any money can be better spent elsewhere on new plant and equipment”.

Respondent **I** – Sub-Contractor

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Interestingly, Consultant **R**, in the “lower turnover” category noted the recent release of rental license plans for BIM software by vendors such as Autodesk.

> “Moving forward, were hoping pay as you go BIM will be a big help with peaks in workload ….. Beforehand we’d have had to splash out ten K a pop [sic] on each new BIM seat”

While Main Contractor **F**, in the “higher turnover” category commented:

> “Not everyone needs a full on BIM licence …. loads of our staff just have Navisworks Freedom[99] on their laptops to navigate BIM models.”

These illustrate some ways in which companies may be able to mitigate the high capital cost of BIM.

A10.8 Application of Qualitative Results to Characteristics of BIM

In an effort to better understand BIM as an innovation, from the results of the analysis, nominal values of high, medium and low were allocated to each of Rogers’s generic characteristics of innovations. Shown at Table A10.5, these indicate that the adoption rate for BIM is supported by its medium relative advantage; however it is inhibited by low compatibility, high complexity as well as low trialability and a lack of observability.

[99] Where, Navisworks Freedom is a free of charge 3D BIM viewer produced by Autodesk.

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Characteristic of BIM	Relative Advantage	Compatibility	Complexity	Trialability	Observability
Summary of Dynamics within Qualitative Data	A number of financial and non-benefits are apparent however these are tempered by a range of inhibiting dynamics.	A small number of supporting dynamics outweighed by inhibiting dynamics, often associated with deep rooted / structural issues within the Industry.	Mostly inhibiting dynamics.	A single inhibiting dynamic.	Not identified within results.
Allocated Notional Value	Medium	Low	High	Low	Not Applicable

Table A10.5 – Qualitative Results Applied to Rogers's Characteristics of Innovations

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Appendix 11 – Detailed Quantitative Results

A11.1 Response Rate and Sampling Accuracy

A total of 2019 companies were approached, comprising 1603 by e-mail and 416 by telephone, to complete the questionnaire generating a total 326 completed surveys. Following initial checking, 15 sets of responses were discarded as critical respondent categorical questions had not been completed, due to an error in the way the online survey was setup. This gave a total of 311 usable responses at a response rate of 15.4%.

Again, it was not possible to exactly match the proposed sampling frame, however the relatively small variance against the larger sampling frame (n=311) and higher number of samples within each of the respondent categories, have led the researcher to conclude this does not constitute a significant deviation from a representative sample of The UKCI for the purposes of quantitative analysis. Breakdowns of responses against the sampling frame are detailed at Figures A11.1, A11.2 and A11.3 below.

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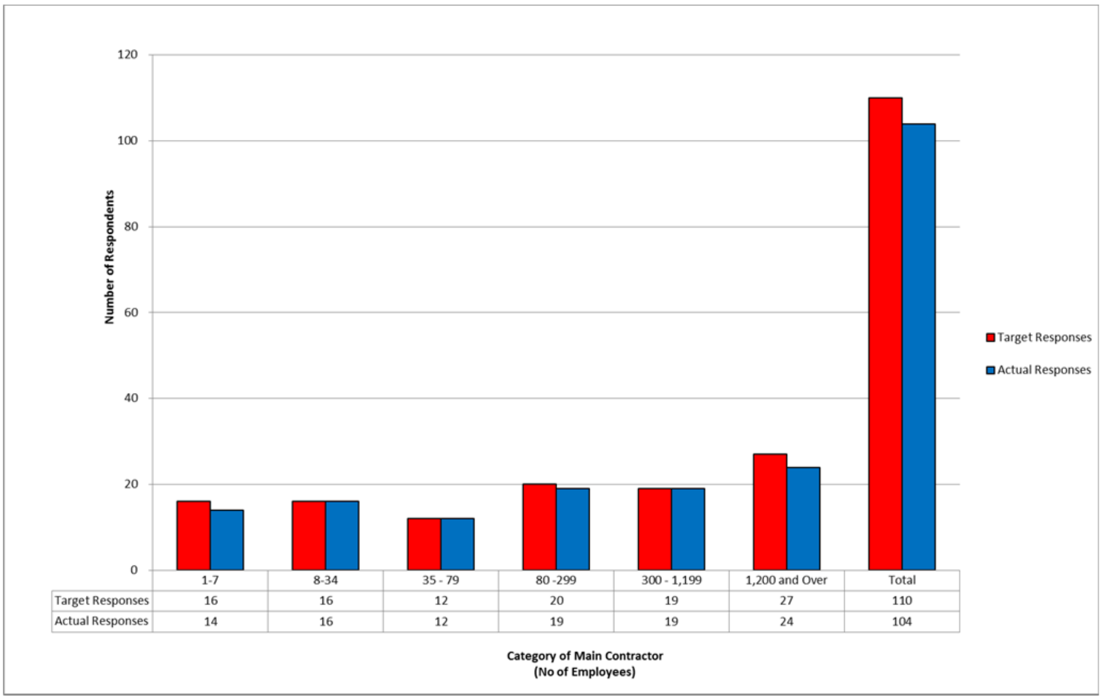

Figure A11.1 – Main Contractor, Stratified Random Sampling.

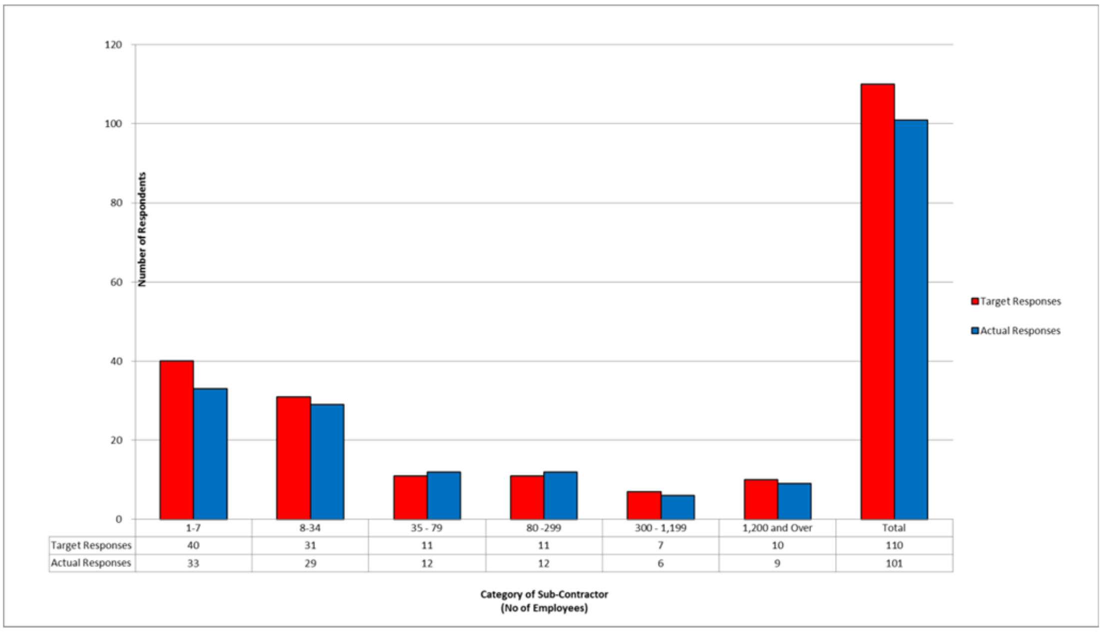

Figure A11.2 – Sub-Contractors, Stratified Random Sampling

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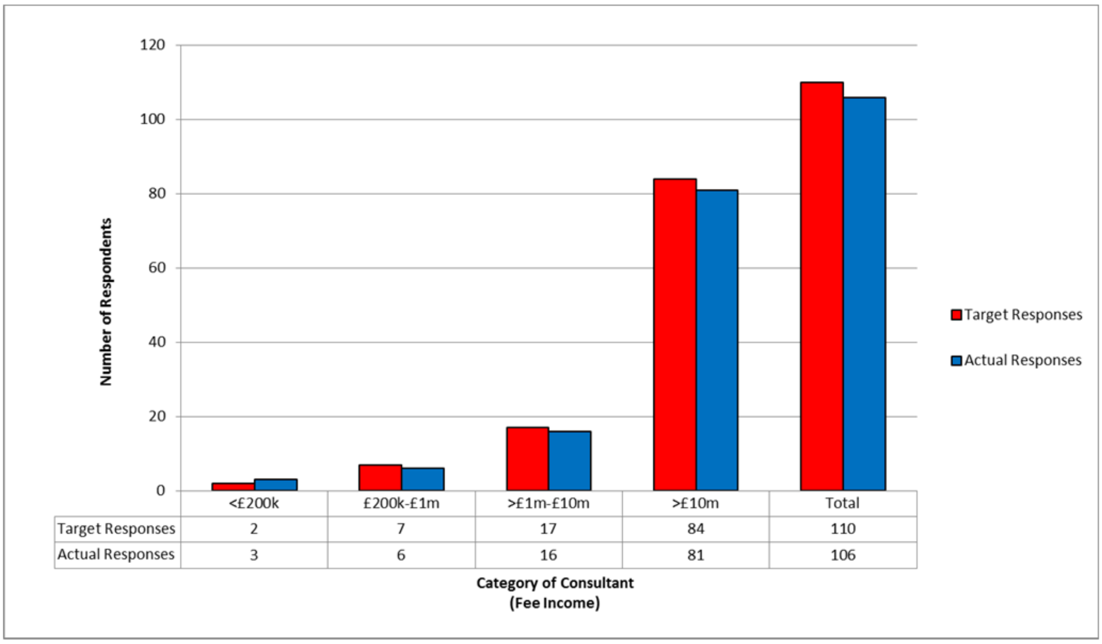

Figure A11.3 – Consultants, Stratified Random Sampling

This sample size (n=311) was slightly lower than the target sample size of (n=330) and gives a sample to variable ratio (STV) (*p*) of 2.99. The researcher acknowledges this is lower than the average STV noted earlier of 5:1 for exploratory factor analysis. However, this sample size itself remains larger than the figure of 300 recommended by Pallant (2010), indicating the data remains suitable for exploratory factor analysis.

The statistical analyses below were carried out using IBM SPSS Statistics V20.0.0 installed on a PC with AMD Phenom II X4 955 processor, 8.00 GB of RAM and Windows 7 Home Premium 64 bit operating system with Service Pack 1.

A11.2 Respondent Information

Of the 311 respondents, the majority were spread across the three categories of designation: “middle management, “chartered professional” and “other” which together accounted for 86% of the sample (267), with a smaller number of upper

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management and prefer not to say, as shown at Figure A11.4. The category "other" included a range of designations including "design co-ordinator", "partner", "acoustician" and "cost lead", with the majority tending to relate to either the respondents job role or their technical specialism.

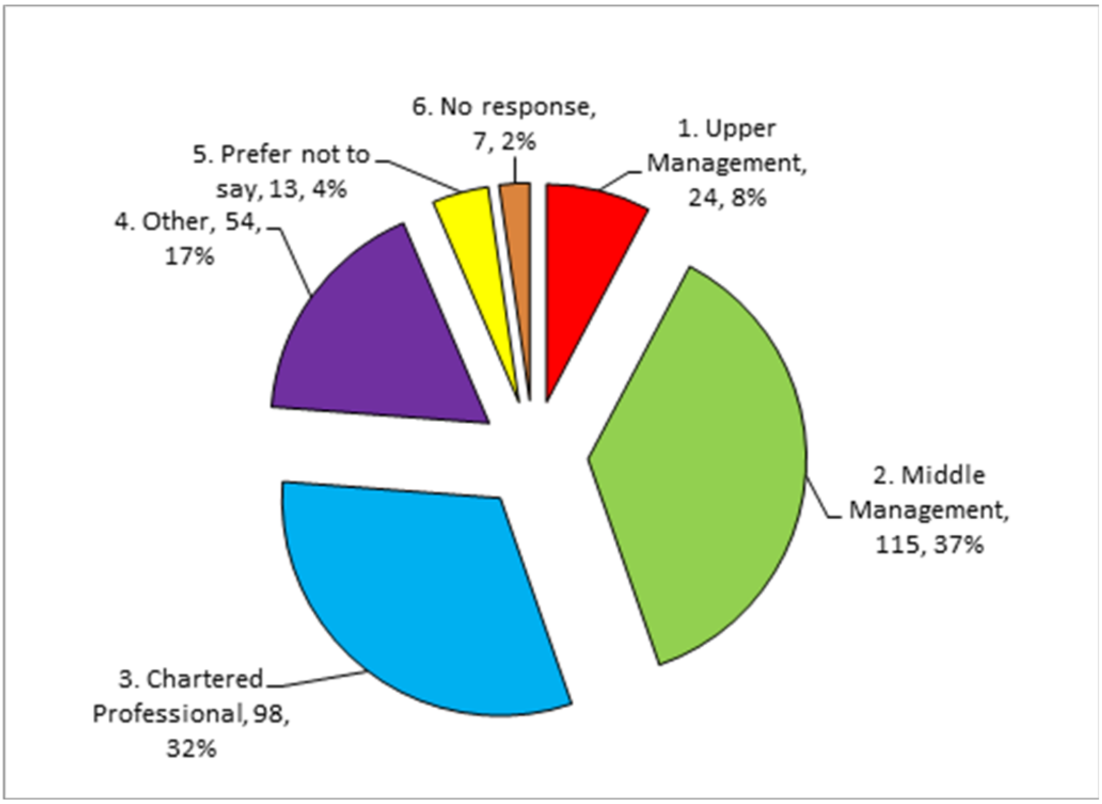

Figure A11.4 – Respondents Designation

As a result of the stratified random sampling frame adopted, a broadly equal spread across the three main categories of employers main business was achieved (1 – Contractor, 2 - Sub-Contractor and 3 - Consultant), as shown at Figure A11.5. Four respondents used the "other" category, using descriptions which included "Architect", "Façade Contractor" and "Services Engineer". However, from these descriptions it was possible to accurately re-categorise all of these, to the three main groups for the purposes of Analysis of Variance, and

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data from all respondents was included in the testing of hypotheses and exploratory factor analysis.

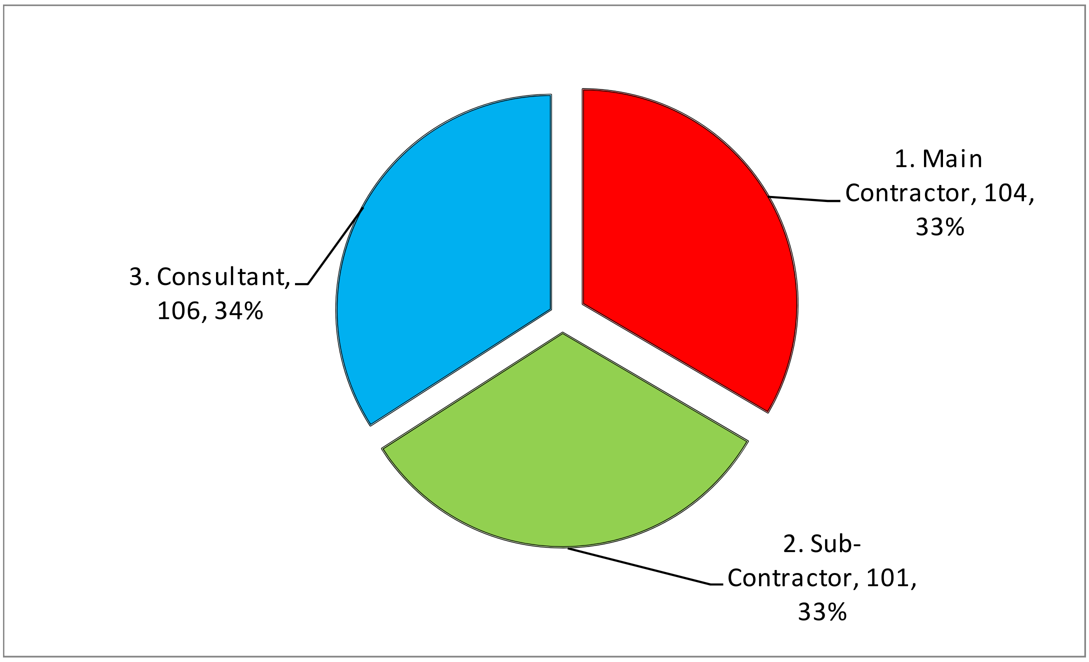

Figure A11.5 – Employers Main Business

A11.3 BIM Usage

Initial graphical analysis was undertaken to establish a benchmark and key metrics of current BIM usage. From the responses to Question 109 – "How long has your employer used BIM?", 96 respondents (31%) did not use BIM with 205 respondents (66%) who did , 9 respondents (3%) who didn't know and 1 respondent (0.3%) who preferred not to say. Of those who did use BIM, 129 respondents had used BIM for less than 4 years, with 72 respondents having used BIM for between 4 and 10 years and 4 respondents having used BIM for more than 10 years. These results, shown at Figure A11.6, indicate the adoption of BIM has been within the past four years, for the majority of BIM users.

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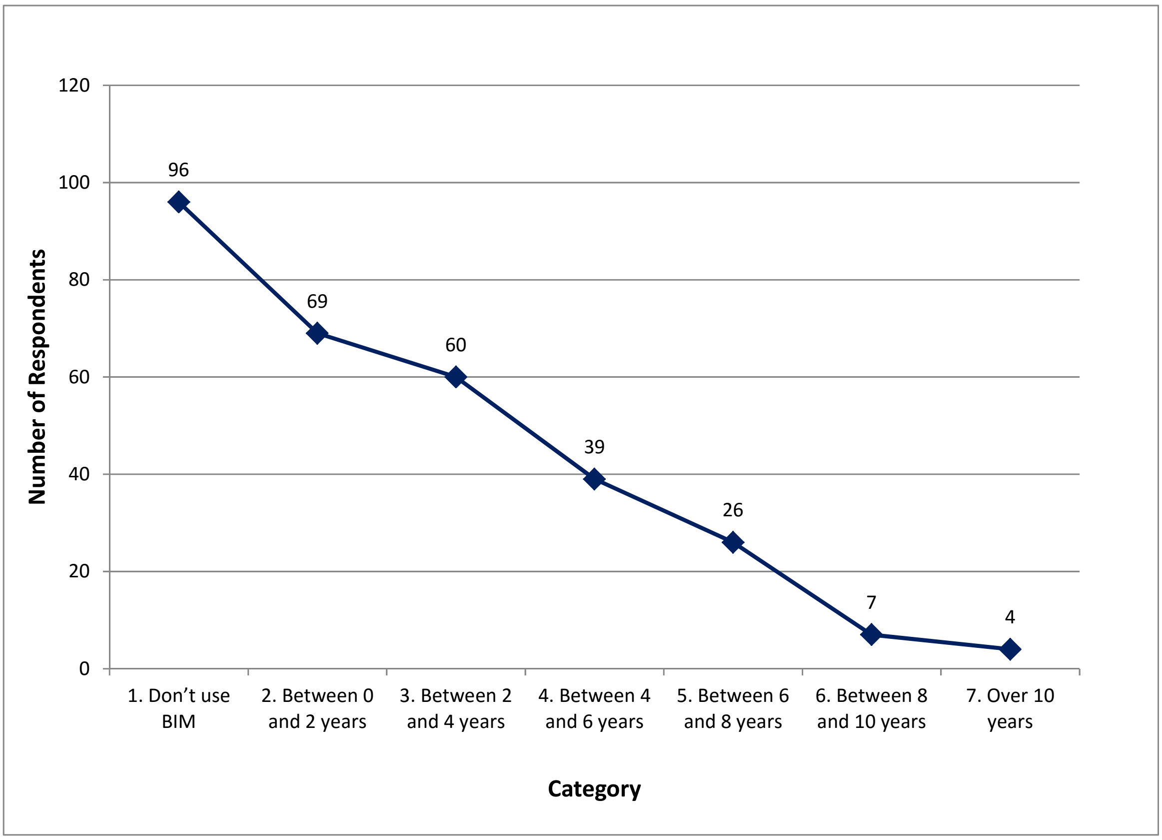

Figure A11.6 – Period BIM has been Used

Graphical analysis of the responses to Question 110 – "What percentage of the work your employer undertakes is currently carried out using BIM?" was also undertaken as illustrated at Figure A11.7. Although 25 respondents (8%) didn't know, and 10 respondents (3%) preferred not to say, 104 respondents (33%) used BIM on less than 50% of their work while only 76 respondents (24%) used it for more than 50%.

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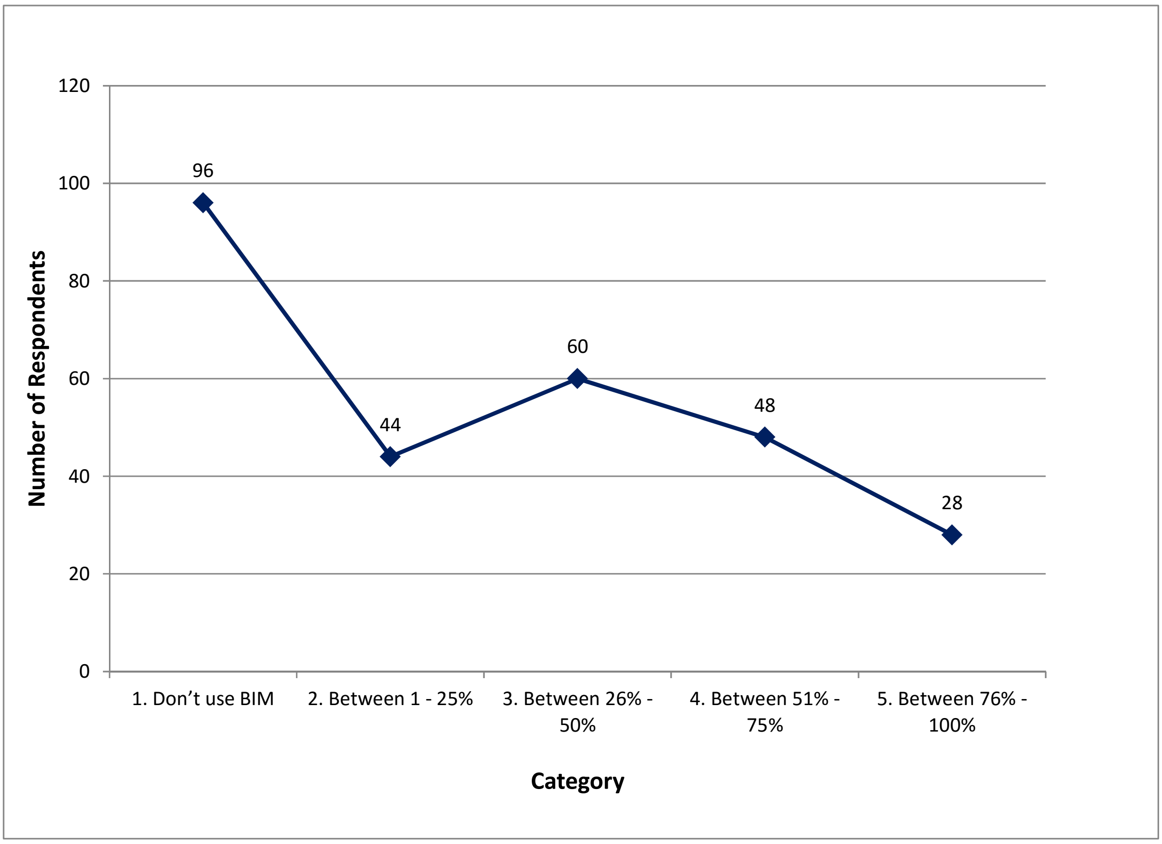

Figure A11.7 – Percentage of Work Carried out Using BIM

Unsurprisingly, the percentages of those using BIM and transferring this data to other companies are slightly smaller, shown at Figure A11.8, indicating a number of companies are undertaking what is commonly referred to within the UKCI as "lonely BIM" where data is not shared.

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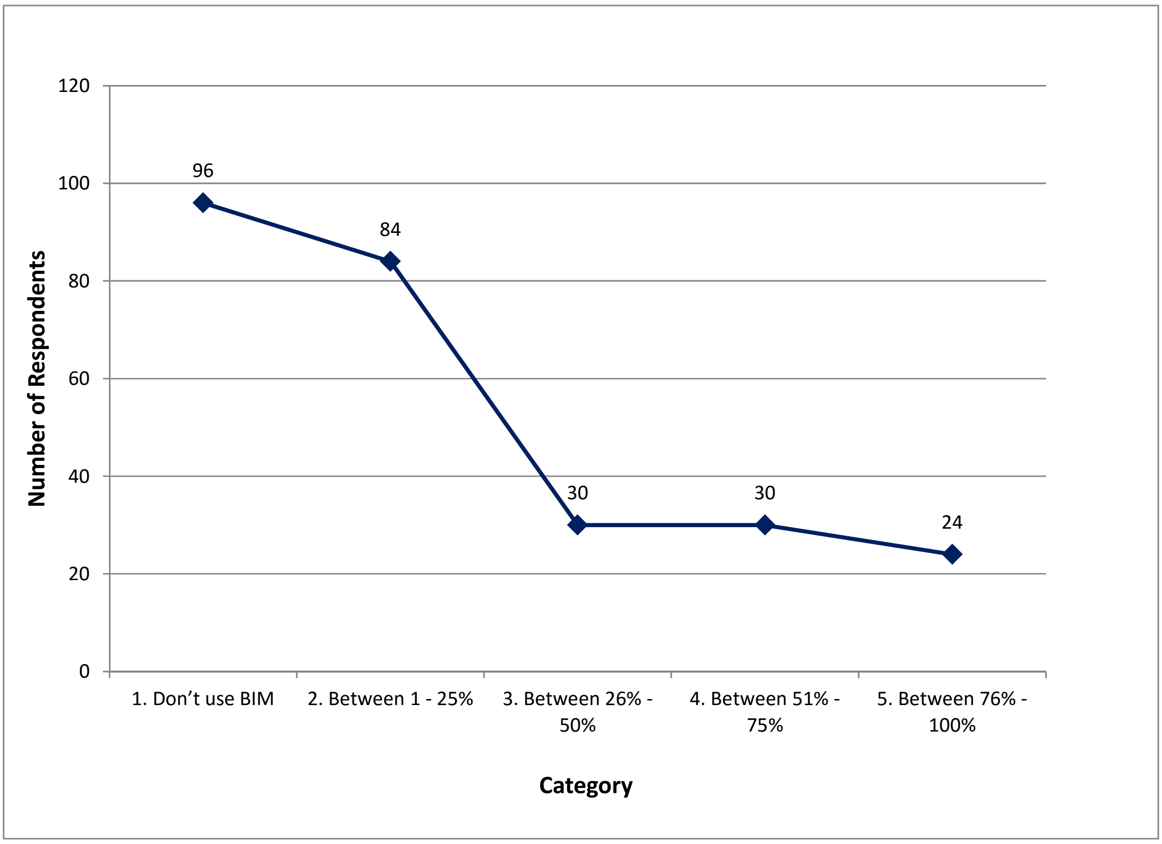

Figure A11.8 - Percentage of Work Carried out Using BIM and transfer of BIM Data to other Companies

To establish the potential for increased BIM utilisation, the responses to Question 112 – "What percentage of the work your employer undertakes could be carried out using BIM?" were analysed and compared graphically at Figure A11.9 with patterns of existing BIM usage

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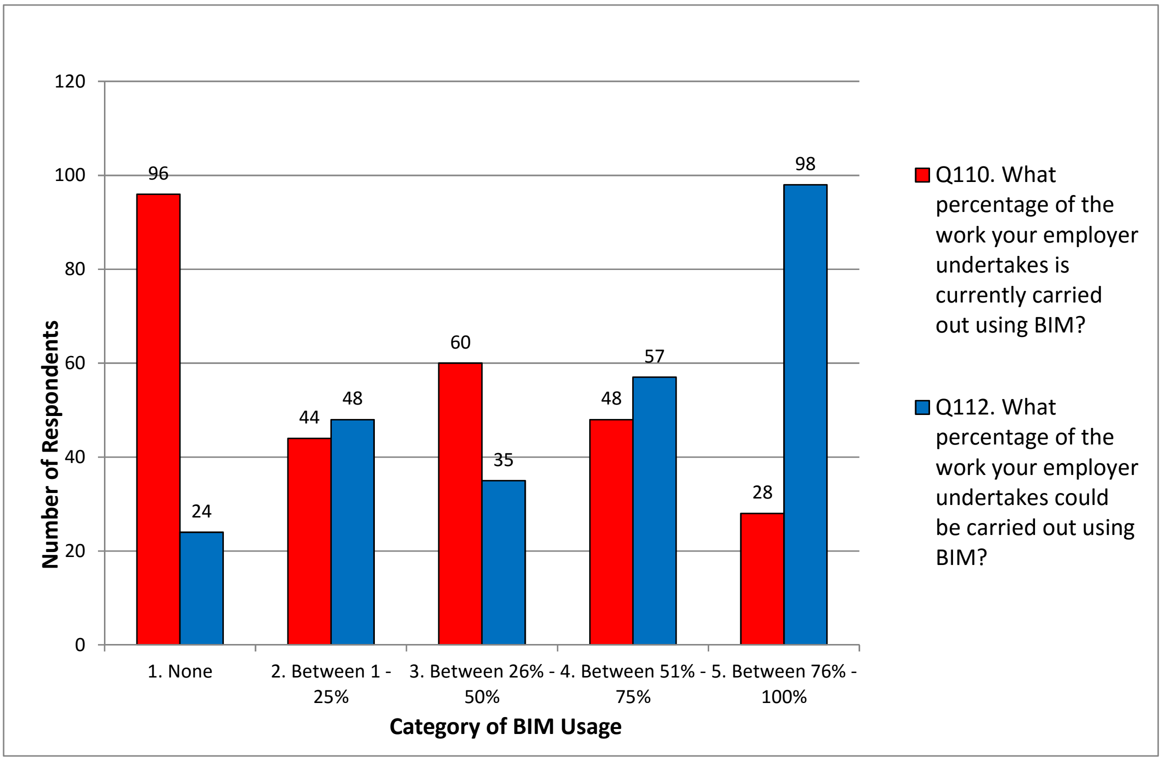

Figure A11.9 - Potential for Increased Utilisation

A11.4 Mapping of BIM Usage Against Innovation Adopter Categories

The final initial analysis, calculated the level of BIM usage for each type of company, excluding those who stated that 0% of their work could be carried out using BIM and who by implication will never adopt it (Table A11.1), and maps the usage data against the five categories of innovation adopters suggested in the literature review at Figure A11.10.

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Group	Overall Sample	1. Main Contractors	2. Sub-Contractor	3. Consultants
Total Category Sample Size (A)	311	104	101	106
Respondents who state 0% of their work could be used for BIM (B)	24	14	8	2
Potential BIM Users Within Group (C) = (A-B)	287	90	93	104
Current BIM Users (D).	180	58	50	72
Current BIM Users as a Percentage of Potential BIM Users (E) = (D) / (C)* 100%.	62.7%	64.4%	53.8%	69.2%

Table A11.1 – Calculation of BIM Usage Percentages

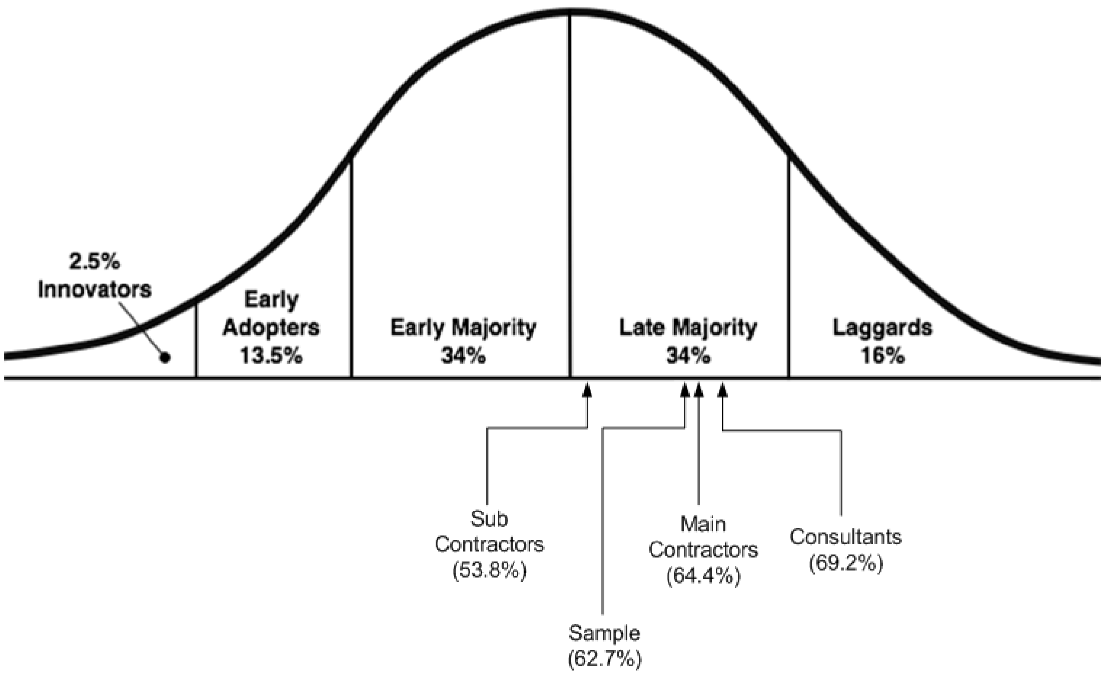

Figure A11.10 – BIM Usage Percentages (Quantitative Data)

Applied to Innovation Adopter Categories (Rogers, 2003)

The results of this analysis indicate that for the sample as a whole, 62.7% of respondents who are of the view that BIM is relevant to their work, have so far

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adopted it. Adoption rates are the greatest among consultants (69.2%) followed by Main Contractors (64.4%), with Sub-Contractors having the lowest rate of adoption (53.8%). These percentage adoption rates were then applied to categories of innovation adopters developed by Rogers (2003) and shown at Figure A11/10. This indicates that the next adopters of BIM across the sample as a whole and all three categories of respondents are likely to be in the Late Majority category.

A11.5 Detailed Statistical Analysis

A11.5.1 Testing of Scales

The reliability of the scales used in the Likert responses were checked using Cronbach's alpha as a measure of internal consistency (Pallant, 2010). Following reversal of scale values for negatively worded items, the resulting value of 0.86, shown at Tables A11.2 & A11.3 was above 0.8 confirming good internal consistency (Pallant, 2010), for this instrument.

Case Processing Summary

		N	%
Cases	Valid	311	100.0
	Excluded[a]	0	.0
	Total	311	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
0.92	*104*

Table A11.2 and A11.3 - Cronbach's Alpha, Scale Reliability

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A11.5.2 Hypothesis Testing

As the next stage in a more detailed statistical analysis of the quantitative data, a number of hypotheses were tested:

The first test was carried out to establish if there was a relationship between the size of company, as measured by turnover, and their usage of BIM.

The null hypothesis, $\mathbf{H_{o1}}$ was set as:

> There will be no relationship between the size of company and the percentage of work carried out using BIM.

The alternative hypothesis, $\mathbf{H_{A1}}$, was then set as:

> There will be a relationship between the size of company and the percentage of work carried out using BIM.

Prior to this analysis, data from those who responded as either don't know or prefer not say to Question 110 – "What percentage of the work your employer undertakes is currently carried out using BIM?", was removed from the data set, leaving a total of 276 responses. Initial analysis of the data using a Chi-Square Test on a table of five by five categories resulted in over 20% of cells having a cell count of less than 5, indicating that the test results may be invalid. To overcome this issue, the data was simplified into a 3 x 3 table and the test re-run, as shown at Tables A11.4 and A11.5 below.

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		What percentage of the work your employer undertakes is currently carried out using BIM?			Total
		Don't Use BIM	1% - 50%	51% - 100%	
What is the approximate turnover (in £ thousands) of your employer for the last complete financial year?	£0K - £999K	46	8	4	58
	£1M - £99.9M	39	57	47	143
	Over £100M	11	39	25	75
Total		96	104	76	276

Table A11.4 – Hypothesis 1, Crosstabulation

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	68.514[a]	4	.000
Likelihood Ratio	68.425	4	.000
Linear-by-Linear Association	40.025	1	.000
N of Valid Cases	276		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 15.97.

Table A11.5 – Hypothesis 1, Chi-Square Test Results

A Chi-Square value of 68.514 (1, N=276) at p=0.000 enabled the null hypothesis to be rejected. This and examination of the cross-tabulation indicates a positive relationship between the size of company and their use of BIM.

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The second hypothesis was tested to explore any relationship between the length of time BIM had been used and the percentage of work carried out using BIM.

The null hypothesis, $\mathbf{H_{o2}}$ was set as:

> There will be no relationship between the length of time BIM has been used and the percentage of work carried out using BIM.

The alternative hypothesis, $\mathbf{H_{A2}}$, was then set as:

> There will be a relationship between the length of time of BIM has been used and the percentage of work carried out using BIM.

Prior to analysis, any respondents who did not use BIM and those responded as either don't know or prefer not say to Q109 (Time BIM has been used) or Q110 (Percentage of work undertaken using BIM) were removed from the data set, leaving a total of 174 responses. As with the first hypothesis, an initial analysis of the data using a Chi-Square Test on a table of six by four categories resulted in over 20% of cells having a cell count of less than 5, indicating that the test results may be invalid. To overcome this issue, the data was reduced into a 2 x 2 table and the test re-run, with the results shown at Tables A11.6 and A11.7.

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		What percentage of the work your employer undertakes is currently carried out using BIM?		Total
		1% - 50%	51% - 100%	
How long has your employer used BIM?	0 - 5 Years	97	49	146
	6 Years and Above	12	16	28
Total		109	65	174

Table A11.6 – Hypothesis 2, Crosstabulation

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.583[a]	1	.018		
Continuity Correction[b]	4.621	1	.032		
Likelihood Ratio	5.403	1	.020		
Fisher's Exact Test				.031	.017
Linear-by-Linear Association	5.551	1	.018		
N of Valid Cases	174				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.46.

b. Computed only for a 2x2 table

Table A11.7 – Hypothesis 2, Chi-Square Test Results

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A Chi-Square value of 4.621 with Yates Continuity Correction[100] (1, n=174) at p=0.032 enabled the null hypothesis to be rejected. This and examination of the cross-tabulation suggests a positive relationship between the length of time of BIM is used and the percentage of work carried out using BIM.

The third hypothesis, tested any relationship between the length of time BIM has been used and the sharing of BIM data, with the null hypothesis $\mathbf{H_{o3}}$ being set as:

> There will be no relationship between the length of time BIM has been used and the percentage of work carried out using BIM and the sharing of data with other companies.

The alternative $\mathbf{H_{o3}}$ hypothesis was then set as:

> There will be a relationship between the length of time BIM has been used and the percentage of work carried out using BIM and the sharing of data with other companies.

As above, prior to analysis, any respondents who did not use BIM and those who responded as either don't know or prefer not say to **Q109.** How long has your employer used BIM? or **Q111.** What percentage of the work your employer undertakes currently involves the sharing of BIM data with other companies?, were removed from the data set. This left a total of 168 responses. This was again simplified into a 2 x 2 table to avoid greater than 20% of cell counts of less than five, with the results of this analysis are shown at Tables A11.8 and A11.9 below.

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[100] Applied as the analysis was based on a 2 x 2 table **PALLANT, J.** 2010. *SPSS Survival Manual, 4th Edition.,* Maidenhead, McGraw Hill.

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		What percentage of the work your employer undertakes currently involves the transfer of BIM data to other companies?		Total
		1% - 50%	51% - 100%	
How long has your employer used BIM?	0 - 5 Years	119	24	143
	6 Years and Above	15	10	25
Total		134	34	168

Table A11.8 – Hypothesis 3, Cross-tabulation

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.106[a]	1	.008		
Continuity Correction[b]	5.740	1	.017		
Likelihood Ratio	6.192	1	.013		
Fisher's Exact Test				.014	.011
Linear-by-Linear Association	7.063	1	.008		
N of Valid Cases	168				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.06.

b. Computed only for a 2x2 table

Table A11.9 – Hypothesis 3, Chi-Square Test Results

A Chi-Square value of 5.740 with Yates Continuity Correction (1, n=168) at p=0.017 enabled the null hypothesis to be rejected. This and examination of the cross-tabulation indicates a positive relationship between the length of time BIM

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is used and the percentage of work carried out using BIM which involves the sharing of data with other companies.

To identify those dynamics of BIM adoption which were considered to be relevant by respondents, the fourth hypothesis $\mathbf{H_4}$, was set as:

> The 95% lower confidence interval of the sample mean will be greater than the critical Likert response value (μ_0) for a neutral response.

The null hypothesis, $\mathbf{H_{o4}}$ was set as $\mu<=\mu_0$, with the alternative hypothesis $\mathbf{H_{A4}}$ of $\mu>\mu_0$. Where μ is the sample mean and μ_0 is the critical Likert rating. Given the 7 point Likert response used, with 4 representing the neutral response, μ_0 was given this value, such that a value >4 represented a perception of “somewhat agree”, “agree” or “strongly agree”.

Table A11.10 shows the 38 questions with a lower confidence interval (at 95% level) of the population mean greater than the critical value 4, enabling the rejection of the null hypothesis. These are sorted into rank order showing the questions with the highest value (of the lower confidence interval) first, indicating the associated dynamics were considered most significant by respondents.

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Ref.	Question	Test Value = 0					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
1	BIM is supported by the Government's mandate for its use on large projects by 2016.	125.4	296	0	5.833	**5.79**	6.01
2	BIM requires a high level of training.	97.45	296	0	5.752	**5.64**	5.87
3	A social / habitual resistance to change is a barrier to BIM.	80.062	306	0	5.527	**5.39**	5.66
4	The ability to provide specialist staff to operate BIM is a barrier to its use.	79.55	302	0	5.453	**5.32**	5.59
5	The decision to use BIM should be made at the start of a project.	68.881	306	0	5.447	**5.29**	5.6
6	BIM is expensive to implement.	77.247	293	0	5.354	**5.22**	5.49
7	The more an organisation uses BIM, the more benefits it receives.	76.566	310	0	5.35	**5.21**	5.49
8	BIM is supported by the increase in use of Design and Build contracts.	82.977	296	0	5.299	**5.17**	5.42
9	The temporary nature of relationships within construction is a barrier to BIM.	72.416	307	0	5.283	**5.14**	5.43
10	The need for short paybacks on investment is a barrier to BIM.	75.152	287	0	5.241	**5.1**	5.38
11	BIM is supported by an improved quality of design information.	70.346	293	0	5.235	**5.09**	5.38
12	The inability to influence the clients' requirements / process within a tender process is a barrier to BIM.	71.381	297	0	5.209	**5.07**	5.35

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13	BIM requires a degree of technical competence across the whole project.	75.148	308	0	5.19	**5.05**	5.33
14	BIM enables effort to be concentrated to when it has the most impact on the project.	65.522	289	0	5.106	**4.95**	5.26
15	The early client mandate to use BIM assists its use.	71.968	309	0	5.103	**4.96**	5.24
16	BIM is assisted by developing relationships between companies across multiple projects rather than one off projects.	68.649	289	0	5.103	**4.96**	5.25
17	BIM is not supported by the focus on lowest cost within the construction industry.	81.539	290	0	5.058	**4.94**	5.18
18	BIM enables the development of accelerated cost plans direct from the model.	62.436	301	0	5.048	**4.89**	5.21
19	The complexity of BIM is an obstacle to its use.	60.113	298	0	5.029	**4.86**	5.19
20	Investment in new specialist software is required to adopt BIM.	65.617	290	0	5.023	**4.87**	5.17
21	The short term focus of the construction industry is a barrier to BIM.	68.791	287	0	5.013	**4.87**	5.16
22	BIM reduces the construction cost of projects.	65.241	300	0	5.003	**4.85**	5.15
23	A lack of high speed ICT infrastructure is a barrier to BIM.	58.942	299	0	4.994	**4.83**	5.16
24	BIM requires a high degree of co-ordination across different companies.	76.017	306	0	4.981	**4.85**	5.11
25	Site led variations and change orders are reduced when using BIM.	58.638	306	0	4.974	**4.81**	5.14
26	BIM allows possible design changes to be more cost effectively explored.	66.718	290	0	4.958	**4.81**	5.1

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27	The need to maintain cash flow is a hindrance to BIM.	68.228	299	0	4.949	**4.81**	5.09
28	The level of control required to implement BIM is outside that of any single party to a project.	60.026	304	0	4.926	**4.76**	5.09
29	Fragmentation within the construction industry is a barrier to BIM.	70.042	296	0	4.9	**4.76**	5.04
30	BIM enables an overall reduction in the time taken to deliver a construction project.	61.27	301	0	4.891	**4.73**	5.05
31	BIM results in improved design quality.	62.072	297	0	4.878	**4.72**	5.03
32	Prescriptive contract documents inhibit BIM.	60.153	307	0	4.839	**4.68**	5
33	Existing practices within the construction industry are too robust to enable the widespread use of BIM.	56.731	301	0	4.82	**4.65**	4.99
34	Company stability is more of a priority than BIM.	68.833	299	0	4.653	**4.52**	4.79
35	BIM is supported by the historic decline in traditional procurement.	58.12	292	0	4.543	**4.39**	4.7
36	Company survival comes before implementing BIM.	51.899	285	0	4.399	**4.23**	4.57
37	BIM is held back by a lack of appropriate company leadership.	56.85	289	0	4.363	**4.21**	4.51
38	The separation of design and construction under traditional procurement is a barrier to BIM.	48.361	295	0	4.322	**4.15**	4.5

Table A11.10 – Hypothesis 4, Dynamics: Relevant

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To identify those dynamics of BIM adoption which were specifically considered not relevant by respondents, the hypothesis $\mathbf{H_{A5}}$, was set as:

> The 95% higher confidence interval of the sample mean will be lower than the critical Likert response value (μ_0) for a neutral response.

The null hypothesis, $\mathbf{H_{o5}}$ was set as $\mu \geq \mu_0$, with the alternative hypothesis $\mathbf{H_{A5}}$ of $\mu < \mu_0$. Where μ is the sample mean and μ_0 is the critical Likert rating. Given the 7 point Likert response used, with 4 representing the neutral response, μ_0 was given this value, such that a value <4 represented a perception of “somewhat disagree”, “disagree” or “strongly disagree”.

Table A11.11 shows the 10 Questions with a higher confidence interval (at 95% level) of the population mean lower than the critical value 4, enabling the rejection of the null hypothesis. These are sorted into rank order showing those questions with the lowest value (of the lower confidence interval) first, indicating the corresponding dynamics were considered the most irrelevant by respondents.

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Ref.	Question	Test Value = 0					
		t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
						Lower	Upper
1	The demand for BIM within the current construction industry market is uncertain.	39.792	296	0	2.929	2.78	**3.07**
2	BIM enables design to be carried out by a smaller team.	39.017	296	0	3.026	2.87	**3.18**
3	BIM is supported by the nature of relationships between companies within the construction industry.	40.16	306	0	3.058	2.91	**3.21**
4	The benefits that individual companies receive from BIM reflect the levels of investment they make.	38.409	302	0	3.1	2.94	**3.26**
5	It is easy to undertake a trial before implementing BIM fully.	39.507	306	0	3.103	2.95	**3.26**
6	BIM is supported by a project by project focus within construction.	43.024	293	0	3.158	3.01	**3.3**
7	BIM is supported by a wider recognition that the construction industry needs to improve its performance.	44.855	310	0	3.174	3.03	**3.31**
8	The benefits of BIM to those who adopt it are easy to observe.	40.233	296	0	3.199	3.04	**3.36**
9	BIM is supported by a stimulation of formal / academic research.	40.753	307	0	3.312	3.15	**3.47**
10	Company management are supportive of BIM.	44.963	287	0	3.405	3.26	**3.55**

Table A11.11 – Hypothesis 5, Dynamics: Not relevant

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A11.5.3 Summary of Relevant Dynamics

Similarly to as with the qualitative results, a summary of statistically significant relevant dynamics is shown diagrammatically at Figure A11.11, mapped against Rogers's 5 suggested categories.

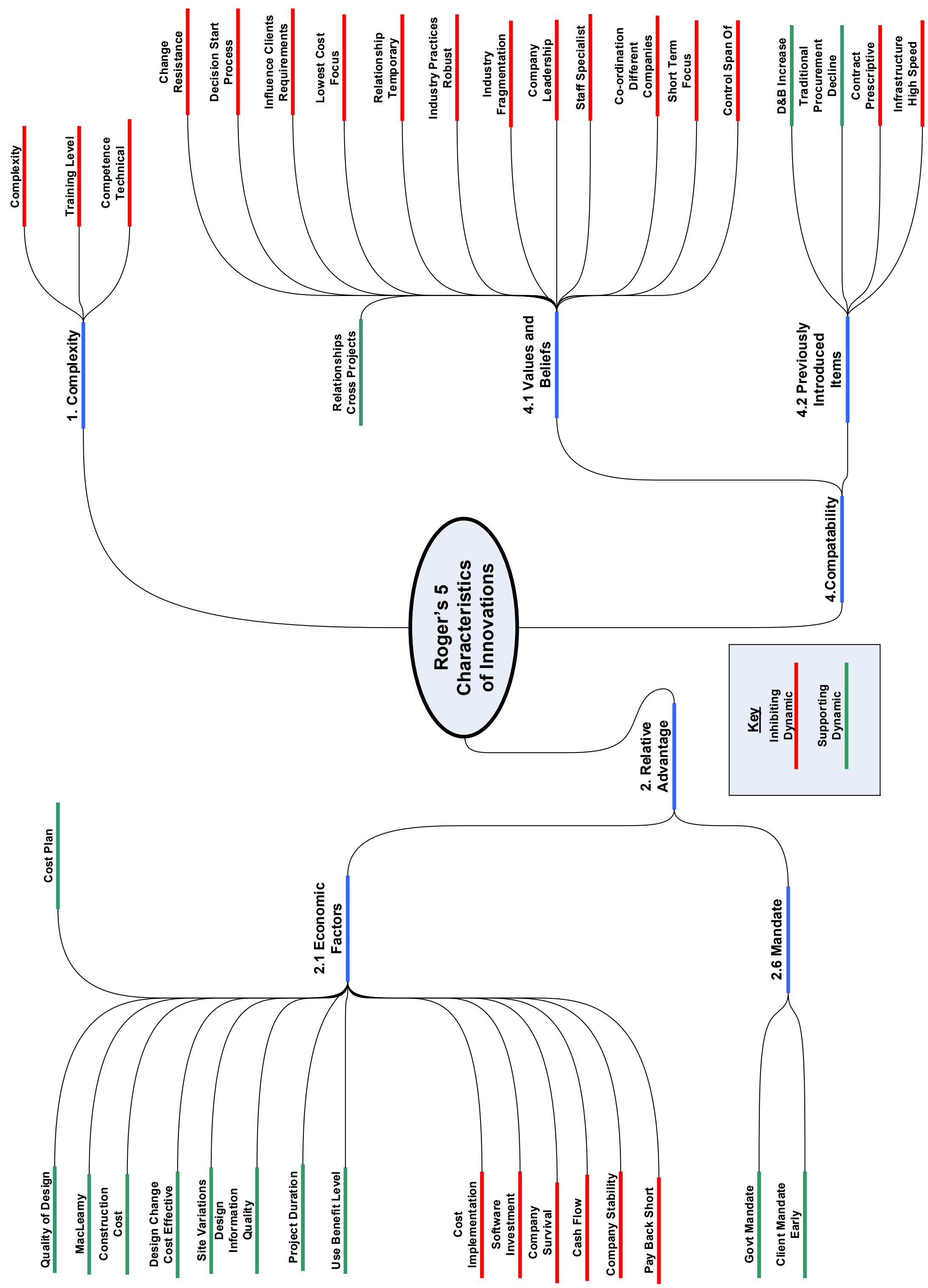

Figure A11.11 – Summary of Significant Dynamics

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A11.5.4 Variation in Dynamics Linked to Company Type and Size

To compare population means on the Likert response variables against a two company characteristics, main business type: $\mathbf{H_{A6}}$ and turnover: $\mathbf{H_{A7}}$, two one way between group analysis of variance (Anova) were carried out. To reduce the risk of a type 1 error when carrying out multiple Anova, the researcher applied a Bonferroni adjustment (Pallant, 2010), resulting in a more stringent alpha value as calculated below.

Normal alpha value	(a):	0.05
Number of tests	(b):	2
New alpha value	(a / b):	0.025

To test for differences in population mean across each of these categories of respondents, the null hypotheses $\mathbf{H_{06}}$ and $\mathbf{H_{07}}$ stated that the sample means are equal across groups representing the company characteristics, with the respective alternative hypotheses $\mathbf{H_{A6}}$ and $\mathbf{H_{A7}}$ stating there would be a statistically significant difference in the sample means across the groups.

The results of the Anova to examine the effects of three company types enabled the rejection of the null hypothesis $\mathbf{H_{06}}$, due to a significant difference in sample means for a total of 12 dynamics at the $p < 0.025$ level. These are shown at Table A11.12 along with descriptive statistics and effect size, calculated using eta squared. For 10 of these questions, the actual differences in population means was also large (=> 0.5), indicating the difference can be considered of practical importance (Pallant, 2010). However, for the remaining 2 questions, although statistical significance was reached, allowing the rejection of the null hypothesis, the actual difference in the mean scores was quite small (< 0.5), indicating the difference can be considered of little practical importance (Pallant, 2010).

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Ref.	Question	Eta Squared	Difference		Descriptive statistics for the pairs of groups where differences occur. Group 1		Group 2	
1	**BIM is supported by a project by project focus within construction.**	0.162 (Large)	Between Main Contractor and Consultant				Consultant	
			Mean Difference =	***1.142***			*μ=*	***2.67***
			p=	*0.004*	*Main Contractor*		*SD=*	*1.301*
			Between Main Contractor and Sub-		*μ=*	***3.812***	Sub-Contractor	
			Mean Difference =	***0.831***	*SD=*	*1.631*	*μ=*	***2.981***
			p=	*0.019*			*SD=*	*1.229*
2	**BIM is expensive to implement.**	0.137 (Large)	Between Main Contractor and Sub		Sub-Contractor		Main Contractor	
			Mean Difference =	***1.329***	*μ=*	***6.029***	*μ=*	***4.700***
			p=	*0.021*	*SD=*	*1.363*	*SD=*	*1.287*
3	**Company survival comes before implementing BIM.**	0.392 (Large)	Between Sub Contractor and Main		Sub-Contractor		Main Contractor	
			Mean Difference =	***1.101***	*μ=*	***4.955***	*μ=*	***3.274***
			p=	*0.013*	*SD=*	*1.046*	*SD=*	*1.739*
4	BIM allows possible design changes to be more cost effectively explored.	0.211 (Large)	Between Main Contractor and Consultants		Main Contractor		Consultant	
			Mean Difference =	*0.432*	*μ=*	*5.175*	*μ=*	*4.743*
			p=	*0.023*	*SD=*	*1.144*	*SD=*	*1.377*
5	**Site led variations and change orders are reduced when using BIM.**	0.291 (Large)	Between Main Contractor and Consultants		Main Contractor		Consultant	
			Mean Difference =	***0.732***	*μ=*	***5.711***	*μ=*	***4.97871***
			p=	*0.022*	*SD=*	*1.202*	*SD=*	*1.358*

6	**The benefits that individual companies receive from BIM reflect the levels of investment they make.**	0.191 (Large)	Between Consultant and Sub Contractor		Consultant			
			Mean Difference =	***0.829***	*μ=*	***3.235***		
			p=	*0.004*	*SD=*	*1.589*	*Sub Contractor*	
			Between Main Contractor and Sub		Main Contractor		*μ=*	***2.406***
			Mean Difference =	***1.231***	*μ=*	***3.637***	*SD=*	*1.391*
			p=	*0.019*	*SD=*	*1.913*		
7	**BIM enables design to be carried out by a smaller team.**	0.169 (Large)	Between Main Contractor and Consultant		Main Contractor		Consultant	
			Mean Difference =	***0.965***	*μ=*	***3.511***	*μ=*	***2.546***
			p=	*0.003*	*SD=*	*1.209*	*SD=*	*1.445*
8	**The complexity of BIM is an obstacle to its use.**	0.201 (Large)	Between Sub Contractor and Consultant		Sub Contractor		Consultant	
			Mean Difference =	***0.964***	*μ=*	***5.519***	*μ=*	***4.555***
			p=	*0.017*	*SD=*	*1.639*	*SD=*	*1.864*
9	Bespoke company specific systems are barriers to BIM.	0.321 (Large)	Between Consultant and Main Contractor		Consultant		Main Contractor	
			Mean Difference =	*0.378*	*μ=*	*4.162*	*μ=*	*3.784*
			p=	*0.014*	*SD=*	*1.439*	*SD=*	*1.032*
10	**BIM is assisted by developing relationships between companies across multiple projects rather than one off projects.**	0.189 (Large)	Between Consultant and Main Contractor		Consultant		Main Contractor	
			Mean Difference =	***0.664***	*μ=*	***5.433***	*μ=*	***4.769***
			p=	*0.011*	*SD=*	*1.414*	*SD=*	*1.03*
11	**The development of design work at risk in a tender situation is a barrier to BIM.**	0.166 (Large)	Between Consultant and Main Contractor		Consultant		Main Contractor	
			Mean Difference =	***0.902***	*μ=*	***4.432***	*μ=*	***3.530***
			p=	*0.017*	*SD=*	*1.509*	*SD=*	*1.092*

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12	**Existing practices within the construction industry are too robust to enable the widespread use of BIM.**	0.151 (Large)	Between Main Contractor and Sub		Main Contractor		Sub Contractor	
			Mean Difference =	***1.31***	*μ=*	***5.469***	*μ=*	***4.159***
			p=	*0.007*	*SD=*	*1.195*	*SD=*	*1.245*

Table A11.12 – Hypothesis 6, ANOVA by Company Type

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When considering company turnover, due to a large variation in the number of respondents across each of the five original categories, the data was simplified into two categories as shown at Table A11/13 below, prior to Anova being carried out.

Original Turnover Category	£0-199K	£200K - £999K	£1M - £9.99M	£10M to £99.9M	Over £100M
No of Respondents	18	43	70	98	82
Simplified Turnover Category	Lower Turnover (£0 - £9.99M)			Higher Turnover (Over £10M)	
No of Respondents	132			180	

Table A11.13 – Simplification of Turnover Category Data for ANOVA

The results of analysis of variance across the two groups of company turnover enabled the rejection of the null hypothesis: **H_{07}**, due to a difference in the sample means, for a total of 16 questions. Along with descriptive statistics and effect size calculated using eta squared, these dynamics are shown at Table A11.14.

In this case 13 questions had a large difference in means, indicating potential practical importance, with 3 dynamics having a statistically significant but small difference in means (< 0.5) indicating little practical importance. For Q23 – Company survival comes before implementing BIM, the results for Sub-Contractors (μ= 4.995) was above the neutral value of 4.0 indicating a significant dynamic for respondents within group while the results for Main Contractors (μ= 3.274) was below the neutral value indicating respondents within this group felt that this dynamic was not significant.

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Similarly for Q96 – The Development of design work at risk in a tender situation is a barrier to BIM, was concluded to be as a significant dynamic by Consultants (μ= 4.432) but not by Main Contractors (μ= 3.530).

Ref:	Dynamic	Eta Square	Difference		Descriptive statistics for the Group 1		Group 2	
1	BIM is not supported by the focus on lowest cost within the construction industry.	0.123 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.150***	*µ=*	***5.722***	*µ=*	***4.571***
			p=	*0.009*	*SD=*	*1.878*	*SD=*	*1.58*
2	BIM is inhibited by risk transfer down the supply chain.	0.169 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***0.702***	*µ=*	***4.492***	*µ=*	***3.790***
			p=	*0.023*	*SD=*	*1.581*	*SD=*	*1.84*
3	Fragmentation within the construction industry is a barrier to BIM.	0.212 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	*0.456*	*µ=*	*4.637*	*µ=*	*5.093*
			p=	*0.013*	*SD=*	*1.727*	*SD=*	*1.64*
4	BIM is expensive to implement.	0.352 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.557***	*µ=*	***6.252***	*µ=*	***4.695***
			p=	*0.004*	*SD=*	*1.697*	*SD=*	*1.85*
5	Collaboration with different types of companies within the construction industry assists BIM.	0.169 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.067***	*µ=*	***3.403***	*µ=*	***4.471***
			p=	*0.012*	*SD=*	*1.335*	*SD=*	*1.22*
6	BIM results in a reduction in requests for information / queries from site.	0.240 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.389***	*µ=*	***3.086***	*µ=*	***4.475***
			p=	*0.024*	*SD=*	*1.471*	*SD=*	*1.67*
7	BIM provides an intelligent collaboration platform.	0.197 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.090***	*µ=*	***3.297***	*µ=*	***4.387***
			p=	*0.009*	*SD=*	*1.946*	*SD=*	*1.97*

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7	BIM provides an intelligent collaboration platform.	0.197 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.090***	*μ=*	***3.297***	*μ=*	***4.387***
			p=	*0.009*	*SD=*	*1.946*	*SD=*	*1.97*
8	BIM enables effort to be concentrated to when it has the most impact on the project.	0.277 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.389***	*μ=*	***4.305***	*μ=*	***5.694***
			p=	*0.014*	*SD=*	*1.331*	*SD=*	*1.07*
9	Implementing BIM leads to tangible financial benefits.	0.306 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.245***	*μ=*	***3.272***	*μ=*	***4.517***
			p=	*0.003*	*SD=*	*1.066*	*SD=*	*1.12*
10	The ability to provide specialist staff to operate BIM is a barrier to its use.	0.155 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	*0.443*	*μ=*	*5.709*	*μ=*	*5.265*
			p=	*0.005*	*SD=*	*1.772*	*SD=*	*1.84*
11	Bespoke company specific systems are barriers to BIM.	0.233 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***0.738***	*μ=*	***4.366***	*μ=*	***3.628***
			p=	*0.014*	*SD=*	*1.082*	*SD=*	*1.33*
12	BIM is supported by the Government's mandate for its use on large projects by 2016.	0.097 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***0.924***	*μ=*	***5.581***	*μ=*	***6.505***
			p=	*0.015*	*SD=*	*1.414*	*SD=*	*1.48*
13	BIM is assisted by developing relationships between companies across multiple projects rather than one off projects.	0.102 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.067***	*μ=*	***5.719***	*μ=*	***4.651***
			p=	*0.019*	*SD=*	*1.494*	*SD=*	*1.76*

13	BIM is assisted by developing relationships between companies across multiple projects rather than one off projects.	0.102 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.067***	*μ=*	***5.719***	*μ=*	***4.651***
			p=	*0.019*	*SD=*	*1.494*	*SD=*	*1.76*
14	The policies within my company support BIM.	0.174 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	*0.412*	*μ=*	*3.830*	*μ=*	*4.242*
			p=	*0.007*	*SD=*	*1.977*	*SD=*	*1.2*
15	It is easy to undertake a trial before implementing BIM fully.	0.082 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.096***	*μ=*	***2.471***	*μ=*	***3.567***
			p=	*0.017*	*SD=*	*1.301*	*SD=*	***1.24***
16	Existing practices within the construction industry are too robust to enable the widespread use of BIM.	0.130 (Large)			Lower Turnover		Higher Turnover	
			Mean Difference =	***1.389***	*μ=*	***5.621***	*μ=*	***4.232***
			p=	*0.008*	*SD=*	*1.984*	*SD=*	*1.91*

Table A11.14 – Hypothesis 6, ANOVA by Category of Company Turnover

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A11.5.4 Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) is a method available to reduce a large number of measured variables into a smaller number of related groups of variables, referred to as factors (Coakes, 2012). A three step technique (Pallant, 2010) was applied, starting with preliminary testing of the data to assess the suitability for factor analysis.

As noted above, the lower than planned level of responses resulted in an STV (*p*) of 2.99:1, the response rate (n=311) is greater than 300 recommended by Pallant (2010) and in this respect the data remains appropriate. The correlation coefficients between variables were also considered, with a reasonable number (23 of 104) having a value of greater than 0.3 (Tabachinck and Fidell, 2007).

The final preliminary tests to assess the suitability of the data for EFA, were Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, the latter of which tests for partial correlation among the variables. The Barlett's test of sphericty returned a value of 0.112, which according to (Pallant, 2010) is not significant (as $p > 0.05$) . The KMO measure of sampling adequacy returned a value of 0.247, significantly lower than the minimum value of 0.6 (Tabachinck and Fidell, 2007). Both of these tests suggest the data is not suitable for EFA and therefore any results could not be considered statistically robust. As this would undermine one of the key aims of the research, this particular analysis was not taken any further.

A11.6 Application of Quantitative Results to Characteristics of BIM

Similar to the analysis applied to the qualitative data, the results of hypotheses 4 and 5 were applied to the five generic characteristics of innovation (Rogers, 2003) as having the most influence on the rate of diffusion. These and the resulting notional values, again shown as high, medium or low, are shown at Table A11/15 below.

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Characteristic of BIM	Relative Advantage	Compatibility	Complexity	Trialability	Observability
Summary of Quantitative Results	While some inhibiting dynamics appear, most dynamics are supportive.	A significant number of deep rooted inhibiting dynamics outweigh the smaller number of supporting dynamics.	A small number of wholly inhibiting dynamics.	The lack trialability is highlighted.	The lack of observability is highlighted.
Allocated Notional Value	**High**	**Low**	**High**	**Low**	**Low**

Table A11.15 – Quantitative Results Applied to Rogers's Characteristics of Innovations

These indicate that the adoption rate for BIM is inhibited by low compatibility, high complexity as well as low trialability and observability, however is supported by its high relative advantage.

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