THE DEVELOPMENT OF 5D BIM FRAMEWORK TO FACILITATE COSTING IN CONTRACTOR-LED PROJECTS

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Date...

ABSTRACT

Building Information Modelling (BIM) as an ambitious Government Construction Strategy (GCS) on all publicly procured sector projects, is leading to a significant shift and changing the dynamics of cost professional functions. This therefore requires the current fragmented construction industry to urgently review approaches to existing cost estimating and cost planning processes leading to a reliable project budget. This drive, along with 2025 construction strategy is key to achieving the requirement of GCS for 25 percent cost reduction. To successfully implement Level 2 BIM, relevant costing framework, enabling 5D BIM cost protocol or standard significant to changing dynamics of cost functions within BIM environment is required to be embedded within design development stages. Using phenomenological qualitative research method and thematic data analytical process, interviews involving 21 participants from seven construction organisations with design, construction and cost management practices were conducted. Scope was intentionally provided for extensive discussion to identify issues beyond the literature findings. Findings suggest strong commitment and leadership from organisational management will facilitate cost savings, generate accurate cost information in a Level 2 BIM project. A considerable cultural shift towards automating and digitising cost functions virtually; stronger collaborative working relationship relative to costing in design development, construction practice, maintenance and operation is required across the built environment. The 5D BIM Costing Framework (5B-CF) which informed the creation of 5D BIM Cost Protocol (5B-CP) as developed would allow contractors fully utilise BIM facilitating more effective 5D costing in a contractor-led project.

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DEDICATION

This piece of work is dedicated to Jesus Christ and His Holy Spirit whose wisdom and inspirations ever remain my greatest treasure in life. Secondly, His anointed servant Bishop David Oyedepo through whom I was introduced to the wisdom and inspiration of the Holy Spirit.

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CHAPTER ONE

INTRODUCTION

1.0 GENERAL INTRODUCTION

Developing an accurate building information model will benefit contractors as well as all members of the project. It will improve planning, construction, save time and money; reduce the likelihood for conflict and error. In this respect, Building Information Modelling (BIM) has proven to be a tool for building models in Architecture, Engineering, and Construction (AEC) sectors. The designed building model supports construction, fabrication, procurement activities and costing.

Sun and Zhou (2010) investigated the impact of BIM application in the construction industry in China within five key performance indicators (5-KPIs) such as quality, cost, time, safety and energy. They found that BIM applications will support sustainable development in the construction industry with the support of laws and regulations. Additionally, Suermann and Issa (2007) reported the evaluation of BIM on construction project and its impact with respect to six primary construction key performance indicators which include quality control, on-time completion, cost, safety, amount per unit performed, and unit per man hour. They found from respondents that the KPIs are in the following order: quality 94%, on-time completion 88%, unit per man hour 86%, amount per unit 80%, cost 80% and safety 54%. Jung and Joo (2011) developed a framework for real world project implementation of BIM to guide research and improve communication, which are divided into BIM technology, BIM perspective, and construction business function (Figure 1). Presently, the entire building process and costing are managed using software with less capabilities such as AutoCad® and Excel®, which often leads to data duplication, inevitable time wasting, and high risk of error propagation (Vozzola et al., 2009).

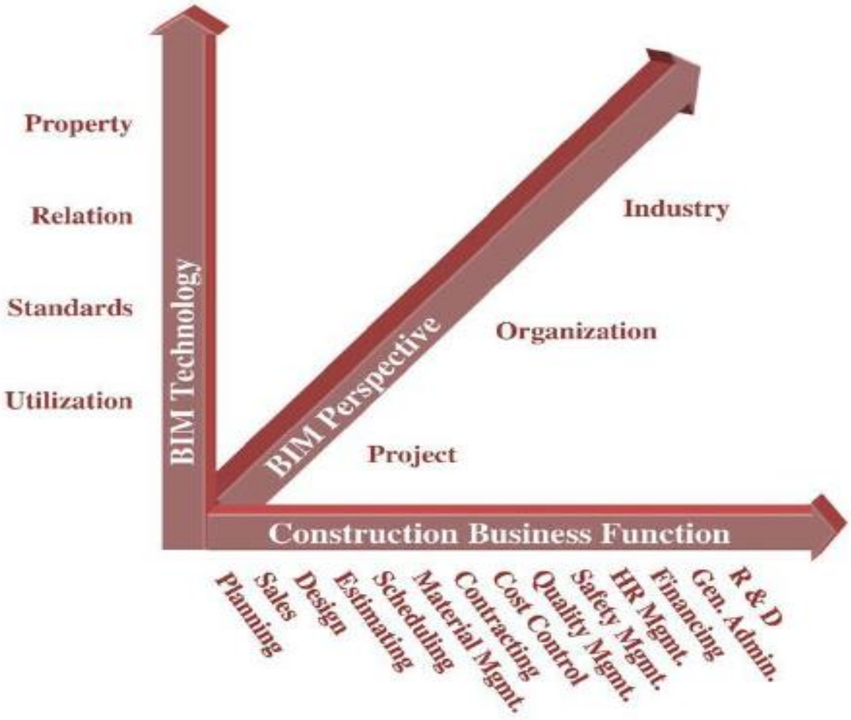


Figure 1.1 BIM Framework (Source: Jung and Joo, 2011)

1.1 DEVELOPMENT OF BIM

Egan (1998) published his seminal report on the UK construction industry entitled 'Rethinking Construction'. The espoused intention was to attain a radical transformation of construction performance through a planned series of change initiatives; identifying five key drivers of change: committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda, and a commitment to people. Sir Egan's initial agenda and the subsequent emphasis on instrumental targets were in no small way directed at overcoming industry failings caused by sector fragmentation. The construction sector has never really existed as a coherent entity and the causes of fragmentation are deeply rooted (Rabeneck, 2008).

Furthermore, since the late 1970s, industry fragmentation has been exacerbated by the vicissitudes of the tax and insurance system which have accumulatively acted to encourage the growth of self-employment (Harvey, 2003). The demise of the public sector Direct Labour Organizations (DLOs) also contributed to eroding the industry's traditional training base. Some of these concerns combined to reinforce the adoption of structural flexibility as the key factor for achieving competitive advantage (Winch, 1998). Consequently, the contracting sector is dominated by 'hollowed-out' firms with few direct employees and raising concerns about the industry's absorptive capacity and its ability to innovate (Gann, 2001).

The Egan initiative was therefore directed at a sector that was already locked into a 'low road' development path (Bosch and Philips, 2003) and the similar but genetically different forces at work were not so easily overcome. This was so given that the improvement agenda were dependent on voluntary action hence it is not a shock that progress has subsequently been slow and patchy. There has been little or no willingness to reinforce the rhetorical exhortation of the Egan Report through regulation or institutional reform. Unlike other markets such as the automotive and aerospace industries, designers had also been switching from manual drafting to CAD. They began to explore 3D visualization and to relate the outputs of their design processes to manufacturing, designing components that could be accurately produced on computer-controlled machines. 'Lean thinking' was also influential and soon the major manufacturers were working closely with their key supply chains, using sophisticated model-based designs to speed up design and delivery of new products to their markets (Sacks et al, 2010).

In the construction industry, however, things were moving at a different pace, mainly due to the highly fragmented nature of the sector which was noted in Sir Egan's report. In the improving the Project Process chapter of that report, he talked about processes that can advance a proposed innovation in the industry and deliver more efficient construction practises which includes Repeated processes, Integrated projects processes, Focus on the end product, Product development, Product implementation, Partnering the supply chain, Production of components etc (Egan, 1998). In the worldwide aerospace industry, for example, there are only a handful of aircraft manufacturers, and they have developed close, long-term commercial relationships with their suppliers. With a history of innovation and a culture of continued investment in research and development, there are high barriers to entry for any company wanting to compete in the aerospace industry.

The global construction industry, in contrast, currently comprises millions of contractors, and many more subcontractors, consultants, materials suppliers and product manufacturers. It is a highly competitive industry in which many businesses work on wafer-thin margins, with little or no investment in research and development. As a result, there is little differentiation between firms; many compete almost purely on price, and only in recent years have we begun to see a small number of major clients looking to develop longer-term partnering or alliance-type framework agreements with key suppliers. The differences between construction and aerospace or automotive are also exacerbated when one considers the products. Aircraft and cars are produced in a handful of factory environments in large volumes to standard core designs with a relatively limited number of configurations. The construction industry's outputs, on the other hand, are often unique, one-off solutions to a client's needs, produced specifically for particular locations, and their design and construction can involve an infinite number of variations, often due to the availability of appropriate skills, knowledge, materials, labour, space, etc.

It is hardly surprising therefore, that BIM has developed more slowly than the adoption of modelling technology in other sectors. But, since the 1980s, some construction businesses have expanded well beyond CAD (Weisberg, 2008; Bjork et al, 2010). Reasons include the lower cost and increased processing power of computer hardware, higher bandwidth telecoms links (again at lower cost), wider availability and use of BIM software outside niche disciplines, and the emergence of industry data exchange standards. However, the main catalyst for change in the UK came after the late 2000s global financial crisis when the UK Government began to demand better value for money and better carbon performance from its public sector projects. Paul Morrell, the Government's chief construction advisor (2009-2012), had already announced interest in BIM, but it took the publication of the UK Government Construction Strategy in May 2011 – to make the industry realize BIM was no longer optional if they wanted to work for public sector organizations. The UK Government explicitly stated that it aimed to achieve "significant improvements in cost, value and carbon performance through the use of open sharable asset information", and industry quickly realized that it would need to overhaul more than just its technology if it was to successfully incorporate BIM into its industry practices.

Nonetheless, the initial focus on technology and software was understandable. The introduction of 3D design techniques improved visualization for project team members, clients, planners and other stakeholders (video walk- or fly-throughs were being laboriously generated by designers in the 1990s, for example).

Design disciplines managing particularly complex tasks – structural engineering and building services, for instance – also began to work in 3D, and could merge their outputs to identify potential problems before construction started on site by using them for 'clash detection' and other coordination tasks. The introduction of 'parametric' 3D design enabled the output of more than drawings and 3D models: an object's geometrical representation, it's physical shape and dimensions, could be augmented by information about its material, cost, colour, manufacturer, etc, and its functional relationship with other components. As designs were amended, so the relationships between items automatically changed. Clearly, therefore, BIM is more than graphical presentation of geometrical information (NBS, 2015). Models can incorporate schedule or sequencing information (3D + time: 4D), cost data (5D), operations information, sustainability data, and more. As a result, the contractors and his supply chain with the specialist subcontractor designers, facilities managers, environmental engineers concerned with programming, cost management, environmental assessment and future operation and maintenance are seeking to exploit BIM.

1.2 PROCUREMENT

Every capital project in the UK is procured through a certain procurement strategy and procurement route with numerous factors on consideration to cut total project cost and achieve value for money. Advent of BIM processes will further complicate procurement issues in existence, therefore procurement related issues need resolution and critical examination in relation to Building Information Modelling since organizations and clients differ in their procurement approaches. Whether is PFI/PPP (Private Finance Initiative) or Design and Build, Management Contracting, Construction Management or traditional method etc, questions arise regarding the mechanism for adoption of BIM with a focus on project cost reduction and the procurement pathway most suitable to follow vis a vis the form of contract when Building Information Modelling is underway.

1.2.1 Procurement Strategy

The procurement strategy identifies the best way of achieving the objectives of the project and value for money, taking into account the risks and constraints, leading to decisions about the funding mechanism and asset ownership for the project. The aim of a procurement strategy is to achieve the optimum balance of risk, control and funding for a particular project (OGC, 2006).

1.2.2 Procurement Route

The procurement route delivers the procurement strategy. It includes the contract strategy that will best meet the client’s needs. An integrated procurement route ensures that design, construction, operation and maintenance are considered as a whole; it also ensures that the delivery team work together as an integrated project team (OGC, 2006).

1.2.3 Value for Money

This is the optimum combination of whole-life costs and quality to meet the user requirement (OGC, 2006). It is further defined as achieving the optimum use of resources (money, manpower, time and materials) each of which may be regarded as equally important. Until recently money was often regarded as the most important resource in the public sector, the cheapest method of construction being the one largely selected. With money becoming more expensive the need to obtain more for a given amount became imperative and this has contributed to emphasis the equal importance of constituent resources. The concept has widened to embrace whole life cost of a project from initial procurement, through design and construction, to maintenance and cost in use and perhaps, the cost of decommissioning in order that the best use/returns can accrue over the lifetime of the building.

1.3 PROBLEM STATEMENT

A Quantity Surveyor (QS) or Cost Consultant is a responsible professional who delivers best value in building and infrastructure and provides the most meaningful advice relative to construction cost information (RICS, 2014). QS or Cost Consultant carries out other numerous activities to ensure the final cost information is within the cost targets of the budgeted amount. These activities include but not limited to cost estimating, cost planning, procurement advice, measurement, preparation of Bill of Quantities (BoQ), cost control and analysis, tender documentation, variations, progress valuations, contractual claims, whole life cycle costing, risk analysis and management, detailed measurement works and final account (Ashworth and Hoggs, 2007; Kirkham, 2007; Olatunji et al, 2010). Traditionally, these functions are time consuming and complicated because of manual engagement of 2D drawings and take-off processes. According to Sabo (2008), manual cost processes involving large amount of cost information from a 2D design is susceptible to human errors, incorrect and disseminates inaccurate information across project parties. The resultant effect is cost overrun, lower precision of project cost information, payment issues, huge volume of variation claims, disputes and litigations, inability to meet project timelines due to incorrect cost advice provided. For instance, design information is more frequently reviewed and updated as the construction project evolves, it is therefore not an easy task to constantly update measurements and estimates with every design change especially when a large amount of manually produced design information is subject to frequent revisions. It is therefore very difficult to achieve cost accuracy in quantity estimation and associated cost functions and can be extremely problematic (Cartlidge, 2009; Cartlidge 2017; Aibinu and Pasco, 2008). Thomas (2010) reported that up to 30% of projects exceeds original project budget which destroys the feasibility studies that informed the project decision and leading to client's dissatisfaction (Mitchell, 2012).

According to Yaman and Tas (2007), cost estimates and cost plans are more likely prepared with insufficient project detail and within a limited timeframe affecting the level of cost accuracy within stages of estimate. The expected percentage error in generation of cost information reduces as design evolves and more design information is made available. Therefore, traditionally induced costing approach is subject to higher risk and errors since estimates and cost plans are generated when project information is still incomplete. Building Information Modelling (BIM) is a collaborative process that collects, share and manage information in real time virtual environment (Eastman et al, 2011; HM Government, 2013) and with capability to link 3D virtual information to the fifth dimension (Mitchell, 2012; Thurairajah and Goucher, 2013). BIM process and the supporting tools have already started to benefit the designers with model-based intelligent design including owners with a more feasible and accessible project within the United Kingdom (RICS, 2014). Low adoption of Level 2 BIM among cost professionals is blamed generally on lack of awareness of capabilities of BIM application towards quantity surveying practices (RICS, 2015, Wong et al, 2014). Particularly, lack of development of 5D costing frameworks, protocols or standards integrated into existing BIM protocols, strategies, frameworks and plan of work like Royal Institute of British Architects' (RIBA) plan of work, 2013 (Wong et al, 2014; RIBA, 2013). The AEC industries and BIM development is moving extremely rapidly but how 5D BIM process is embedded within a design, construction and maintenance integrated functions is not defined. There is yet no established 5D BIM framework or protocol to facilitate digital measurement: tailored to influence and impact construction industry practice towards automating and digitising cost functions enabling generation of accurate cost information. Since cost is a key parameter for effective construction management process, it is therefore essential to develop a costing framework and protocol that deploys 5D BIM to overcome these inefficiencies - integrating BIM processes and tools into current design and construction practices particularly in a contractor-led project.

1.4 RESEARCH QUESTIONS, AIM AND OBJECTIVES

Application of BIM within the dynamics of cost functions can improve quantity surveying (QS) practices. However, the QS and other cost professionals appear to be lagging as compared to other professionals within the UK construction sector (Smith, 2014; Mitchell, 2012). This research study will look at the industry practice as it relates to the field of BIM and find ways to develop and incorporate 5D BIM costing frameworks and protocols into practice ensuring more efficient BIM process solutions.

1.4.1 Research Questions

Hence, the following research questions:

1. What is the position of existing literature with respect to current state of BIM and its use in costing processes?

2. To what extent is the contractor and supply chain involvement in design and construction phases in terms of 5D BIM costing practice?

3. What costing framework will help to facilitate 5D BIM costing in a contractor-led project?

With the above research questions to be answered during the research study, the study is developing an approach to allow contractors to fully utilise BIM for more effective costing. This is because it is necessary to incorporate contractors and the supply chain within BIM processes, as the current state-of-the-art limits the contractor's ability to contribute their vast experience and knowledge to the project during the design phase (Eastman et al., 2011, Garlick, 2016). This implies that the contractor, architect, designers, quantity surveyors, cost estimator and fabricators etc should work together from the start of the project to make optimum use of the BIM process. In addition, large value of contractor's knowledge is lost after the model has been developed without the collaboration of the contractor.

1.4.2 Research Aim

The aim of this study is to develop a framework to allow contractors to fully utilise BIM for more effective 5D costing. It is beneficial to develop BIM and associated costing processes integrating the contractor's perspective with a focus to improve communication, mitigate contingencies, minimise sequential conflicts that could translate to risks, uncertainties and risks with impact on final project cost, errors passed to the subcontractors in designs and reduce errors transferred to subcontractors.

1.4.3 Research Objectives

In view of the above research aim, this study will address the following objectives:

1. Undertake a critical analysis of research in the field of BIM and its current use in costing.
2. Carry out semi-structured open-ended interviews informed by research with industry practitioners who are experienced in carrying out BIM projects.

3. Develop a framework (5B-CF) through primary data using interpretative phenomenology and thematic analytical approach alongside to generate themes.
4. Evaluate the framework to determine suitability for industry 5D BIM processes and practice.
5. Develop a protocol (5B-CP) from key research findings of the framework as impact to industry.
6. Determine future directions of contractor costing using BIM and to identify further challenges and benefits of 5D costing in BIM.

1.5 JUSTIFICATION

With the mandate for Level 2 BIM strategy that came into effect April 2016 (Cabinet Office, 2016), the UK Government through its GCS is targeting collaborative working and construction efficiency (Cabinet Office, 2011 & 2016). Among many other things is pushing for cost reduction by 25% of all publicly capital-intensive projects, digitising construction industry processes and more effective integration of a project team through the implementation of level 2 BIM. Currently contractors have seen the huge benefits involved in BIM implementation on a contractor-led procurement projects (Smith, 2017). This includes better digital designs (3D models) with improved documentation and visuals (Level 1), improved collaboration within the project team and disciplines (Level 2), integration of several multidisciplinary (Level 3), improved interoperability, on time completion, cost reduction, information management process and product, reliable decision base, clash detection, conflict resolution, data management, quality control. However, there is no focus hitherto on how 5D BIM could facilitate costing in a contractor-led procurement projects such as design and build, construction management, management contracting, public and private partnership (PPP). The industry rather is still grappling with the error prone traditional way of generating cost information which in most cases has defeated project objectives, destroyed feasibility investigation that informed project investment and overall undermine project success (Mitchell, 2012; Smith, 2014; Chuan and Sheng, 2017). The industry being influenced by resistance to change and inability to adapt existing working culture to the new BIM value adding and innovative process, hence the need for this research investigation seeking to develop a costing framework with ability to resolve the traditional cost concerns using 5D BIM approach to facilitate costing activities.

The proposed research is targeted towards practitioners within the construction industry as well as students and researchers in academia. For practitioners (contractors), it will provide not just a deeper understanding of BIM as it relates to innovative cost estimation using 5D BIM approach but also a practical information including some applications that are available, their benefits and limitations, the needed infrastructure and successful implementation. Developed costing framework and 5D BIM cost protocol will help tailor industry practice towards generating accurate cost information for tender processes. For researchers and students on this subject, it will provide broader information on BIM implementation strategy, process and requisite technological tools relative to project cost estimating and cost planning for current/future reference and for further study in the field of BIM and 5D BIM.

1.6 OUTLINE METHODOLOGY

The study adopted a qualitative approach, in particular phenomenological investigation and used thematic analytical process to generate research themes and patterns. Phenomenological research is a qualitative method of inquiring a given concept, which involves exploring an in-depth understanding of a phenomenon experienced by different individuals (Creswell, 2007 and 2013) while thematic analysis is essentially a method for identifying and analysing patterns in qualitative data (Clarke and Braun, 2013). Data was collected using semi-structured open-ended interview from key industry practitioners with relevant experience and skills in BIM projects across a spectrum of construction organisations involved with virtual environment. Collected audio recorded data was transcribed, analysed using thematic analytical process and interpreted while generating themes. Significant statements were identified from transcribed data, creating meaning units and themes, advancing textural and structural descriptions into an exhaustive description of the invariant structure called "essence" of that which is experienced. A 5B-CF and 5B-CP is developed using the themes with potentials to integrate 5D processes within innovative BIM industry practice. A designed structured interview questions with a closed Yes/No quantitative research orientation is used to evaluate proposed research framework. Throughout the entire research, the required ethical procedures and conduct in relation to confidentially, anonymity, integrity as stipulated by the University of Wolverhampton research ethics, is strictly adhered.

1.7 GUIDE TO RESEARCH REPORT

1.7.1 Chapter One

This captures general introduction of research focus. Developments of BIM, procurement, problem statement, research questions, aim and objectives of the research. Justification of the chosen research topic and the outlined methodology to be used

1.7.2 Chapter Two

Review of the relevant literatures. Aspects of reviewed literature includes the history of Building Information Modelling (BIM), UK construction industry, BIM capabilities, cost planning and design stages, BIM as a solution to complex design and cost planning processes, BIM maturity levels, Common Data Environment (CDE), and emerging research focus.

1.7.3 Chapter Three

A further review of relevant literatures covering measurement standards, traditional estimating approaches, backgrounds of BIM based cost estimation, a snapshot of BIM assisted cost estimation tools and rethinking construction.

1.7.4 Chapter Four

This chapter discusses in detail the methodological approach of research inquiry and covered other sub topics like research philosophy, approaches to research inquiry, Qualitative research justification, Quantitative and Qualitative research approaches, research methodology outline and literature review justification, philosophical assumptions and worldviews. It further detailed thematic data analytical process.

1.7.5 Chapter Five

This chapter presents the findings of the study as set out in the research aim and the discussions of the research findings.

1.7.6 Chapter Six

This chapter presents the development of 5D BIM Costing Framework (5B-CF), presentation of framework, evaluation of 5D costing framework and a resultant development of 5D BIM Cost Protocol (5B-CP)

1.7.7 Chapter Seven

This is the summary of how research aim and objectives were met, contribution to knowledge, conclusions and further research recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

The UK Construction Industry has recently been mandated to implement Level 2 BIM on all centrally procured public sector projects (Cabinet Office, 2016) and requires an urgent appraisal of the current fragmented approach to existing cost estimating and cost planning process. An examination of Level 2 BIM implementation and the current dynamics of improved cost functions, required level of detail/information at different project phases and level of proficiency of a multi-disciplinary project team is required. A further assessment of existing traditional cost estimating approaches, its challenges and barriers, BIM based cost estimating process in a contractor-led procurement towards a seamless BIM and 5D process implementation is needed. The challenge of creating a balance in delivering high performance construction projects and cost-effectiveness providing value for money is a key drive towards the UK Government Construction Strategy for Level 2 Building Information Modelling (BIM) implementation on all public-sector projects. This initiative is with a requirement for 25% reduction in overall cost of a project establishing the most cost-effective means (Cabinet Office, 2011). Further key considerations within the strategy includes reduction in overall project time, early contractor involvement, high quality product performance, improved sustainability and integration of process information (automated processes). This allows integrated team to gain good understanding that promotes requirements, mitigate cost uncertainties, develop innovative solutions, plan and mobilise resources, managing risks to accelerate delivery and reduce costs (Pittard and Sell, 2016).

It is widely acknowledged that this paradigm shift in the scheme of digital development will witness a meaningful industry process change relative to means and method of project procurement, delivery and built asset operations. This chapter is therefore set to undertake a critical analysis of research in the field of BIM and cost function practices using a search strategy with criteria for inclusion and exclusion of relevant reviews of article and well-defined to interrogate existing literatures. This intends to deploy a systematic search applying unambiguous procedures in identifying and reviewing articles.

2.1 SEARCH STRATEGY

The UK Government through its ambitious construction strategy to digitise construction process using Level 2 BIM and the demand for all asset data to be electronic aiding industry process and strengthening practices is looking to develop needed competences and protocols required to implement the strategy (Cabinet Office, 2011). The prevailing inefficiencies surrounding traditional costing process, estimating, tendering, valuation and measurement approaches and the challenges in generating accurate 5D cost model (cost information) from a 3D BIM model in the UK construction industry practice inspired my interest towards this investigation. This challenge towards a seamless level 2 BIM adoption defined the basis and quest for review of existing literature. To locate relevant published articles significant to this research, databases were searched using electronic devises. Journals, BIM related text books, Cost management text books, government documents, industry published standards were used to generate information as interrogated. The search process entails a systematic approach applying explicit procedures (inclusions, search terms) in identifying and reviewing articles. A preliminary search was performed to establish boundaries for this research and assisted in defining the depth and breadth of the study scope retaining the investigation within the defined topic. Secondly a focus review was done using standard electronic databases such as **Science Direct, Google Scholar, Taylor and Francis online Group Journals, Construction Information Service Journals**. The outlined databases were used in identifying studies eligible for inclusion while carrying out this study. Using all available sources finally, studies with explicit significance were identified and covers critical evaluation of literature as required. To establish rigour, established and recognised standards were utilised to weigh all relevant materials as recommended by Lincoln and Guba (1985). Confirmability, reliability and validity checks of reviewed literatures were carried out as suggested by Anney (2014). This process was undertaken to underscore the credibility of literature findings. The studies considered relevant were searched thoroughly by combining different key search terms. If the results of two combinations of terms were large, a third term was used to achieve a manageable number of studies as shown in Table 2.1 below:

Table 2.1: **Search Terms Used for Literature Review**

1	Building Information Modelling (BIM)	Combined with
2	Virtual Design Construction and 5D BIM	And
3	BIM in EU/world	
4	5D BIM and Digital Quantification	
5	BIM Based Costing	
6	BIM and Quantity Surveying	
7	BIM for Integrated Construction	
8	BIM and Digital Value	
9	Digital Quantification	
10	BIM, Common Data Environment and Interoperability	
11	Traditional Costing and Measurement Approach or Traditional Costing Approach	
12	Contractor Costing or BIM Based Cost Estimation	

Reference list of articles were also searched to identify additional relevant report. Prominent authors were noted in the field and as a result author searches were conducted. Manual searches of the electronic catalogue of the University of Wolverhampton were carried out.

Strategies were developed for examples using citation alert to keep up to date with the new and emerging literatures.

2.1.1 Inclusion and Exclusion Criteria for the Studies

The inclusion criteria for studies included in the study focused on the study aim as found in chapter 1 of this study and also met the following criteria:

- Building Information Modelling publications
- Traditional measurement, cost estimation and cost planning
- Costing functions and practices (existing, potential and intended approaches)
- 5D BIM digital quantification
- BIM for integrated design
- Studies that used quantitative, qualitative and mixed method approaches
- Studies published in English between 1990 – 2016

Articles excluded from the study were those that did not meet the inclusion criteria as stated above. If the article met the inclusion criteria but was not empirical article such as report, audited articles or narratives then it was excluded from the critical appraisal process however the researcher considers those articles if they were appropriate in the final discussions of findings and literature review (Appendix F).

2.2 HISTORY OF BIM

Professor Chuck Eastman proposed the concept of Building Information Modelling (BIM) and established Georgia Tech as the leader in the development and application of BIM (Eastman et al, 2008; Talamo and Bonanomi, 2015). Chuck is widely known as the 'Father of BIM. Graphisoft in 1982 developed software ArchiCAD based on the concept of BIM, but Graphisoft company called it "Virtual Building" instead of "BIM" at the time. Graphisoft in 1984 introduced technical concept of Virtual Building Model for Architecture design by

ArchiCAD software (Gu and London, 2010). Virtual Building Model (VBM) technology is regarded as the earliest presentation of BIM technology. The very first presented 3D model was not the computer solid modelling used in AutoCAD rendering or animation, but a model database with a great number of additional building information which storage all the geometry information and corresponding technical information for the whole project in architecture design program but because of the limitation of technology at that time BIM was not promoted widely. BIM technology really began to draw attention in 2002 by Autodesk when they released Building Lifecycle Management BLM/BIM white papers officially proposed construction of information technology solutions of the two wheels – that is BLM and BIM. In succession Autodesk launched BLM/BIM solutions such as Buzzsaw, Composer and Revit, DWF to 3D etc. Thus, BIM technology gradually received world building industry recognition. At the same time BLM concept based on BIM approach became the primary concerns of the built industry and academia. (Lin et al, 2011)

The principal difference between BIM and conventional 2D CAD is that the use of BIM means a paradigm shift from 2D-based documentation and staged delivery processes to a digital prototype and collaborative workflow. The foundation of BIM is a coordinated and information-rich data building model with capabilities for virtual design and construction (VDC). BIM is also different from 3D CAD because 3D describes a building by independent 3D views, data in these 3D drawings are graphical entities only, in contrast to the intelligent contextual semantic of BIM models. A building information model carries all information related to the building production including its physical and functional characteristics and project life cycle information, in a series of "smarts objects" (Wang et al, 2009)

Nowadays, in building design, using BIM technology "Virtual Architecture" design will replace 2D CAD and become future computer aided architectural design mainstream. BIM technology has gained the attention of experts, some European countries have started popularizing BIM technology especially Finland, Norway, Germany and other countries. Based on the vast application of BIM software technology, the popularisation rate has reached 60-70%. Along with the architectural design and build, management began to constantly using building information model (BIM) technology.

The innovation of BIM which started in 2002 is to transform the artistic rendering of finished design with the intention to simplify both design and construction process (project planning strategies and consequent project cost control). Presently, the CAD software tools use for BIM is made up of an intelligent CAD capable to capture and analyse design concepts, and correctly uphold organised design data (data management). In addition, its benefit extends to ability to forecast and communicate challenges and opportunity in schedule, project risks, execution and increase cost estimating power while running a project. Similar explanation portrays BIM as a specific of application software which even manages the stakeholder relationship at different points within the project lifecycle and at a variety of different levels and it is also regarded as a process scene which is characterized intermediary information to facilitate development of building. BIM like every other technology or software has its ups and downs. BIM with its multi functionality has its challenges as well as benefits.

Over the past few years, anyone involved in UK construction could not fail to notice Building Information Modelling (BIM) because reference to BIM has dominated as prevailing subject. Not surprising as it forms part of major UK Government Construction Strategy which mandated the use of Level 2 BIM for all Central Government projects from Summer 2012 and its pushing for full BIM implementation by 2016 (JCT, 2013). The UK Government has set out an ambitious vision towards adopting BIM on all public sector projects as BIM is now rapidly approaching maturity since its emergence (RIBA, 2012). The aim is to assist design and construction teams in using BIM to provide a more efficient, intelligent and cost effective design process and to offer enhanced services to clients, particularly in relation to the whole life value of buildings (RIBA, 2012). The Royal Institute of British Architects (RIBA) has published the BIM Overlay which provides "straightforward guidance" on each RIBA work stage in other to successfully design and manage construction projects in a BIM environment (RIBA, 2011). Evolving BIM technology will support sustainable design, procurement, cost effectiveness etc and will transform modes of working in the UK construction industry. It will affect ways design data is generated, shared and integrated; it will reflect in new protocols, definitions, and activities. BIM is inevitable as it makes sense. BIM will not fade away although the term might because it will become embedded: to ignore it will amount to more waste of resources within the construction circle. BIM is a natural development of what has been done previously since building models has always been done in various ways. BIM technology has become sufficiently robust offering much more in that the complete modeling of a building from inception to operation has potential significant to improve efficiency in design, mitigate risk and reduce waste. Some commentators have suggested that there are financial and skills barriers to the adoption of BIM by smaller practices and that the benefits to smaller practices may be more limited. However, the RIBA believes that, as happened with the introduction of CAD, a tipping point will soon be reached when BIM will gain widespread acceptance as a transformative technology and working philosophy at all scales of practice. The principles of BIM can be applied to both complex projects with large multi-disciplinary design teams and large numbers of specialist sub-contractors and also to smaller, bespoke projects undertaken in a more traditional manner (RIBA, 2012). BIM is seen as being a key contributor in the drive by the Government for its estate to be more energy and cost efficient from both a Capex (capital cost) and Opex (operating cost) perspective; the UK Government has mandated construction industry to respond to the challenge that has been set.

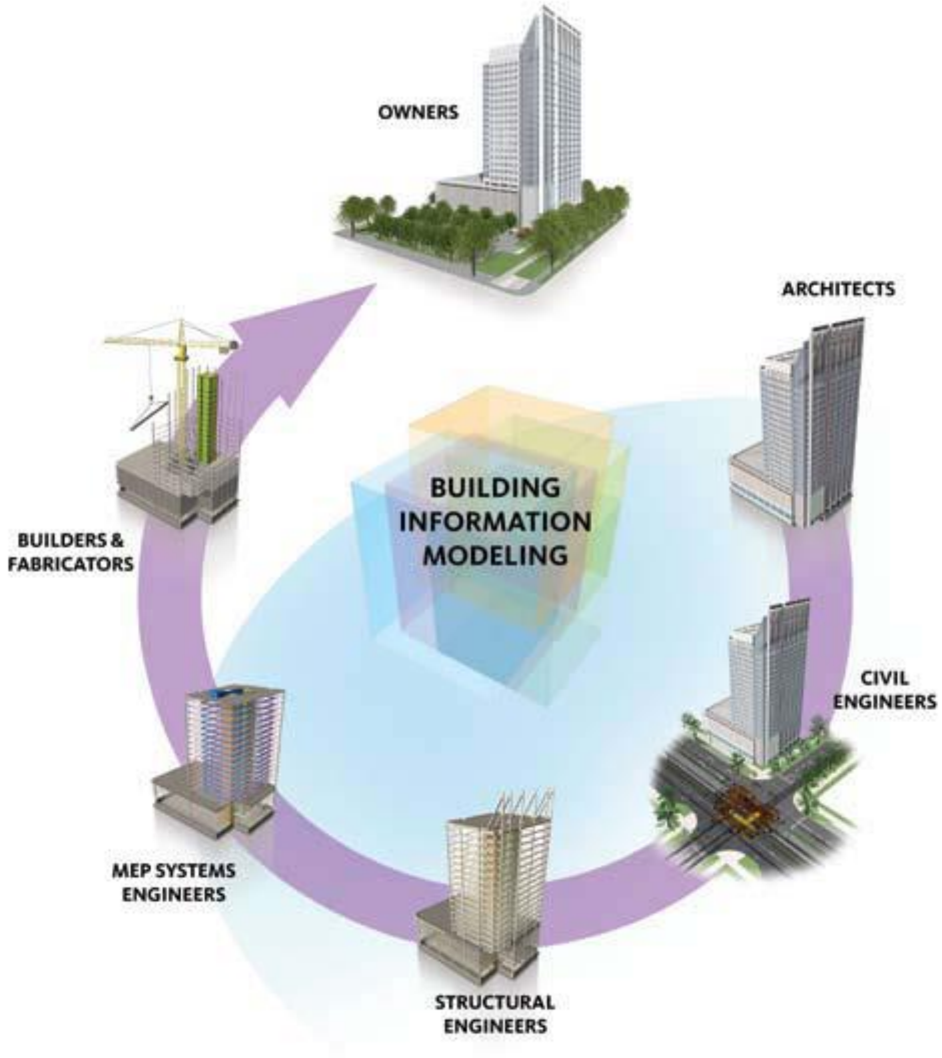


Figure 2.1: Lifecycle of a building (Source: Autodesk, 2013)

However, how BIM processes and technology will impact upon project cost estimate is not entirely predictable yet it is deployed by project key stakeholders and team members as shown in Figure 2.1. It's known from few journals that the construction industry has not been quick in taking up some of the benefits offered by certain IT developments. With BIM it will be different not primarily as a result of Government's mandate as started in 2016 but because of the natural progression in the construction market and something that has been adopted elsewhere in other parts of the world. Although the UK Government has not taken a perfect prescriptive approach regarding how BIM will be developed and used (legal restrictions/issues, tendering, bidding, forms of contact, extent of model coverage etc), it is good that the UK construction market are encouraged to get involved while an appropriate costing framework is developed. BIM will, certainly in the short term but possibly longer term, likely develop in such a way that there are several models related to a project. However, some firms, right from the beginning, will see BIM as an opportunity of providing an effective means of offering a fully integrated service (inception/initiation, construction and operation/maintenance) to clients by, amongst other things, enabling a complete visualisation of the whole project before construction commences (JCT, 2013). In order to provide a complete in-house service a significant amount of consolidation may take place within the construction industry, especially amongst those serving the larger end of the market. On the other hand, it may mean the larger entities simply winning work and then outsourcing/sub-letting it to other providers. Either way if the number of competing companies is reduced, competition may also be reduced (JCT, 2013).

In 2004, the National Institute of Standards and Technology (NIST) published a report stating that poor interoperability and data management costs the construction industry, approximately $15.8 billion a year, or approximately 3-4% of the total industry. Since this report, many have labeled Building Information Modeling (BIM), an emerging technological information management process and product, as the answer to this problem. From the pending release in July 2007 of the National BIM Standard (NBIMS), a BIM (i.e. a single Building Information Model) is defined as “a digital representation of physical and functional characteristics of a facility.” Furthermore, a BIM represents a shared knowledge resource, or process for sharing information about a facility, forming a reliable basis for decisions during a facility’s life-cycle from inception onward. In the words of the NBIMS Executive Committee Leader and former Chief Architect of the Department of Defense, Dana K. “Deke” Smith, R.A., “A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" (NBIMS, 2007). Building Information Modelling is a method to describe the building and its spaces, structures, components and materials with their essential information and properties. The model acts as a container for related information. BIM can also be described as a collaborative approach, making sure the right people get the right project information at the right time (SCRI FORUM, 2011). The government's chief construction adviser Paul Morrell informs that soon building information modelling (BIM) will become obligatory on publicly-procured projects that cost more than 50 million pounds.

"We have commissioned a team drawn from BIM users across the industry, both clients and suppliers, and software developers to prepare a route map that show how we can make a progressive move to the routine use of BIM. I am convinced that this is the way to unlock new ways of working that will reduce cost and add long-term value to the development and management of built assets in the public sec-tor"(SCRI FORUM, 2011).

If BIM is to be adopted in such a short space of time then there would not be enough BIM capable practitioners within the industry to do what is being talked about. However, creating a set of requirements that will allow the UK market to adjust itself accordingly will help greatly. BIM as the emerging technological information management process and product is stated to have improved interoperability and reduce construction waste, maintain a near perfect data management throughout a project life cycle but the influence it has on project cost estimation is not known. The impact on the costing during the project life span and how BIM implementation and adoption affects cost estimating is yet to be known or adopted by the UK construction industry practitioners.

2.3 INTERNATIONAL PERSPECTIVE ON BIM ADOPTION

Across Architecture, Engineering and Construction (AEC) industries, many countries around the world are developing standards, protocols and guidelines to support their ambitious strategy towards BIM implementation. Each country has a defined approach that guides implementation across AEC projects tailored to address specific needs of the project owners, multi-disciplinary project team, subcontracting organization, specialist trades, service suppliers, insurance, liabilities, users, constructors and technology. The below sets a brief explanation of developments with respect to BIM implementation for different countries around the globe but is not exhaustive:

2.3.1 United States of America

In 2006, the United States through the General Services Administration (GSA) delivered a guideline outlining a BIM implementation plan to integrate the use of BIM in the AEC of the United States. Consequently, GSA established a mandate demanding BIM compliance from all planners as a condition to a successful application of GSA funding schemes (GSA, 2007) making the US one of the earliest initiators of BIM guidelines and mandate for public sector projects. The US public sector is the early beneficiary of BIM implementation due to refined guideline that transfers and allocate risks associated with BIM implementation plan, establishing protocols that define the granularity of roles and responsibilities of participating project party and explicitly detailing conflict resolution plans for issues resulting from existing contracts and policies. Stakeholders of public sector became encouraged to comply with BIM mandate confirming that about 60% and increasing number of the US Architects use BIM in their projects (AIA, 2008).

2.3.2 France

The French minister of Housing and Development in April 2014 announced the new "Building 2.0", which promises to deploy BIM as the main process for public projects and outlining that BIM will become obligatory in all state-owned projects by 2017.

2.3.3 Other European Countries

UK, Netherlands, Denmark, Finland and Norway Governments currently demands the use of BIM for their public projects. In November 2013, EU voted to support the utilisation of electronic tools such as BIM for public works contracts. AEC leaders in the EU supports parliamentary vote with a stance that it will modernize EU public sector processes. This support is possibly viewed to aid BIM adoption and allowing EU member states to specify requirements and mandate BIM for publicly funded construction projects. This is to advance European competitiveness and make construction more efficient.

2.3.4 Finland

According to Kiviniemi et al (2007), a survey conducted in Finland to determine the wide spread and use of BIM for Architects shows that 93% of Architects were using BIM in construction and 33% of the 93% were at Level 3 BIM. There was also an indication that close to 60% of the Engineers in Finland use BIM for both private and public sector projects (Khemlani, 2007). BIM implementation in Finland stands out as significant improvement on the tools and process including policies and contract documentation has been made as seen in Figure 2.2. Though BIM was initiated in the USA earlier before the EU, there is no comparing in terms of wider improvement and spread particularly in Finland. This BIM improvement and quick spread is profit driven occasioned by AEC leaders and Facilities Managers in Finland. Finnish FM organisations in 2007 deployed BIM tools in projects leading to establishing detailed modelling protocols and guidelines in 2009 to enhance implementation within project design phase. Consequently, the established protocols and guidelines were used by governing body of public properties for pilot projects with an outcome of enhanced developments in the public sector projects.

2.3.5 Canada

The responsibility of BIM adoption and implementation into the Canadian built industry is the duty of the Institution of BIM in Canada (IBC). Their primary aim is to lead and facilitate full implementation of BIM with a prime focus on industry stakeholders educating them with the basic method in understanding roles and assessing capacity, capabilities and competence enabling credible input into BIM process.

2.3.6 India

The fast-paced population growth in India has provided an enhancement and platform for BIM implementation. There is a strong, trained, qualified strong workforce and BIM experienced professionals in Indian's construction industry whose BIM implementation skills traversed national boundaries into the USA, UK, Canada, Middle East, Australia and other Asian countries.

2.3.7 Ireland

Though the use of BIM in the USA is widespread and Singapore has demonstrated great innovation in this scheme by mandating planning applications to be submitted in BIM format with New York setting same requirements, Ireland has completed number of high profile projects including the refurbishment of the fabrication plants in the Intel facility in Leixlip between 2011 – 2014 accounting for $5bn investment (SCSI, 2017). Ireland also utilized BIM in delivering the National Children's Hospital at the St James' Hospital campus, on the Grangegorman Development and across PPP programme. Large to medium sized Irish main contractors and specialist construction organisations and specialist manufacturers have invested in BIM (process and technologies) and as a result have won several contracts in the UK leveraging the UK's BIM mandate (SCSI, 2017).

2.3.8 United Kingdom

May 2011 saw the UK announced and established a strong interest in collaborative working through adoption and implementation of BIM (process and technologies) in their construction process covering life cycle of public projects and this was published in a construction strategy report. The UK Government mandated the use of Level 2 BIM on all centrally procured Government projects in 2016 (GCS, 2011 and 2016). This was due to Government's awareness of the benefits of BIM in cost and time savings, quality and overall project outputs including merits it could offer to project stakeholders. Figure 2.2 shows the advancement UK has made so far in this journey of working in a BIM environment. Though the UK has published several standards in the form of Public Available Specifications (PAS) documents, protocols and guidelines for seamless BIM implementation yet UK construction industry and her stakeholders still struggles with lots of barriers in seeking to implement change. Barriers to implement BIM on new builds, existing buildings and infrastructure, existing industry culture, lack of BIM knowledge and education, cost of BIM software and hardware as well as associated costs network storage and access to model. Further concerns are raised regarding information security, liabilities, insurances, ownership of intellectual property, interoperability. Some amendments and particularly cultural shift is perhaps deemed necessary for a smooth BIM implementation within the UK construction industry.

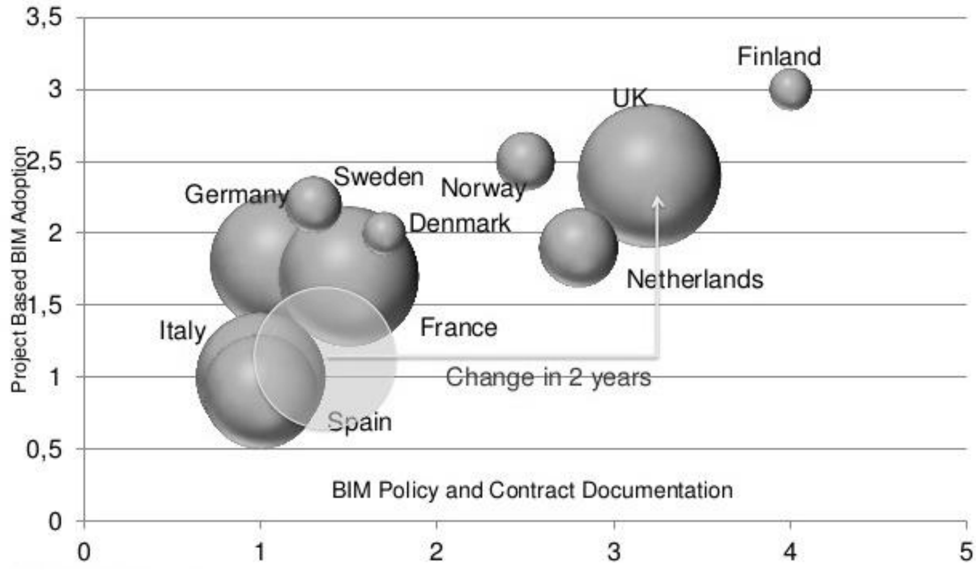


Figure 2.2*:* BIM Adoption in Europe (Source: Autodesk, 2013)

2.4 CHALLENGES OF BIM ADOPTION AND IMPLEMENTATION IN THE UK

There are general issues challenging BIM adoption and implementation in the UK AEC (design, construction, operations and maintenance) vis-à-vis specific issues to varying aspects of implementation. Inability of organisational management to address and emphasis cultural change (ways of working), integrate BIM processes and tools into current practice to increase cost effectiveness and value of construction process, provide effective leadership on construction digitization, there is also the challenge of process-related risks and technological related issues. Having a full grasp of these challenges will aid the users to develop plans for long term improvement and to prepare them for successful BIM adoption.

According to Azhar et al (2008), Eastman et al (2011) and McAdam 2010) there is an argument on legal issues that relates to design liability, model ownership, protection of data copyright in a BIM collaborative working. This infers that the information requirements are not explicitly stated from the outset of the project, design scope and responsibilities not clearly defined leading to inaccuracy of information input. Responsibility matrix is not well defined and questions are raised regarding allocation of design and construction related risks in a BIM project. McAdam (2010) is arguing that collaborative BIM functions removes binding contractual relationships and project agreements and therefore maintains a stance that contractual documents requires some adjustment for suitability; ownership rights and responsibilities especially when project team members are providing proprietary information for use on a project requires clear definition within contract document according to Rosenberg (2007). This is with an objective to avoid disincentive with potentials to discourage team members from realizing full model value. Varying risks could be associated with an ill-informed BIM implementation and could be counter-productive leading to increased waste, reduced competition and at a significant cost rather than intended value benefits. Greater variation claims could arise particularly when a poorly designed model is put out for tender purposes.

There is also lack of implementation knowledge of BIM standards for model integration and management by multi-disciplinary teams making automated quantification of accurate cost information difficult. Integrating design and construction related information from a multi-disciplinary team to a single model requires access of the inter-disciplinary team to the model. Established protocols, structures and procedures are necessary to ensure consistency of information and formatting in a common data environment. Different organisations adopting a bespoke protocols, structure and isolated procedures for an intended collaborative workflow generates lots of inconsistency and creates conflicts in sharing and managing project data. Consequently, Weygant (2011) suggest a frequent performance of 'model audits' to avoid such challenges. Interoperability which is defined as the ability to exchange construction data between applications enabling automation process and avoiding double data entry is a technology related challenge (Smith and Tardif, 2009). It is strongly advised to research on file exchange compatibility of software before a selection of software applications are made for inclusion in the client's requirements. Licensing issues is also a risk that may constitute a barrier towards BIM adoption and seamless implementation particularly when a project team member other than the design team or the employer (equipment or material vendors) makes a data input to be integrated into the model. Licensing issues may arise if the design is not produced by a licensed designer given the project location (Azhar, et al., 2012; Thompson and Miner, 2007).

Human and cultural issues are another major barrier confronting BIM adoption and implementation (Yan and Damian, 2008). This is a latent issue with BIM application. Getting people to alter their working culture which they are so familiar and comfortable with is always a huge task. There is an ongoing resistance to change among the working people due to an overwhelming thinking of outright change of the traditional approach to a BIM collaborative strategy (Crotty, 2012). Olatunji et al (2010) substantiated Crotty's position by agreeing that collaborative BIM strategy is regarded as a major disincentive to innovation because it is seen to overlap the existing professional boundaries backed by doubts generated by lack of case study evidence showing financial benefits of BIM. Significant transformation can be realized according to Eastman et al (2011) but would require time and cost for BIM education.

2.5 BIM FOR CONSTRUCTION LIFECYCLE

The value of BIM also extends beyond design and construction and into the asset's lifecycle management, delivering information that the owner/operator can use for facilities management, operations, maintenance, refurbishment or eventual demolition etc. As an indivisible part of the built asset, digital data will be something that is also liable for modification and expansion as updates, repairs or redevelopments of the physical asset take place. If this is likened to a car's service history, the owner will keep the manual up-to-date, and, if the modified car is sold, will be able to provide the new owner with a model that remains as detailed and accurate as it was when the original vehicle was purchased. Moreover, the data about the physical asset will potentially be augmented by additional information about its in-service performance. Just as Formula One racing cars now generate huge amounts of data from every test-drive or race, so data can be routinely collected from, say, an office building showing its energy use, temperature, humidity, heating, lighting, equipment use, etc, over time. Such real-time data will provide constantly updated information for post-occupancy evaluation; BIM can thus be used by the owner-operator to model and evaluate energy efficiency, monitor the building's life cycle costs and optimize its cost efficiency. As such BIM could also be invaluable to 'repeat clients' in informing future design, construction and operation of similar facilities. Similarly, it will provide designers with actual data about the performance of the built asset, rather than them having to make assumptions and undertake model simulations.

With a focus on a reduced transaction cost and less opportunity for error in delivering construction projects in the UK, organisations with a full 3D collaborative working capabilities work on a shared platform. However, construction is generally lagging behind in comparison to other industries in adoption of the full potentials offered by digital technology (Cabinet Office, 2011). A lack of compatible systems, standards and protocols, consistent varied project requirements from both clients and lead designers, have inhibited widespread adoption of technology with the capacity to ensure that all team members are working from the same data and that:

- The implications of alternative design proposals can be evaluated with comparative ease;
- Projects are modelled in three dimensional (eliminating coordination errors and subsequent expensive change orders)
- Design data can be fed direct to machine tools, creating a link between design and manufacture and eliminating unnecessary intermediaries and;

- There is a proper basis for asset management subsequent to construction (Cabinet Office, 2011).

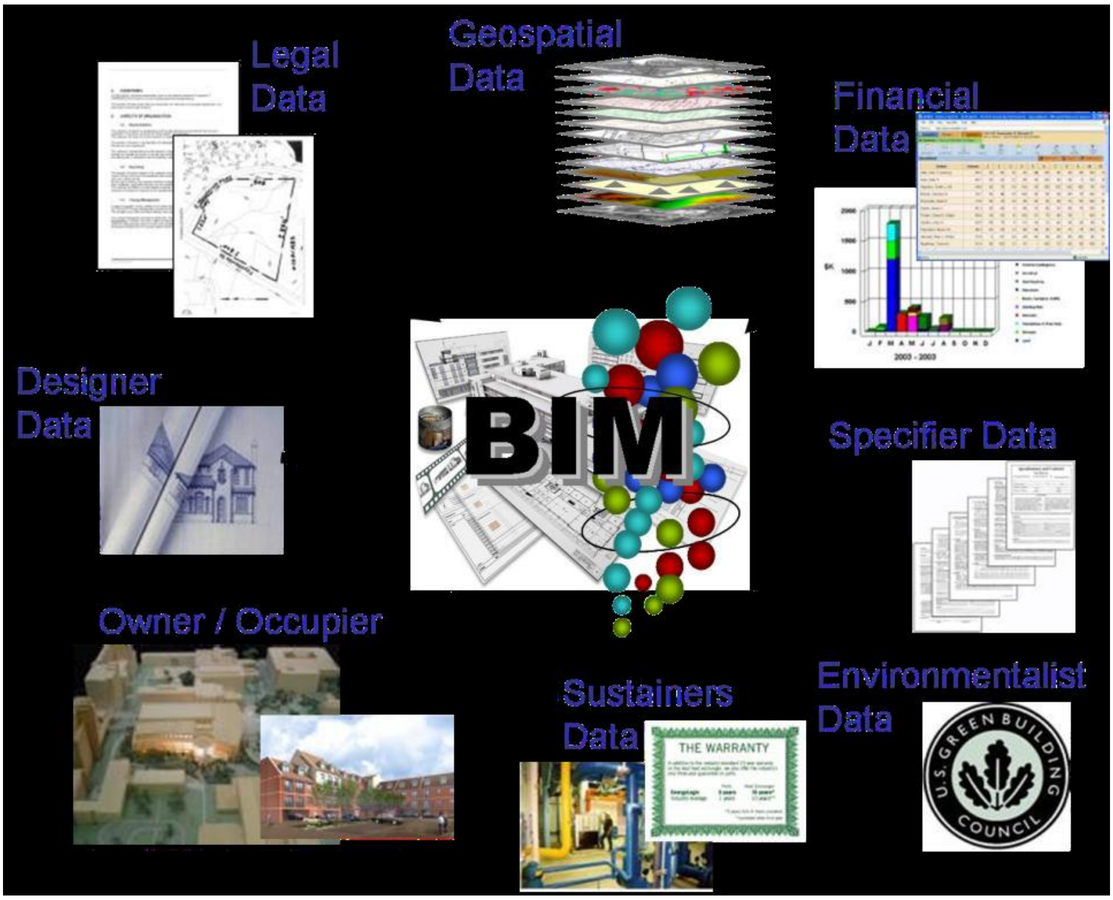


Figure 2.3: Communication, collaboration and visualization with BIM model (Source: NIBS, 2008)

The Cabinet Office has been given the responsibility to co-ordinate Government's drive to the development of BIM standards, systems, and protocols to ensure all members of the supply chain will work collaboratively through Building Information Modelling (BIM). The year 2016 has seen the UK Government require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum (Cabinet Office, 2011) - (Figure 2.2). BIM ensures best value at every stage of the project life-cycle. Government Construction Strategy promotes integrated supply chain as well, has approach to asset creation, maintenance and operation. Extends to all capabilities and markets, from infrastructure and professional services to construction and asset management and provides client with wealth of new information regarding the building or infrastructure that is built and managed (Cabinet Office, 2012).

Early definitions which assert that Building Information Modelling (BIM) is simply a 3D model of a facility are far from the truth and do not adequately communicate the potential of digital, object-based, interoperable building information modelling processes and tools and modern communications methods (NBIMS, 2010). The increased interest in BIM reflecting the UK Government Construction Strategy to deliver all capital public projects with BIM has resulted in various papers, discussions and conferences on the BIM subject and although some opinions on certain aspect are converging, there are wider range set of views on myriad aspects. The difficulty in stating clearly what BIM actually is for those seeking strategic overview of the subject and to consider how the construction industry might embrace BIM working methods in their practices cannot be over-emphasized. Conflicts in defining relative terminologies create further confusion for anyone researching on BIM subject for the very first time. However, as defined in the original National Building Information Modelling Standards (NBIMS) document "BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception (earliest conception) to demolition." Eastman (2008) defines BIM as a modelling technology and associated set of processes to produce, communicate and analyse building models. GSA (General Services Administration) defines BIM as the development and use of multi-faceted computer software data model to not only document a building design but to simulate the construction and operation of a new capital facility or a recapitalised (modernised) facility. The resulting Building Information Model is a data-rich, object based, intelligent and parametric digital representation of the facility, from which views appropriate to various user’s needs can be extracted and analysed to generate feedback and improvement of the facility design. In other words GSA states that BIM is a process (eg modelling) and a product (eg a model) used throughout the facility lifecycle. Many have a dimensional perspective of BIM as a 3-dimensional representation of the built environment, primarily for use during the design and construction phases. This narrow focus is inconsistent of BIM. Building Information modelling is the process of generating and managing information about a building during its entire life cycle. The National Institute of Building Sciences (NIBS, 2007) notes the following about BIM. "The scope of Building Information Modelling (BIM) directly or indirectly affects all stakeholders supporting the capital facilities industry. BIM is a fundamentally different way of creating, using, and sharing building lifecycle data." BIM is a digital software system and an open standards-based collaborative business process targeting lifecycle facility management. It includes: 3D (visualisation); 4D (time-schedule/lifecycle analysis); and 5D (cost-estimating/capital planning) which serve as a common, centralised repository/portal for all lifecycle building related information, from concept through deconstruction. If implemented, nearly every piece of information that an owner needs about a facility throughout its life can be made available electronically.

Building Information Modelling (BIM) is a new approach to design, construction, project scheduling and facility management in which a digital representation of the building process is used to facilitate the exchange and interoperability of information in digital format (Vozzola et al, 2009). With BIM technology, an accurate virtual model of a building is constructed digitally. It can be considered a process for developing design and construction documentation by virtually constructing the building or the infrastructure on the computer screen before actually building it (Bloomberg, 2012). When completed the computer- generated model contains precise geometry and relevant data needed to support the construction, fabrication, and procurement activities needed to realize the building. It is an important computer application that came after CAD technology in the built and construction industry. It is a multidimensional model {3D, 4D (time) and 5D (cost)} in which a virtually unlimited range of visual and non-visual project and building related information is tagged or attached to each model element as a collection of attributes (Bloomberg, 2012).

BIM also is defined as an open standards based information repository for the facility lifecycle (Qing et al, 2011). It is also a tool for visualizing and coordinating Architecture, Engineering and Construction work to avoid errors and omissions. BIM can be described in two ways; modelling and application. From modelling perspective: BIM means Building Information Modelling based on the three-dimensional digital technology, integrate the construction project and related information of engineering graphic models and also contains the engineering physical properties and functional properties and its related project cycle information such as digital model. From the application standpoint, BIM means Building Information Modelling, building information model is fully digital, support various operations of construction projects. It is dynamic and can add all kinds of project information in project life cycle freely, to meet each kind of demands. (Qing et al, 2011). From ICT perspective Arayici and Aouad (2010) defined BIM as the use ICT technologies to streamline the building lifecycle processes to provide a safer and more productive environment for its occupants, to assert the least possible environment impact from its existence, and to be more operational efficient for its owners throughout the building lifecycle. BIM in most simple terms is the utilization of a database infrastructure to encapsulate built facilities with specific viewpoints of stakeholders. It is a methodology to integrate digital descriptions of all the building objects and their relationships to others in a precise manner, so that stakeholders can query, simulate, and estimate activities and their effects on the building process as a lifecycle entry (Coates et al, 2012). Therefore, BIM can help with providing the required value judgments for creating a more sustainable infrastructure, which satisfy their owners and occupants.

2.6 UK CONSTRUCTION INDUSTRY OVERVIEW

The current clamored construction innovative implementation trend within the UK construction industry and the difference that BIM innovative approach can offer to improve design and construction process will set a functional performance pace in the industry. BIM offers myriad business and construction benefits with a wide coverage from the inception phase to the operational phase of a project. Few among many increasing benefits are immediate 3D design visualization, enhanced coordination as conflicts between systems are easily seen and addressed early in the process before they become costly change orders, ability to model schedule scenarios and site logistics by time loading the elements of the model (4D), ability to link the model elements to cost data for real cost estimating (5D) and to facilitate a transparent bid process, transition of the model to the users after construction for use in building operations and maintenance. It extends to less rework, better profitability, and accurate documentation, shared access to information, visual representation at all stages, enhanced quality, increased opportunity for new business, reduced project duration, fewer legal claims, tracking and analysis of design construction and operational information critical to the project success etc. The UK construction industry has not fully integrated all these benefits offered by Building Information Modelling (BIM) in the construction processes. According to Crotty (2012), there are three major issues or features that are likely to have a significant bearing and influence on the adoption of the BIM approach/dissemination in the United Kingdom which are;

- Economic Structure – decision makers
- Fragmentation within the UK Construction Industry
- Changing roles and relations

2.6.1 Economic Structure – decision makers

Construction firms within the UK construction industry are quite enormous but only a minute proportion constitutes a substantial size. According to the Office of National Statistics (2009) for example - in 2008 there were 53,500 registered contractors in the UK industry but only 283 of them employed 300 or more people. These substantial sized companies constitute 0.14% of the firms in the industry, employed 24% of the total construction workforce and generated 35% of the industry's output. Building Magazine (2009) recorded that 30 of top UK firms accounted for 80% of the turnover of the top 75 UK contractors. It follows that the UK economic mass is largely concentrated in a relatively small number of relatively large construction firms. Seeing that most innovation in construction takes place on projects (Crotty, 2012), it then follows that to deal with complex and as diverse as construction issues are, it is natural that people should create mental model, simplified versions of reality, that they can use for analyzing and problem solving or for predicting future developments hence BIM. These substantially large companies are potentially the strong influencers to disseminate BIM approach and method through their supply chain and the industry as a whole.

2.6.2 Fragmentation within the UK Construction Industry

Most companies who engage in business within the circle of modern construction industry become quickly noted that all is not well in construction. High profile industry but low esteem yet its qualitative performance critical to national economy. The industry due to its national importance resulting from its immense contribution to the national economy is subject to regular official and semi-official investigation (Crotty, 2012). Murray and Langford (2003), pointed out the summary of major loopholes in the UK construction industry which are:

- The dislocation between design and construction as a key issue and urged closer integration within design teams and between designers and constructors
- They identified short-term thinking as a strategic industry problem and urged major clients, governments and quasi-governmental bodies in particular to provide long term continuity of work in the industry

- They identify uncoordinated, incomplete design information as a common cause of poor construction performance. The tendency of client teams to want to rush to site is noted
- Lack of management skills as further cause of poor performance on site
- They proposed innovative modes/models of project organization and novel forms of contract as a way to overcome the above identified problems.

Murray and Langford (2003), has demonstrated that the UK construction industry has shown repeatedly of her awareness to its failures and to a greater extent embrace the consciousness to improve. The Egan Report (1998) in the wake of big review, Government and the industry jointly established a body called Construction Excellence (CE) to identify measure and analyse the causes of poor performance in the construction. The most important single recommendation to emerge from Egan and subsequent initiatives was that the industry should make consistent attempt to reduce confrontational issues among its players and should instead embrace collaborative methods of working. Partly as a result, over the past 10-15 years the UK construction has been something of a laboratory for strategic and project partnering, for the use of frameworks and other non-confrontational approaches to procurement (Crotty, 2012). According to SmartMarket Report (2009) for example, although implementation of BIM is currently far more advanced in the USA than it is in the UK, the use of collaborative forms of contract in the American construction industry lags behind British practice though the American industry has realized that BIM can be implemented in collaborative project organizations much more effectively and are now developing its own collaborative approach called Integrated Project Delivery (IPD). Standard forms of contract and the necessary procedures have already been developed to support project teams attempting to carry out projects in a more collaborative approach (AIA, 2007)

2.6.3 Changing Roles and Relations.

A number of pre-existing and long term trends will shape and contribute to the development of BIM in the UK. Though the industry is reputed for conservatism and inertia, in recent decades, the industry is undergoing a functional dramatic transition both in organization and in ways projects are carried out. Decades ago main contractors on a project self performed the majority of work on a single or large projects but today construction services supplied by wide range of sub-contractors, procured and coordinated by the main contractors using the supply chain has become a norm within the industry. This indeed is a novel development. As Satoh and Morton (1995) puts it, the concept of the general contractor carrying out a complete building project, using his own labour force and equipment, on a fixed price, lump sum basis, became normal only in the mid nineteenth century. Prior to that individual craftsmen or small teams of craftsmen were hired – trade by trade – directed by the client or his architect. Murray and Langford (2003) reports resulted in sustained improvement in industry performance and also recommended collaborative approaches which will pay off in the implementation of BIM in the future.

2.7 LATHAM, EGAN AND FARMER’S CONTRIBUTIONS

In retrospect, the 1994 report of Latham “Constructing the Team” which was the final report of the Government/industry review of procurement and contractual arrangements in the UK construction industry highlighted fragmenting issues constituting a strong to the overall industry productivity. Among other recommendations outlined to tackle and address integrated construction problems like teamwork, better project performance and improved project quality, particularly the report emphasized the use of coordinated project information and a productivity target of a 30% real cost reduction should both be launched and integrated as a contractual requirement. The report also touched on the development of a construction strategy code of practice which potentially was developed and launched as UK Government Construction Strategy 2011 with a follow-up update in 2016 to foster cost reduction, improved value, reduction of carbon emission and collaborative workflow among other things.

Then four years later Egan as the Chair of the construction task force came up with a report "Rethinking Construction" focusing on the scope for improving the quality and efficiency of UK construction (Egan, 1998). The report revealed the under-achievement of the UK construction industry with low profitability and overall performance dissatisfaction. Five key essential drivers with potentials to deliver quality, improvement, collaboration and efficiency as needed to set the agenda for the construction industry were identified: committed leadership, a focus on customer, integrated processes and teams, a quality driven agenda and commitment to people. The report emphasized effective performance measurement and the use of performance data by the industry to inform its client, it reemphasized a reduction of both cost and project defect by 10% and 20% respectively. Egan further substantiated the stance of Latham by recommending radical changes to the construction process making it transparent and explicit to the industry and its client. The report stated "the industry should create an integrated project process around the four key elements of product development, project implementation, partnering the supply chain and production of components. Sustained improvement should be delivered through the use of techniques for eliminating waste and increasing value for customer". Substantive changes in industry culture and structure were also mentioned as a driver towards overall industry improvement. The perception of the clients and public regarding the performance of the construction industry as compared to the rest of the industry is one of poor management, poor quality and poor value of products resulting in poor service and in premature repair or replacement.

Having launched the UK Government Construction Strategy in 2011 and 2016 as a response to the earlier reports, Farmer (2016) was commissioned to do a further review of the industry who published a report on the UK Construction Labour Model "Modernise or Die – Time to decide the industry's future". The report reiterated poor productivity, poor predictability, structural fragmentation, leadership fragmentation, low industry margins, adversarial pricing models and financial fragility, lack of innovation within the industry among other factors that has constituted a strong barrier to the industry's growth and change objectives. The existence of fragmentation and challenges of low performance in delivering projects within the UK construction process seems to be a recurring decimal spanning over 20 years without a strong solution to address both the existing and evolving issues. Hence an introduction of a construction strategy using Building Information Modelling (BIM) as an innovative process to foster stronger collaboration, create, manage and share coordinated construction data, reduce cost and construction waste, improve productivity and facilitate reduction in carbon emission. The above industry reviews by Latham, Egan and Farmer has flagged obvious need for implementation of review findings and seeking a more innovative means of promoting profitability, cost and time savings, having better overall industry performance and creating alignment between industry and client's interest.

2.8 INDUSTRIES SECTOR COMPARISON WITH THE UK CONSTRUCTION INDUSTRY – DIGITIZATION OF INDUSTRY PROCESS

Building Information Modelling is the process of generating and managing information about a building during its entire life cycle. The National Institute of Building Sciences (NIBS, 2007) notes the following about BIM. "The scope of Building Information Modelling (BIM) directly or indirectly affects all stakeholders supporting the capital facilities industry. BIM is a fundamentally different way of creating, using, and sharing building lifecycle data". BIM is a digital software system and an open standards-based collaborative business process targeting lifecycle facility management. It includes: 3D (visualisation/geometric data), 4D (time-schedule), and 5D (cost-estimating/capital planning) which serve as a common, centralised repository/portal for all lifecycle building related information, from concept through deconstruction. Building information modelling is set to revolutionize the delivery of construction projects. It will help the industry and its clients move from inefficient, fragmented and paper-based information process to a seamless flow of structured construction data, incentivized to deliver whole life project value. The technology, the associated structures, protocols, standards and processes are still being developed, but with the recent UK Government's BIM mandate, quicker response to this innovative approach within the industry is likely to form the nucleus for successful BIM collaboration.

The construction sector has never really existed as a coherent entity and the causes of fragmentation are deeply rooted (Rabeneck, 2008). Furthermore, since the late 1970s, industry fragmentation has been exacerbated by the vicissitudes of the tax and insurance system which have accumulatively acted to encourage the growth of self-employment (Harvey, 2003). The demise of the public sector Direct Labour Organizatios (DLOs) also contributed to eroding the industry's traditional training base. Some of these concerns combined to reinforce the adoption of structural flexibility as the key factor for achieving competitive advantage. Consequently, the contracting sector is dominated by 'hollowed-out' firms with few direct employees and raising concerns about the industry's absorptive capacity and its ability to innovate (Gann, 2001). The Egan's initiative was therefore directed at a sector that was already locked into a 'low road' development path (Bosch and Philips, 2003) and the similar but genetically different forces at work were not so easily overcome. This was so given that the improvement agenda were dependent on voluntary action hence it is not a shock that progress has subsequently been slow and patchy. There has been little or no willingness to reinforce the rhetorical exhortation of the Egan Report through regulation or institutional reform. Unlike other markets such as the automotive and aerospace industries, designers had also been switching from manual drafting to CAD. They began to explore 3D visualization and to relate the outputs of their design processes to manufacturing, designing components that could be accurately produced on computer-controlled machines. 'Lean thinking' was also influential and soon the major manufacturers were working closely with their key supply chains, using sophisticated model-based designs to speed up design and delivery of new products to their markets (Cholakis, 2011). In the construction industry, however, things were moving at a different pace, mainly due to the highly fragmented nature of the sector which was noted in Egan's report. In "the improving the Project Process" chapter of that report, he talked about processes that can advance a proposed innovation in the industry and deliver more efficient construction practices which includes repeated processes, integrated projects processes, focus on the end product, product development, product implementation, partnering the supply chain, production of components etc (Egan, 1998).

In the worldwide aerospace industry, for example, there are only a handful of aircraft manufacturers, and they have developed close, long-term commercial relationships with their suppliers. With a history of innovation and a culture of continued investment in research and development, there are high barriers to entry for any company wanting to compete in the aerospace industry. The global construction industry, in contrast, currently comprises millions of contractors, and many more subcontractors, consultants, materials suppliers and product manufacturers. It is a highly competitive industry in which many businesses work on wafer-thin margins, with little or no investment in research and development. As a result, there is little differentiation between firms; many compete almost purely on price, and only in recent years that a small number of major clients looking to develop longer-term partnering or alliance-type framework agreements with key suppliers is beginning to aggregate. The differences between construction and aerospace or automotive are also exacerbated when products are considered. Aircraft and cars are produced in a handful of factory environments in large volumes to standard core designs with a relatively limited number of configurations. The construction industry's outputs, on the other hand, are often unique, one-off solutions to a client's needs, produced specifically for particular locations, and their design and construction can involve an infinite number of variations, often due to the availability of appropriate skills, knowledge, materials, labour, space, etc. It is hardly surprising therefore, that BIM has developed more slowly than the adoption of modelling technology in other sectors. However, since the 1980s, some construction businesses have expanded well beyond CAD. Reasons include the lower cost and increased processing power of computer hardware, higher bandwidth telecoms links (again at lower cost), wider availability and use of BIM software outside niche disciplines, and the emergence of industry data exchange standards. Again, the main catalyst for change in the UK came after the late 2000s global financial crisis when the UK Government began to demand better value for money and better carbon performance from its public sector projects. Paul Morrell, the Government's chief construction advisor (2009-2012), had already announced his interest in BIM, but it took the publication of the UK Government Construction Strategy in May 2011 – to make the industry realize BIM was no longer optional if they wanted to work for public sector organizations.

The UK Government explicitly stated that it aimed to achieve "significant improvements in cost, value and carbon performance through the use of open sharable asset information" (Cabinet Office, 2011; The Infrastructure and Project Authority, 2016), and industry quickly realized that it would need to overhaul more than just its technology if it was to successfully incorporate BIM into its industry practices. Nonetheless, the initial focus on technology and software was understandable. The introduction of 3D design techniques improved visualization for project team members, clients, planners and other stakeholders (video walk- or fly-throughs were being laboriously generated by designers in the 1990s, for example). Design disciplines managing particularly complex tasks – structural engineering and building services, for instance – also began to work in 3D, and could merge their outputs to identify potential problems before construction started on site by using them for 'clash detection' and other coordination tasks (Barnes and Davies, 2015). The introduction of 'parametric' 3D design enabled the output of more than drawings and 3D models: an object's geometrical representation, it's physical shape and dimensions, could be augmented by information about its material, cost, colour, manufacturer, etc, and its functional relationship with other components. As designs were amended, so the relationships between items automatically changed (Sanchez et al, 2016). Clearly, therefore, BIM is more than graphical presentation of geometrical information. Models can incorporate schedule or sequencing information (3D + time: 4D), cost data (5D), operations information, sustainability data, and more, so BIM is often referred to as 'nD' modelling. As a result, project managers, designers, surveyors, environmental engineers and facilities managers concerned with programming, cost management, environmental assessment and future operation and maintenance are today learning about BIM.

2.9 BIM CAPABILITIES

BIM is the representation of the digital evolution from traditional 2D model to 3D mode and even to 4D model (scheduling) and 5D model (cost estimating) with a database through the building lifecycle. Special capabilities of parametric modeling and interoperability facilitate this evolution process as detailed below:

2.9.1 3D BIM Application

BIM model is an intelligent visual and data based process that gives architecture, engineering, and construction (AEC) experts the perception and authoring tools in delivering a more efficient plan, design, construct as well as a facility management (Davies and Barnes, 2015). Build it twice once virtually and once physically is the process benefit encouraging virtual construction. Building Information Modelling presents various 3D Models such as design models (architectural, structural, MEP – Mechanical, Electrical and Plumbing and site/civil structural models), Construction model involving federating and splitting of design models into construction sequences. 3D BIM model contains advanced information such as drawings, materials, components, schedules, energy analysis, HVAC systems, COBie data sheets, and more. This allows information to be secured as well as available to each key discipline team member to access and contribute their intelligence to the project. The model simplifies the collaboration workflow of a project as well as savings in costs, time, and human errors. Any change, alteration or variations to the model instantly updates all the data reflecting in update of sources such as schedules, constructability, costs and risks (Andersson et al, 2016). 3D BIM models export IFC files formats strengthening an effective and flexible collaborative platform to various software within a multi-disciplinary team. This can then be taken to the next level with constructability and coordination, 4D scheduling, and 5D cost planning.

Model walkthroughs and clash detections are made possible within a 3D BIM environment providing great visualisation tool, exposing risks, identifying potential site issues and resolving perceived construction problems enabling contractors and designers to work more effectively together. By identifying potential constructability issues early in the design phase, clashes that would have been detected so late causing construction delays and needing quick decisions would be identified and resolved during design coordination of the 3D model of varying building systems including subcontractors integrated shop drawings before actual construction starts. Schedule simulation possesses capabilities that allows project owner an insight into evolving construction process and acts as a useful marketing tool for the project team while enabling the contractors to visualise how the entire building or facility will develop (Davies and Barnes, 2015). In 3D BIM virtual mock-ups model is made available for better understanding and aesthetical and functional project decisions, helping the owner to test a fraction of the physical construction of the building. Confidence for the use of prefabricated offsite products increases with the visualisation and simulation of the model having greater assurance due to integrated level of construction information that manufactured products will fit once transported to construction site for installation (fit for intended designed purpose).

Deployment of 3D model for differing functions within level 2 BIM process has generated other dimensional references such as 4D (adding timeline to the model), 5D (the linking of 3D BIM model data to the 5th dimension to generate cost data and cost schedules), 6D (facility management) and 7D (the green model – sustainability). Potentially 3D BIM model has become a platform that improves all project processes cross-functioning through planning, design, construction, operation and maintenance stages.

2.9.2 4D BIM Application

Traditionally, "planning consists of those processes performed to establish the total scope of the efforts, define and refine the objectives, and develop the course of action required to attain those objectives. The planning processes develop the Project Management plan and the Project documents that will be used to carry out the project" (PMBOK, 2013). Project planning is therefore closely aligned with developing the project strategy. The difference is that planning is focused on optimising the sequencing of the work as a prerequisite to scheduling, which on its own is a key subset of planning (developing the overall project strategy) (Sarker et al, 2012). As Information is frequently limited, planning then requires good understanding and experience of the project work starting early in the design phase, and involving all key stakeholders (PMBOK, 2009). The main benefits of planning and construction scheduling are gained by engaging in the process – therefore the planning process should be participatory and evolutionary. Project planning is viewed as a common starting point from which to adapt as project detail evolves and not as a script. Plans are flexible and adaptable, allowing the opportunity to pursue a variety of options as the more detailed working schedule is developed. Planning is the early process of determining how the work will be accomplished and involves analysing alternatives and developing method statements. This is the platform where 4D BIM application is leveraged to strengthen the choice of alternatives and extracting accurate scheduling information from a BIM model.

4D BIM modelling is adding the fourth-dimension schedule to the 3D model. The fourth-dimension model links the 3D elements with the project delivery timeline to provide users a virtual simulation of the project in the 4D environment. The linkage to project timeline makes it possible to graphically visualize the projects schedule and users can simulate the building site and construction at any point developing real time schedule and workspace planning. This type of simulation provides considerable insight and allows for early detection of planning errors. Instead of realizing planning mistakes later on in the construction phase, and having to resolve problems on site which can be very costly, mistakes can be eliminated already in the design phase (Eastman et al., 2008). Meaning that 4D BIM application has an integrated capability to verify and optimize site logistics and operations (like temporary components such as crane, traffic access, lorries, lifts and large items) to visually plan and manage space utilization of a construction site throughout the project ((Davies and Barnes, 2015). Various alternative solutions of conducting construction can be simulated and weighted against each other to find the most beneficial solution (Eastman, et al., 2008). By adding 'time' to the information in the project model (linking attributes to the construction programme), it becomes possible for contractors to review the construction of the building. 4D tool can be particularly useful for a challenging construction site or a large complex project to examine the critical path activities, consider real time work schedules, handle logistics such as craneage and deliveries and to redefine in general terms how the building is to be constructed (RIBA, 2012). An advanced interoperability process will make it easier to consider more buildability options, allowing a number of construction options to be prepared and translated into a 3D representation of the construction process. With progressive model update reflecting activity on site, 4D application can be a useful tool in reviewing progress against the baselined programme and highlighting where progress is behind. The objective of maximizing the efficiency of the project strategy with respect to cost and time is to be balanced against the risks associated with new methods of working and the overall quality of the finished deliverables. Changes in design within the BIM model can be identified and impact on critical activities known with overall indication and assessment of the corresponding impact on the overall project delivery. The tool can also be useful in exploring ways to make up time lost. Conversely, the contract administrator can deploy the programme for assessing delays and any applications for an extension of time (RIBA, 2012).

2.9.3 5D BIM Application

Construction suppliers traditionally determine project cost, requirements and material quantities by performing manual takeoffs, interpreting data manually while completing costing tasks, a process integrated with potentials for human error (RICS, 2015). Traditionally, a CAD drawing is scanned and manually interpreted to calculate quantities that make up building cost (Pittard and Sell, 2016) in contrast to digital measurement software like CostX 6.6 that allows users to strip a building model of its layers, analyze and examine individual designs in isolation for visual takeoff. This eliminates error prone process for manual takeoff and manual spreadsheet reporting formats improving management of cost information, structured information exchange, management of cost data, efficient cost modelling and accurate data interpretation. With 5D BIM process, digital construction information allows contractors, employers and the project team to generate accurate cost and essential estimating information with model element attributes like size, area, object family type, and productivity projections (Davies and Barnes, 2015). 5D BIM model is the linking of the fifth dimension to the 3D BIM model extracting non-graphical data and model attributes to generate cost information and material quantities within a level 2 BIM collaborative environment. Evolving design changes within the model automatically adjusts to improve progressive accuracy of cost performance. 5D model is expected to link BIM model to cost data through a digital model information for quantity takeoff generating accurate project cost estimation. The ability of BIM models to generate cost information and quantity schedules will allow for faster cost value of a given design (RIBA, 2012). However, given that the model mapping of item properties is not yet embedded in BIM objects, Crowley (2013); Monteiro and Martins (2013) observes that the current QS practice appends object properties in the estimating tool for takeoff suitability. If the model objects are not properly coded in the design software to suit the QS functions then the first step towards supporting cost and quantity schedule, would be to develop a Cost Breakdown Structure (CBS) associated to a Work Breakdown Structure (WBS) and units that enables the QS populate cost plan easily (Drogemuller and Tucker, 2003).

Option appraisal of different design alternatives at the early stage is more accurately assessed and with the designers in possession of the cost information at their fingertips, the iterative design process will be accelerated, making it more likely that the designs are aligned with client's budget. How cost consultants will provide and integrate cost information into the model along with the methods of outputting area and quantity information in a way that will translate into a reliable cost plan that takes due cognizance of project specific cost drivers and market trend will need serious consideration.

2.9.4 6D BIM Application

6D BIM refers to the linking of the 3D model information to a sixth dimension for lifecycle management of a facility (operations and maintenance) and uses a standard Public Available Specification (PAS) 1192:3 to guide user's implementation. PAS 1192:3 is a companion document to PAS1192:2 (capital/delivery phase of a project) focusing on the operational phase of asset regardless of the commissioning route and commencing at handover (BSI, 2014). 6D also refers to as-built BIM model linked with asset management information of building's components. This allows optimisation of whole life cost of managing portfolio of assets though can be complex and vary based on the utilisation requirements. Generated construction model is updated (as built and not as intended) with accurate 'as built' information and handed to the owner at completion of the construction final stage in COBie format. This is part of the ambitious UK Government construction strategy for fully collaborative 3D BIM with all project and asset information, documentation and data being electronic from 2016 (Cabinet Office, 2011) – thus representing minimum requirement for Level 2 BIM on publicly procured projects.

COBie is a structured asset information for the commissioning, operation and maintenance of an asset often in a neutral spreadsheet format that will be used to supply data to the organisation to populate decision making tools and asset management system (BSI, 2014). Information within COBie is data arranged and processed into meaningful patterns, and put into context for operational use. Operation and maintenance (O&M) manual is created including warranty information for model elements in consort with data sensor tools with ability to capture and feedback future maintenance data when and where required. Some 6D application software tools have capabilities that deals specifically on virtual navigation. This is done through a model linking any type of document to model element and same time accessing product information and maintenance manual database through an integrated programme that signals if installed objects are within their warranty periods with capabilities for distance inspection of installed products. This level of information provision for the O&M purposes enhances efficient cost control and ultimate cost savings in managing, and evaluating portfolio of assets (BSI, 2014).

2.10 BIM INTEROPERABILITY – INDUSTRY FOUNDATION CLASS (IFC)

BIM as the emerging technological information management process and product is stated to have interoperability and construction waste. Multiple applications with overlapping data requirements support various tasks of design and construction (Eastman et al, 2011). Interoperability is the ability to exchange data between applications and for multiple applications to jointly contribute to the work at hand which in turn smoothes workflows and sometimes facilitates their automation. Interoperability has traditionally relied on file-based exchange formats limited to geometry, such as DXF (Drawing eXchange Formats) and IGES (Initial Graphics Exchange Specification) (Eastman et al, 2011). A critical aspect of BIM repositories is that they allow management of projects at the building object level, rather than at a file level (Gallaher et al, 2004). BIM repository helps manage the synchrony of multiple models as its fundamental purpose, representing a project. Interoperability is the ability to pass data between applications, and for multiple applications to jointly contribute to work at hand (Eastman et al, 2011). The need to manually copy data that is already generated in another application is eliminated by interoperability. Iteration during design phase is greatly discouraged by manual copying of data meanwhile it is needed to finding best solutions to complex construction project issues such as structural or energy design. Errors and greater level of inconsistency are also inevitable in manual copying of data and constitutes a far greater restriction in automating best business practices. Currently the National BIM Standard (NBIMS) is being undertaken to standardize the data required for particular exchanges. As parallel efforts are made throughout Europe to develop effective exchanges, its becoming increasingly clear that the starting point for better design and construction management is improving workflows which is the main focus of BIM interoperability. Automation of exchanges can eliminate errors, streamline workflows and shorten construction process. There is a growing need to coordinate data in multiple applications through a building model repository though file and XML based exchanges facilitate data exchange between pairs of application (Eastman, 2011). Extensible Markup Language (XML) is a markup language which is designed to transport and store data (Refsnes, 2009). XML structure which is called "schema" can support the data exchange between different applications, and most of them are desktop applications. The XML Schema was developed as an alternative to full scale IFC models to simplify data exchanges between various AEC applications and to connect Building Information Models through Web Services. However, XML is mostly used for small amounts of business data exchange between two applications and is not powerful enough for complex information exchange (Eastman et al, 2008; Refsnes, 2009). Interoperability supports different capabilities and addresses various problems in exchanges of data across types of BIM application. The most common form of data exchanges are between a BIM platform and the set of tools it can support – structural and thermal analysis, quantity take-off, scheduling and procurement applications and this is where BIM platforms native data model are translated (Eastman, C. 2011).

2.11 BIM MATURITY LEVELS AND DIAGRAM

BIM is a key driver in the pursuit of efficiency savings reflecting in lower construction capital cost, faster delivery and lower emissions and has varying maturity levels (JCT, 2016). It's also vital to note that BIM is not just software rather a technologically enabled process engaging interoperability software and methodologies to deliver efficiency creating required digital information about a facility. In order words, is a data-rich model with defined attributes such as space, systems, products, materials and presents model element physical and technical relationship with respect to whole life cycle needs (HM Government, 2015). BIM maturity levels define degrees of process output and workflow in stages though organizations tend to develop their own methods for measuring BIM maturity. BIM level 2 is to provide a basis for internal and external communication to ensure that communication is based on the same reference point. It is vital to consider that some observers believe that BIM should be the abbreviation for 'Building Information Management' and others use the term BIM(M) alluding to 'Building Information Modelling and Management'. The BIM maturity diagram sets out why Building Information Modelling is more accurate.

The BIM maturity diagram prepared by Mervyn Richards and Mark Bew in 2008 illustrated the most effective way to understand BIM (RIBA, 2012). The BIM maturity diagram depicts the BIM maturity levels (levels 0, 1, 2, and 3) which is broadly referred to in the construction industry to the degree that the UK Government's staged or phased implementation is based on these levels. As stated above, from summer 2012 according to the phased BIM implementation as contained in the Government Construction Strategy (2011), projects will be required to implement level 2 BIM with the UK Government's aspirations being to have fully collaborative BIM with all projects and asset information, documentation and data being electronic as minimum by 2016. The maturity regarding utilization of BIM is described by levels ranging from 0 to 3, where 0 is the lowest and 3 is the highest level of progression. What parts of BIM which are included in each BIM level is specified. This enables task managers to always have a next maturity level, including more parts of BIM to progress towards. For example, services as BIM coordination could be provided to a client in order to reach level 1 (NBIMS, 2007).

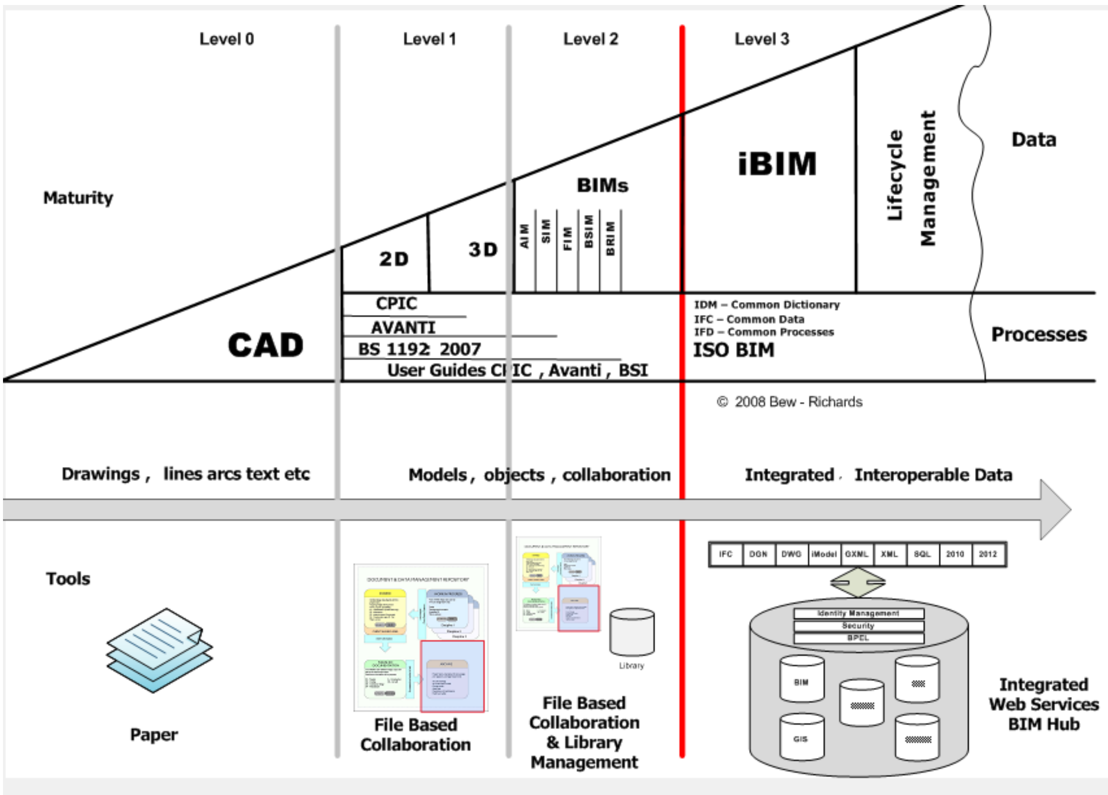


Figure 2.4: BIM Maturity Diagram (Source: RIBA, 2012)

2.11.1 Level 0 BIM

At level 0, as illustrated in Figure 2.3 the horizontal line that separates data and process management which does not start until level 1 BIM is that common standards and processes in relation to the use of CAD which failed to gain proper traction as the use of CAD developed. 2D computer-aided design (CAD) processes had developed without Common Standards being adopted throughout the industry (RIBA, 2013). Designers found it difficult to move seamlessly from one project team to another due to varying manuals and CAD standards in use by different practices. It depicts and demonstrates the 2D CAD files for production information which is a process which involved majority of design practices for many years. 3D is utilized in the design phase but there is no coordinated connection to the models of other disciplines or requirements regarding documentation for information exchange (NBIMS, 2007). Many of the 3D softwares which are employed in the day-to-day work have functions that could be classified as BIM. However, these functions are not utilized at the present time and there is unexploited potential which could be benefited from it (NBIMS, 2007).

2.11.2 Level 1 – 3D Coordination

At level 1, 2D and 3D builds upon CAD but the data created it's only for the purposes of visuals. These models do not contain that aspect of BIM definition that acknowledges 'a shared knowledge resource for information' but excludes other project team members (RIBA, 2012). This level of BIM allows only one party to utilize the benefits of the model and it's referred to as 'lonely BIM' – the model is not collaboratively used among team members. The use of 3D tools beyond this level has been limited to large infrastructural projects, in such project sizes the use of 3D tools is increasingly becoming a common place. 'The larger M&E contractors have embraced BIM to assist their design processes using supplementary checks undertaken with proprietary software to ensure that co-ordination issues are resolved during the design phase rather than on site. This is a significant step towards the aim of minimizing waste and inefficiencies in current design and construction processes' (RIBA, 2012). In BIM maturity, level 1 implies a well-functioning coordination between different disciplines as it embraces the need for management processes sitting alongside design processes. The work of CPIC and Avanti commenced simultaneously with level 1 BIM projects and at the same time set out processes for information management which has been integrated into BS 1192:2007 (RIBA, 2012). As the building information models of different disciplines are interconnected, clash controls can be performed (NBIMS, 2007). An example of an additional service that can be provided at this level is identification and organization of information flows within the project, which is a prerequisite for creating a common understanding regarding goals in the project (NBIMS, 2007). Further work is underway to develop and improve standards to support standardization process relative to design process and also create efficient consistency in the way the industry works from project to project.

2.11.3 Level 2 – 3D Environment

The National Building Specification (NBS) defines Level 2 BIM as "a distinguished collaborative working where all parties use their own 3D CAD models, but not necessarily working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties and is the crucial aspect of this level. Design information is shared through a common file format, which enables any organization to be able to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it. Hence any CAD software that each party used must be capable of exporting to one of the common file formats such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange)". At level 2 BIM, individual discipline models are used for collaboration, these models contain intelligent data. As the model develops, it is progressively enriched with relevant discipline data such as scope of work and project stage and then integrated with other project team information before being federated. BIM standards, protocols, principles and practice is adopted by all project members (clients, subcontractors, main contractors, suppliers, consultants and designers) to ensure all digital representation have same reference point of all aspects of the facility (JCT, 2016).

The full potential of the contained intelligent data is not realized at level 2 but will be a platform for data presentation for over five million pounds government project given in COBie format. All key integrated project team at level 2 are essentially required to produce 3D information models; however these models need not co-exist in a single model. Designers by better understanding and application of BS 1192:2007 can ensure a seamless logical progression of each designer's model before it is engaged by another designer or even the subcontractor designer (RIBA, 2012). Though at level 2 BIM there is a basic requirement to be working collaboratively with 3D BIM but not with any obligation towards the 4D schedule, 5D cost and operation elements to be incorporated within the model (Isikdag et al., 2012). 'It is not anticipated that the legal, contractual or insurance issues currently utilized by the industry will change for level 2 but it is fair to say that level 2 BIM does expose some of the deficiencies of current contractual documentation' (RIBA, 2012). For instance, the role and responsibilities of the Information Manager, various Designers and Contracting parties needs to be considered in order to become clearer particularly in relation to Performance Specified Work. Essential outputs at various stages will also require greater definition and in order for the Lead Designer to coordinate the progress seamlessly at this BIM level, inputs are to be clarifies at each design stage. At Level 2 BIM the current fragmentation of the design team fueled by the designing subcontractors will need replacement by the Integrated Teams effectively working collaboratively under new forms of procurement using more efficient working methodologies.

2.11.4 Level 3 – Integrated Single model

According to NBS, Level 3 BIM is defined as "full collaboration between all disciplines by means of using a single, shared project model which is held in a centralized repository. All parties can access and modify that same model, and the benefit is that it removes the final layer of risk for conflicting information and this is known as Open BIM". The greatest BIM challenges arise when moving from level 2 BIM to level 3 and the perceived 'legend' of the single project model. At level 3 BIM, more advanced models are required and higher degree of collaboration requiring single shared project model is required. Services from both level 1 and 2 are provided with a highly integrated model between the different disciplines (NBIMS, 2007). Examples of services which can be provided at level 3 are more advanced time and cost estimation, programmed with a parametric design, as well as maintenance models which is fully integrated with the client's management and maintenance systems. Through level 3 BIM, cost estimating is carried out with the 5D function, by linking the model to an estimating database (Haque and Mishra., 2007). Mena et al. (2010) discusses that this can be done through sources such as Building Cost Information Service (BCIS), to provide high level cost information, which is useful during the early project stages. Certain software providers are now publicizing that it is possible to develop detailed cost plans through linking a '5D Cost Library' to BIM, which performs the functions of an estimating database. A 'master' library can be formed, in addition to several project specific variation libraries, making the process highly productive and easily repeatable (VICO Software, 2012), allowing varying levels of detail to be applied to estimates, depending on the project stage. The idea is that level 3 should represent the cutting edge of BIM technology, not impossible, but certainly unusual to reach. The content of level 3 should be periodically updated as the technological development progress (NBIMS, 2007). With level 2 resolving the methods deployed by various designers working in 3D environment, collaborative information use will not be the challenge with the single model but the information harnessing to a greater use. To enhance the value of information use in level 3 BIM software interoperability will be absolutely required. At level 3 BIM, it will be possible for early design analysis on environmental performance reducing iterative design time (RIBA, 2012), cost models will be derived faster from the model engaging new costing interfaces. Health and safety analysis can be parallel with the design during the construction and maintenance of the structure, key performance index, asset management and other feedback information to be in consonant with intelligent processes enabling information in the model to develop during design and to be used as part of a Soft Landings approach, and to inform and improve future projects (RIBA 2012). At level 3 BIM, certain design processes will need to be developed and refined to enable a clearer and a more established methods to be deployed especially in setting out how many parties can work in same model environment at the same time. With better scope of service and responsibility documentations integrated in the design processes, fears of some insurance and legal observers will be truncated, but the implications and legal issues associated with copyright, responsibilities and scope of services need to be identified and discussed if level 3 BIM is to be successful (RIBA, 2012). The single project model will not be a free for all as some observers predict because the software already exist to limit read or write access to each user and with more sophisticated design management programming techniques, it will be possible to prevent designers working on same area at the same time.

2.12 COMMON DATA ENVIRONMENT (CDE)

BS 1192:2007 (Collaborative production of architectural, engineering and construction information – code of practice) defines the collaborative working process for project collaboration and efficient data sharing (BSI, 2007). To deliver centrally coordinated actions with potentials in reducing construction costs by 20% (CAPEX cost savings) which is the key ambition of the Government Construction Strategy (2011) for BIM implementation, all construction stakeholders need to work collaboratively. CDE is key to achieving an integrated digital process that promotes coordination, reliability of project information through design, construction and operational gates. PAS 1192-2:2013 defined Common Data Environment (CDE) as a “single source of information for any given project or asset, used to collect, manage and disseminate all relevant approved files, documents and data for multidisciplinary teams in a managed process”. Working in a CDE allows project information to be shared by different project stakeholders and also between stage gates of design, construction and operation. For instance, an engineer is able to source information from an architect to prepare energy calculations or a contractor can coordinate project team inputs and outputs as well. The main driver for integrated collaborative working or working in a collaborative environment is the ability to share and re-use data without any loss of data intelligence or misinterpretation. The CDE is a key tool to effective collaboration, communication, quality control, avoidance of waste and information sharing among all project team members (internal and external). There are four aspects relevant to CDE as illustrated in the Figure 2.5 below.

- Work in Progress (WIP): Non-verified design data used by in-house design team - This is data held in production which is not yet checked and verified for use outside the authoring team (AEC, 2012). The model files held in WIP is developed in isolation with information that each stakeholder is responsible for. It concludes with the approval gate representing transition to SHARED (Figure 2.4) where data is checked, reviewed and approved by the lead designer.

- Shared: Verified design data shared with the project team - Through a shared document and data management repository or exchange protocol, each project stakeholder makes design data available for formal access by all project team members and is accessible from a central location as demonstrated in Figure 2.5. This facilitates coordinated, integrated and efficient way of working. The data is checked, approved and validated for BS 1192 workflow compliance. Checks for authorisation here includes EIR deliverables and completion of PLQs. It concludes with the authorised gate and is authorised by the employer representing transition to PUBLISHED DOCUMENTATION.

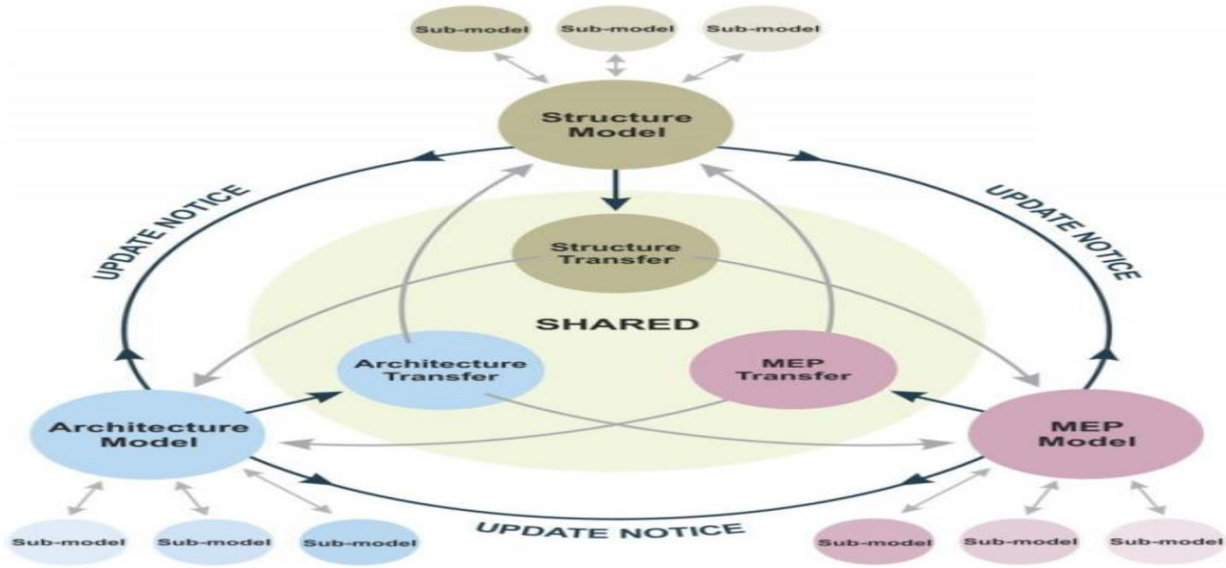


Figure 2.4 Common Data Environment (CDE) shared central location (Source: AEC, 2012)

- Published/Issued: Co-ordinated and validated design output for use by the total project team – Exported data and 2D electronic drawings as produced from BIM is stored here with other relevant project documents. It is checked, approved and authorised in compliance with BS/PAS 1192 requirements. According to AEC (UK) BIM Protocol (2012), “Information within a BIM is inter-dependent and changes in one view may affect other views. As such the BIM files and all associated views shall be treated as “Work In Progress” or shared as un-controlled documents until such time as they leave the BIM environment in a non-editable format”. It concludes with the published gate representing transition to ARCHIVE.

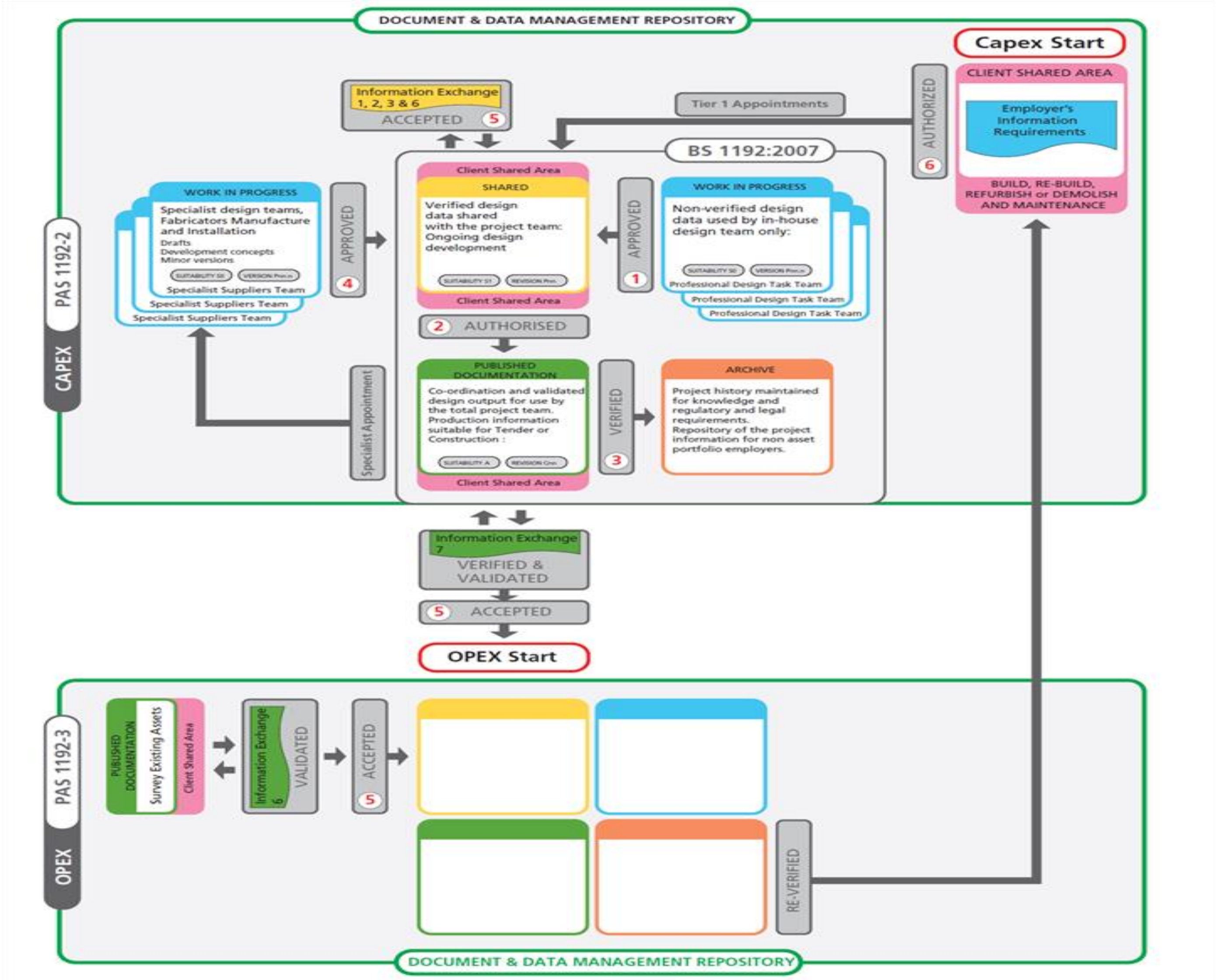


Figure 2.5: Extending the common data environment (CDE) (Source: BSI, 2013)

- Archive: Project history maintained for knowledge, regulatory and legal requirements – This is used to record all progress as each project milestone is met and holds a record of all transactions and change orders to provide an audit trail in the event of a dispute. As constructed information is also checked and verified in the published section to allow transition through verified gate to the archive section (PAS, 2013)

2.13 CHAPTER SUMMARY

Existing literature in the area and practice of Building Information Modelling unveiled an implementation trend across all Architectural, Engineering and Construction (AEC) countries with several standards, guides and protocols developed and tailored to address varying project needs. Several publications of BIM practice standards in the form of PAS documents, frameworks, protocols and guidelines for digital process implementation have been published and made available to the UK construction practitioners yet the construction industry and her stakeholders still struggle with lots of barriers in seeking to implement a digital practice particularly the challenges of industry structural and leadership fragmentation. Barriers to implement BIM on new builds, existing buildings and infrastructure, existing industry culture, lack of BIM knowledge and education, cost of BIM software and hardware as well as associated costs network storage and access to model are some of the key literature findings. Issues of cultural barriers, lack of integration of cost modelling tools and appropriate definition of design input at a required design stage (design scope) leading to inaccuracy of information input are some of the findings presented in this chapter. Added to the challenges are lack of strategic leadership on construction digitization and BIM process implementation, process and technological related challenges and risks: information requirement not explicitly stated from the project outset are major issues with BIM implementation as discovered from literature.

Further concerns are raised regarding information security, liabilities, insurances, ownership of intellectual property, interoperability. Some amendments and particularly cultural shift is perhaps deemed necessary for a smooth BIM implementation within the UK construction industry and this aligns with Latham, Egan and Farmers recommendations on industry solution to address the challenges of low profitability and overall performance dissatisfaction. Recommended viewpoints from Latham, Egan and Farmer include how to tackle under-achievement of the UK construction industry, lack of dedicated and committed leadership towards integrated teams and processes, poor productivity and predictability, structural and leadership fragmentation, adversarial pricing models and lack of industry innovation. A comparative overview of the UK construction industry and its current workflow model in comparison with other industry sectors also reveal a process setback with wider margin on process efficiency, digital leadership and technological advancement. The above challenges as seen from literature findings seems to be a recurring decimal spanning over many years without a strong solution to address both the existing and evolving issues. Radical changes to the construction process is therefore required making it transparent and explicit to the industry and its client. The next chapter of the study will explore existing traditional costing strategy and BIM based costing and will consider difficulties and solutions of embedding digital 5D cost modelling into BIM practice and process.

CHAPTER THREE

TRADITIONAL COSTING AND BIM BASED COSTING PROCESS

3.0 INTRODUCTION

Building Information Modelling (BIM) as one of the process and technological development in the architecture and built environment, has progressed from assuming the position of another research output into a commercial reality given its growing rate of adoption and implementation till date. Industry-wide adoption of construction digitisation through BIM enabled platforms is predicated on collaboration. An increasing collaboration amongst multi-construction professionals has positioned BIM as the most promising emerging technology leading a significant revolution on building designs, constructions, maintenance and operations (RICS, 2015).

Digital capabilities of BIM deploy potentialities that virtually represents the physical and functional characteristics of a built facility providing a shared source of information among project parties thereby forming reliable bases for decision making process throughout the whole life cycle of a facility (Eastman et al, 2011). It is co-opting a paradigm shift in the industry from Quantity Surveying conventional practice (paper based information management process) which is time consuming, error-ridden, cost ineffective to automated digitisation process through advanced technologies providing more value for money regarding time, cost, quality and scope. Traditional estimating and measurement process is accelerated through BIM's capability of automated processes. It brings further benefits which includes extracting quantities directly from BIM model, exporting measurements to spreadsheet through linking modelling tools with estimating plug-ins, increased visualisation at concept stage, virtual reality (VR) designs and optimises facility management through life cycle. BIM as a database of components in the design and construction of a building, can quantify accurately using relevant software tools all the necessary materials required for construction while reducing greatly the margin for error (Haque and Mishra, 2007). At present, industry capacity to deliver cost effective and high-performance construction projects providing value for money is challenged due to lack of 5D digital framework and protocol as required during costing functions. Therefore, innovative technological process which puts BIM as prime catalyst needs urgent industry consideration. The traditional QS status quo currently engaged by the cost practitioners needs to evolve into a digital function to keep track of technological benefits.

3.1 TRADITIONAL COSTING APPROACH

There is a worldwide paradigm shift in construction practices and buildings are becoming more complex with diverse procurement approaches. Clients are beginning to demand facilities that are built on time, within budget and provide ‘value for money’ for the complete lifecycle of the facility. Due to integrated complexities from the outset to post commissioning of large projects, there is an urgent prompt from industry for a digital planning approach of costing activities, time schedules and ultimately what Ashworth and Perera (2015) allude to as ‘getting it right the first time’ meaning ‘build it twice’ once virtually and once physically. To meet this collaborative obligation, early project collaboration of the developers, design team, contractors and their supply chain, end users and facility managers involved throughout whole lifecycle of projects are required to work in tandem, communicating visually to facilitate target cost design rather costing an already completed design (RICS, 2015). Hence project design, work activities, cost estimation and cost planning must be undertaken together and start right at the beginning during the feasibility planning stage and continue throughout the whole lifecycle of the project to monitor the cost budgets acting as a live document consistently interrogating the geometric BIM model. Certainly, this enables better cost benchmarking and cost analysis framework (Benge, 2014).

Considering the Royal Institute of British Architects (RIBA) key activity tasks identified in the RIBA Outline Plan of Works 2007 (RIBA, 2007) showcasing a traditional approach – Figure 3.1. The existing nature of construction is such that often the cost of a project is not known until after the final design decisions (Stage C - Concept Design) has been made and in some cases may even be after the construction itself has been completed (Ashworth and Perera, 2015). Following this linear process, the prime characteristics of this procurement route as suggested by Cartlidge (2013) is that there is "little or no parallel working, resulting in a sometimes lengthy and costly procedure". The main contractor whose construction expertise ensures a fully streamlined process if involved early, has no input into the design as they are not appointed until after the drawings and tender drawings have been finalised and fully measured Figure 3.1. It is seen in same figure below that there is no contractual or collaborative working relationship between the design and construction team during the pre-contract stage. Value engineering cannot be fully adopted or full value-added design cost considerations which is critical for 5D BIM costing process and collaborative working frameworks to be achieved as highlighted in (Ashworth and Perera, 2015).

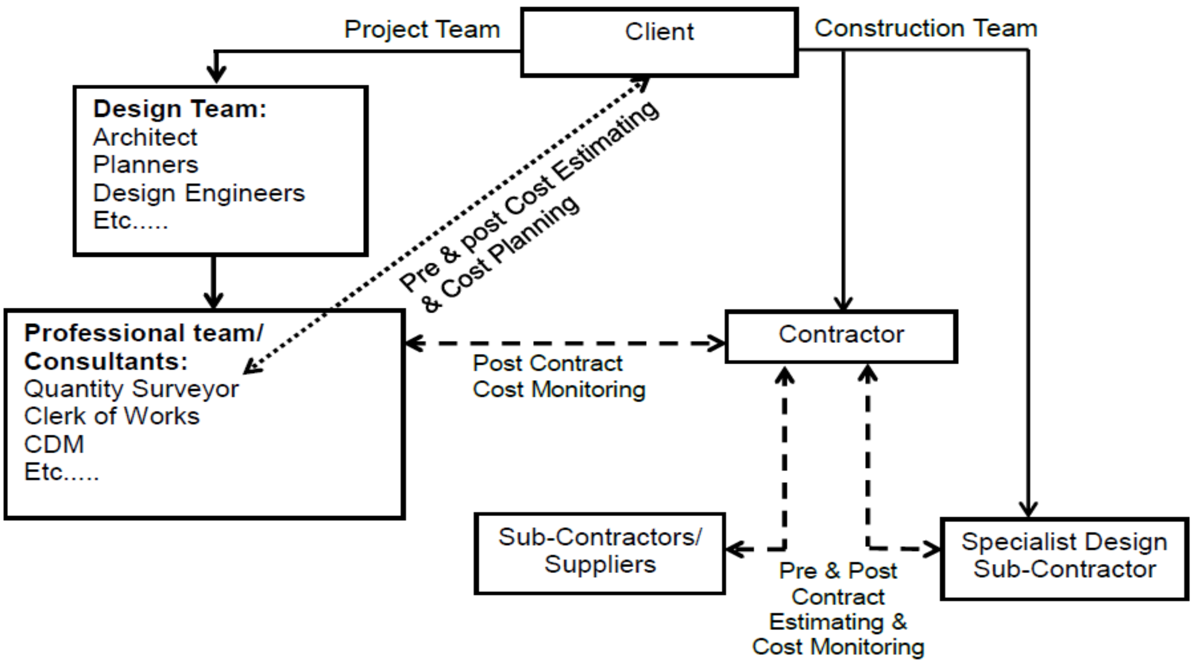


Figure 3.1: Traditional Project Delivery and relationship of cost planning activities

The recurrent traditional construction process is problematic because different design decisions have varying cost implications embedded, and to ensure that the best decisions are made, it is imperative to adopt a reliable mechanism where costs of design options can be established before final design decisions are made and implemented. More importantly, following the good practice guidance of soft-landing to truly assess the functionality of the project and validate the whole life cost implications of the building's operational performance at the project brief and early project inception (Usable Buildings Trust, 2014). The purpose of pre-contract costing is to produce a forecast of the probable cost of a future project before the building has been designed in detail and contract particulars prepared. In this way, the client is able to consider - right at the inception stage - alternative schemes that can achieve similar objectives, and is aware of the projects likely financial commitments even before extensive design work is undertaken to enable developers make arrangements for sourcing finance (Ashworth and Perera, 2015). Since 1963, the RIBA have presented the linear planning model (RIBA, 2007), however due to the global changes in the way that projects are delivered and managed, as well as the acknowledgement of BIM integration and collaboration; a new online flexible RIBA Plan of Works 2013 (RIBA, 2013) is provided which is a build-up on 2012 BIM overlay (RIBA, 2012). This can be tailored to suite procurement practices acknowledging that tendering happens throughout the project not just confined to stages G and H as used in traditional setting (Figure 3.2).

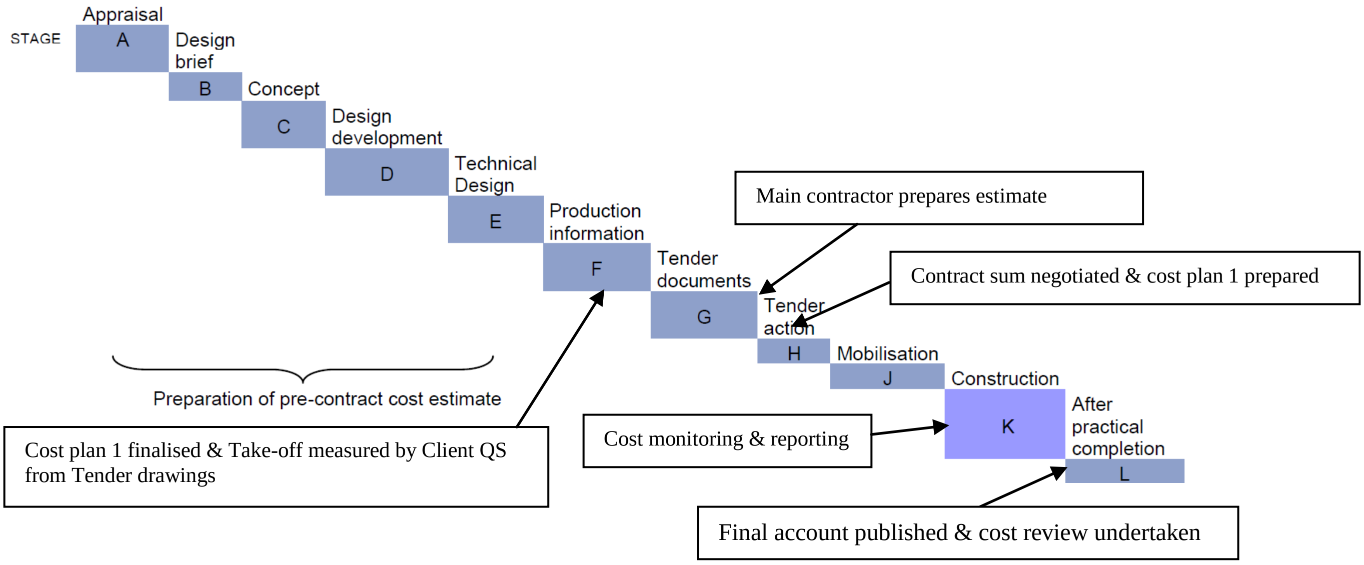


Figure 3.2: RIBA Plan of Work 2007 Stages – highlighting cost estimate and cost plan outputs (Adapted: RIBA, 2007)

Figures 3.1 and 3.2 shows a traditional preparation of pre-contract cost functions limited to feasibility and technical design stages. As the scheme design progresses to a more detailed design (from superficial to elemental costing), more information becomes available (data drop increase), therefore initial cost estimates and cost targets need to be reviewed to ensure it is as accurate as possible with subsequent design inputs considered and up to-date. The traditional procurement approach is not value add in terms of value proposition and cost related challenges until the construction stage, invariably causing potential delays as design evolves and affecting accurate cost information in particular when massive changes are required (RICS, 2015; Cartlidge, 2013; RICS, 2014).

3.2 DIFFERENT TRADITIONAL COSTING APPROACHES

Several approaches to preparing pre-contract cost estimates currently exist with embedded weaknesses and strengths in relation to industry best practices. Available data from clients determines the type of cost estimating technique or method considered to be adopted with varying degrees of cost certainties and uncertainties.

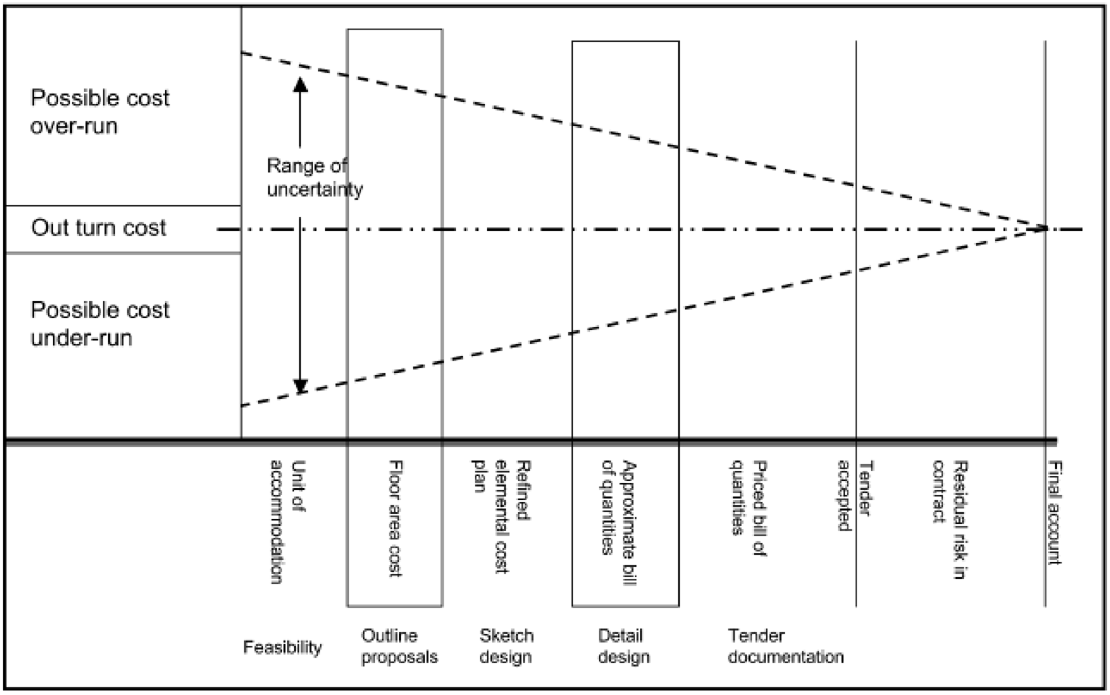


Figure 3.3: Degree of cost uncertainty and traditional costing approach

Applicability of some techniques is easier when compared to other approximate costing techniques and the reliability of the cost outputs is dependent on the credibility and quantity of data available.

3.2.1 Functional Unit method

This is a single price rate method based upon cost per functional unit of the building or standard unit of accommodation e.g. cost per bedroom, uses interpolation of cost between buildings of similar nature to obtain a cost range for a ball park figure only as there may be many intangibles - storey height and drawing for a true comparison. The level of cost accuracy in the estimate produced however is directly linked to the information supplied by the client (Kirkham, Brandon and Ferry, 2015; Ashworth and Perera, 2015). This type is ideal when trying to ascertain an approximate cost budget or guide price for a proposed building project without the aid of any detailed plans as expressed in RIBA DPoW 2013 stages (RIBA, 2007). Cost data is typically sourced from indexed data of past projects where the contract sum is divided into the number of functional unit e.g. cost per bedroom for a hotel. The previous cost data is analysed, compared and then interpolated to allow for changes to specification, basic design as well as making allowance for location, market forces and inflation (Cartlidge, 2013; RICS, 2012).

3.2.2 Superficial method

Also known as cost/m2 is a single price rate method based upon the usage area known as gross internal floor area (GIFA) and uses published analysed cost database e.g. Building Cost Information Services (BCIS), Standard form of contract (Elbeltagi et al, 2014; RICS, 2014; Cartlidge, 2013; BCIS, 2012). Appropriate method where an early budget cost is required without any specific details other than approximate size. More accurate than functional unit as the costs can be manipulated to reflect the criteria set by the client brief. This method is based on the fact that there is a close relationship between construction cost and the floor area of a building i.e. the greater the floor area, the greater the construction cost (Kirkham, Brandon and Ferry, 2015; Ashworth and Perera, 2015) - RIBA stage 1 and 2. Cost data is typically sourced from previous past projects where the contract sum is divided by the project GIFA and then multiplied by the new GIFA. This floor area is measured between the internal faces of the enclosing walls, and it includes internal walls, partitions, columns, stairs, chimney breasts, lift shafts, corridors etc. All sloping surfaces are measured flat on plan. Care needs to be taken when calculating GIFA and what is classed as usable space e.g. circulation areas are included (Ashworth and Perera, 2015; BCIS, 2012).

3.2.3 Approximate Quantities

This method relates to assessing in detail and combining into composite items all associated cost of the actual work to be carried out using bill of approximate quantities. That is where it might not be possible to measure items of work accurately but will require full drawings and specifications of the entire project measured upon project completion (Ashworth and Hogg, 2007). This is presumed to provide the most accurate form of estimate traditionally and it’s a useful approach where early start is required on site. This form is very similar to measuring using detailed rules of measurement: NRM2 (Cartlidge, 2013; RICS, 2007) though it is still subject to variation claims through risks of inaccurate measurement, missing items of work. Inability to justify extent or value of work tasks done leads to construction disputes and the likes. Needs digitisation of estimating functions to improve accuracy of quantity generation.

3.2.4 Elemental Estimating

Costs are estimated by breaking the building down into its major elements. The rates are calculated by "measuring the size/amount of the element and multiplying by a unit rate" using a combination of the above estimating techniques (Benge, 2014; RICS, 2014; Cartlidge, 2013; BCIS, 2012). This method is excellent for forming cost targets and usually becomes the formal cost plan used throughout projects.

Early cost estimation relies upon the use of quality historic design and cost data and is a forecast of the contract sum to enable a prediction of the future estimated cost as well as the accuracy of the estimate (Ashworth and Perera, 2015; CIOB, 2009). Before commencing the detailed design or the construction phase it is essential to consider the associated costs involved while setting the project budget and best practice to review those costs as design develops. When selecting a method to use, a number of factors must be taken into consideration, which includes the information available about the project, the stage of the project cycle, the time available, the experience of the estimator, the form of cost data available and the amount of cost data available (Cartlidge, 2013). The availability of project data therefore dictates the type of estimate required and equates to the stages of the traditional procurement approach where the most accurate estimate is undertaken when full designs have finally been agreed incorporating many revisions (RICS, 2012; Cartlidge, 2013). The practice is to choose the technique which will yield the most accurate estimate within the time available, given available information. Defined costing techniques above has been engaged by industry practitioners for years – the QSs, cost mangers, cost consultants, clients and contractors still struggle with the inefficiency and inaccurate tender sum embedded within the process. The challenges of traditional approach like poor data management, changes or alteration by project stakeholders/client, inexperienced QSs/estimators, poor understanding of measurement rules, poor value of products, wrong interpretation of drawing/designs, improper breakdown of building works into measurable items, error filled BoQ and tender sum, missing information, late information, insufficient detail, conflicting information still burdens the entire process. Figure 3.3 shows the input data process of different cost estimating techniques with varying degrees of cost inaccuracies at project milestones. The possibility of cost overrun and cost underrun as a result fluctuates and exists throughout the cost estimating and cost planning processes leaving a residual risk factor even after the tender process has been initiated and completed. This defines further issues and practice challenges both at the design, construction, operation and maintenance phase of any project. The Canadian Construction Association (2012) commissioned a taskforce to assess the degree of accuracy for different estimating technique linked to the RIBA 2007 stages and in the UK, a corresponding stage percentage error was also analysed by RICS (2014). Findings for both studies were as follows:

> *"At concept design, cost variance ranged between 20-30%*
>
> *When 33% of design is developed, cost variance ranged between 15-20%*
>
> *When 66% of design is developed, cost variance ranged between 10-15%*
>
> *When 100% tender documentation is complete, cost variance ranged between 5-10%"*

Equally in the UK, expected percentage of errors show thus:

> *"Conceptual estimates during schematic design range between 10-20%*
>
> *Semi detailed during design development range between 5-10%*
>
> *Detailed when plans and specification have been produced between 2-4%"*

Each of the findings reported some level of inaccurate cost information at varying levels of design development, filled with uncertainties and project budget risks. If change orders and design revisions are to be initiated as the project evolves, given the integrated high percentage of error at design stages, it then follows that variations claims and compensation proposals could result in contractual disputes especially during settlement of final project cost (final account). Due to the fragmented linear style as shown in Figure 3.3, quality of early design information with no integration of the design and construction team, accuracy of the cost models will remain compromised even after the project has started on site. With 5D BIM integrated construction with common data approach, cost certainty is improved as opposed to the substantive range of cost uncertainty embedded traditionally (Elbeltagi et al, 2014; Ashworth et al., 2013). Hence the RIBA DPoW 2013 promoting new procurement routes with early contractor involvement, acknowledging 5D BIM embedded processes, and a more standardised measurement classification (NRM1-3 suite) to be used consistently throughout the lifecycle of the project - enabling better cost control and cost predictability at pre-contract.

3.3 TRADITIONAL MEASUREMENT PROCESSES

Traditionally, the choice of unit of measurement and cost outputs are dictated and still will be on the level of detail available (BCIS, 2012). Construction costing and estimating always uses some form of measurement, whether measuring the material quantity e.g. volume of concrete or counting the number of external doors or if no drawings count the number of bedrooms required by the client. The same rules of measuring or counting apply to any model, diagram or description. However, this does not mean that the contractor would use the same measurements as per the standard rule of measurement – they would manipulate the data to contextualise to the quantities of material e.g. ordering of material quantities, this technique is known as ‘builder’s quantities’ hence error filled bill of quantities and rates (Cartlidge, 2013; Ashworth, Hogg and Higgs, 2013).

During tender estimation, detailed project cost in form of bill of quantities (BoQ) is developed using Standard Method of Measurement (SMM) for construction industry practice (Matipa et al., 2010). Measurement standards have been in existence for nearly a century providing set of rules and guidelines for QSs to measure and price building works (RICS, 2014). Due to its limitations on the required procurement variability, different forms of measuring standards were deployed for industry practice especially when employing procurement methods that does not need a detailed BoQ and tender documents. According to Cartlidge (2011), "the format presented in SMM7 is specifically related to the preparation of BoQs but not to cost estimates or cost plans. Therefore SMM7 is unable to support QS in providing cost advice due to its failure to suit the new approach of cost planning, particularly when capturing cost information". In the absence of a specific set of standards, SMM has been adopted for cost estimating and cost planning (RICS, 2014). Various sets of standards were as a result used for measurement and description of building works by the QS which compromised data integrity and created doubts among the project team members regarding the provision of cost advice. Prior to the publication of the NRM measurement suite, there were no standard measurement rules for cost estimating recognised by the QS profession, causing a lack of consistency and structure towards the production of measurement data or cost planning through the whole life cycle of the project (RICS 2012). Added to this lack of structure is the manual take off process undertaken by the QS where various detailed 2D drawings are required to be interpreted and cross checked for any discrepancies among different professionals, design team and trade suppliers inputs due to lack of joined up integration (Cartlidge, 2014; RICS, 2014; Bylund and Magnusson, 2011). The Royal Institute of Chartered Surveyors (RICS) was moved towards developing a new set of rules for measurement known as New Rules of Measurement (NRM) as a result of the inappropriateness of standards and the compromise of data integrity fuelled by application of differing measuring rules and standards. NRM was developed in three distinct volumes to cover the whole lifecycle of construction process – from initiation of project definitions and strategies through to completion and building occupation supporting the RIBA framework stages for project lifecycle and NBS developed BIM standards.

According to RICS (2012), “NRM 1 provides vital guidance on the quantification of building works for the purpose of preparing cost estimates and cost plans. NRM 2 was prepared to guide the detailed measurement and description of building works for the purpose of obtaining a tender price while NRM3 extends indispensable guidance on the quantification and description of maintenance work for the purpose of preparing initial order of cost estimates during the preparation stages of a building project, cost plans during the design development and pre-construction stages, and detailed, asset-specific cost plans during the pre-construction phases of a building project”. In summary NRM 1 basically identifies information requirement from BIM for cost advice at the project early design stage, NRM 2 is for the production of tender document to obtain tender sum while NRM 3 is for asset maintenance but stretches from initial cost estimate through design development and pre-construction stages to asset specific cost plans during the preconstruction phase of a building project. NRM if well applied within the cost functions of a BIM project will meet the requirements of RIBA-DPoW 2013 unlocking principles that develop an NRM BIM tender though issues regarding designing to a correct level of detail and object naming conventions need urgent resolution.

3.4 TRADITIONAL COST ESTIMATING AND COST PLANNING APPROACHES

Cost estimating is the process of collecting, analysing and summarising data to prepare an educated projection of the anticipated cost of a project (Ashworth and Hogg, 2007). Estimating is basically at the heart of cost planning of construction work as it allows developers to calculate project budgets controlling and regulating main contractor’s functions as well as being used to form a cost planning tool. This enables the client to make informed decisions on affordability and risks (Ashworth and Hogg, 2007; Benge, 2014). The process of cost control begins at the inception of a project particularly where the "guide prices or indicative costs" are required (Ashworth, Hogg and Higgs, 2013) and identifies this as a pre-tender estimate or more recently under NRM1 - order of cost estimate (Benge, 2014; RICS, 2012). Conventionally, the QS functions is mainly associated with cost estimating and cost planning, production of bill of quantities (BoQs), interrogation of tender processes and documentation, procurement input, payments, construction cost control advice, valuation preparation, contractual claims and final accounts. However, changes in procurement strategies with the developments in the construction sector in particular Building Information Modelling (BIM), have expanded the role and responsibilities of QS to cover whole lifecycle costing, value management and decision drive, risk analysis and resolution, project and construction management, facilities management, contractual disputes and litigation (Ashworth and Hogg, 2007).

The resultant effect of construction industry fragmentation and the linearity of the design process, influences traditional cost estimating activities to be performed at a time when the conceptual design is much advanced or even completed, which is not very supportive in helping varying stakeholders of a project team during the design process to make informed decisions (Forgues & Iordanova, 2010). The traditional estimating methods and the estimator would rely solely on the plans and specifications to make the determinations of what is required. Typically, cost estimating done from quantification of components was very time consuming: counting, checking and recounting. The counts from one firm could vary greatly due to human error and would carry over right through to the construction bid. These errors could prove quite costly if a job was awarded to a low bidder with incorrect counts on a high cost item. Very often, generated cost information highlights latent budget concerns and a cost engineering process is required to reduce construction costs and often at the expense of performance criteria, sustainability aspirations and construction material and quality. Performing value engineering and cost estimating from the beginning of the design process would possibly enable a faster, more cost-accurate and effective project delivery, higher quality buildings, and increased cost control, reduced variation claims and employer cost predictability (Sacks et al, 2010). According to literature, variation of over 40% with the initial budget is frequent in these cases (Flyvbjerg et al., 2003, and Winch 2010). Although BIM-based cost estimating tools have been available for some time, only a handful of large construction firms have been able to fully leverage this functionality. Nowadays, the AEC (Architecture-Engineering and Construction) industry is facing a technological change represented by the transition from CAD-based (Computer Aided Design) documentation to BIM (Building Information Modeling) (Winch, 2010). Unlike the CAD drawings which were limited in information presenting only independent views as plans, elevations, sections, BIM opens an expanded range of possibilities due to the immense amount of information which can be encapsulated and later extracted from the digital model. The emergence of BIM presents the opportunity to use the detailed design elements and quantifications needed by today's estimators and quantity surveyors (Mena, et al., 2010). Designs require earlier validation for more accurate estimates and can be used earlier culminating in improved cost predictability, reducing number of estimates required and making less room for errors filled processes.

Managing cost is an important priority in construction management. Since cost estimating is usually realized at the end of a project phase by different stakeholders using datasets and information that are heterogeneous, it is a highly fragmented, resource intensive and ineffective process especially on large or complex projects. One of the BIM promises is to tackle this problem by providing a unique source for cost estimating covering the entire lifecycle of the project. According to Kahnzode et al (2008) a "3% cost accuracy could be achieved from front-end cost budgeting to building construction cost. However, the technological and work organization challenges of implementing BIM-based estimating into one of the key stakeholders of the supply chain, the general contractor, is little documented in the academic literature".

The role of an Estimator is a potential platform for a success of an organization. He is responsible for predicting the economic costs for projects in a way that is both clear and consistent (Brook M., 2004). Quantity surveyor or an estimator primarily owns the function of generating and pricing of bill of quantities, preliminary cost estimation, economic feasibility analysis, cost analysis, project control, bill rates, pricing tender documents, variations and final account (Buchan et al, 2003). The estimator or the QS is involved from initial conception to handover and running of building, overseeing cost while providing value to the client. The profession is involved in accurate forecasting of the scope, cost, and durability of construction projects - compiles and analyze data on all the factors with influence on cost such as material, plant and equipment, labour, location and duration of project. The extent of size, shape or function of any proposed work notwithstanding, it's essential to have a good method for producing an accurate cost estimate for the items of building or infrastructural work. Main contractor or SMEs cannot afford to make an unrealistic offer to a client who is instructing the work being undertaken. Therefore, it is important to understand the concept of cost estimating as the process of pricing items of work based on the information, specification and/or drawings available in preparation of submitting an offer to carry out the work for a specified sum of money (Buchan et al, 2003). The specified sum is known as the "tender sum" and will be made in the context of a form of contract, which will include the condition under which the specified sum may be varied. The estimator must be confident that the tender sum is accurate as the standard form of building contracts does not permit the contractor to recover additional sums of money from the client due to errors in the estimating process (Buchan et al, 2003). The traditional way of cost estimation is full of errors ranging from inception to operational phase even to post construction stages. This could arise from wrong interpretation of drawings as discussed earlier producing error-filled bill of quantities and generating incorrect pricing of those items of work. Hence the introduction of BIM in the UK construction industry as a digital innovation to assist in checking errors and improve standards, reduce clashes and consequently making construction processes error-proof.

3.5 CHALLENGES OF TRADITIONAL COST ESTIMATING AND BENEFITS OF DIGITAL QUANTIFICATION

Building Information Modeling (BIM), is a 3D, 4D or 5D digital construction design tool used for sharing information between designers, clients, owners, quantity surveyors, builders, estimators and any other stakeholders in a particular project (Howard and Bjork, 2008). It brings with it both great benefits and a few challenges in regard to cost estimation. BIM as a database of components in the design and construction of a building, can quantify accurately all the necessary materials required for construction while reducing greatly the margin for error (Haque and Mishra, 2007). With traditional estimating methods, the estimator would rely solely on the plans and specifications to make the determinations of what is required. Due to the multiple layers of digital drawings from CAD or the piles of papers from drawings, items on the architectural drawings may be duplicated in such places as the reflected ceiling plan, or the electrical lighting plan, and can be counted more than once. Another problem is that a key item may be overlooked by the takeoff specialist when it is drawn in by an architect as a design element. An example might be a back lit architectural detail that was never picked up by the electrical engineer. The detail would then get overlooked by the electrical estimator. It would then be the responsibility of the electrical contractor to provide it at his expense during construction.

With the multi-dimensional aspect of BIM, and the file sharing capabilities, everyone is able to see exactly what is contained in the project from a single dimensional image. This sharing feature is huge improvement over traditional methods. BIM is capable of providing the detailed design elements and quantifications needed by today's estimators and quantity surveyors and can reduce tender design enquiries as a result of virtual design interrogation (Mena et al., 2010). Typically, cost estimating done from quantification of manual drawing components was very time consuming: counting, checking and recounting. The counts from one firm could vary greatly due to human error and would carry over right through to the construction bid. These errors could prove quite costly if a job was awarded to a low bidder with incorrect counts on a high cost item. But with a model of the completed project, these oversights are rare and provide for a more accurate estimate and consistency from one estimator to another (Kraus et al., 2007).

BIM provides the estimator the ability to generate material surveys and cost estimates from conception through completion, with accuracy that can only be gained through a dimensional model (Kraus et al., 2007). Building information modeling takes into consideration the overall life of the building as well its future maintenance and use. This is helpful in preventing the equivalent product being accepted as a substitution for specified materials in the estimation, when the properties are actually different and building integrity would be compromised. BIM is an asset to the world of estimating as well as a landmark innovation in the building industry. Professional estimators know there is more to cost estimating in BIM than simple automation of estimating from objects to spreadsheets. Cost estimators also understand the challenges and obstacles beyond the technology that must be overcome if cost estimating is to become a viable dimension of BIM (Azhar and Brown, 2009). There are two basic aspects of BIM:

1. BIM is intended to improve industry efficiency and productivity with accurate and complete information.

2. BIM should support the entire lifecycle of a facility, and therefore information contained in the model should facilitate the work of all stakeholders. Cost estimating, 5D in BIM is emerging, and the industry associations of professional estimators are working together with the BuildingSmart Alliance (BSA) to define and develop processes in BIM that bridge the gap between traditional cost estimating and BIM processes. These associations include the Association for the Advancement of Cost Engineering, the American Society of Professional Estimators, and the Royal Institution of Chartered Surveyors (RICS). These group responds to the increasing demand for cost estimating, 5D in BIM. The traditional estimating process requires some changes in the process to produce valid and accurate estimates using BIM.

3.6 TRADITIONAL COST PLANNING

Cost Planning involves variety of procedure used by Quantity Surveyors and Building Economics. It is a difficult process to define since cost planning process is engaged at different phases of a construction process – Figure 3.4. It can be defined as the mechanism for assessing the cost implications of different design decisions, its main focus is to provide cost advice for design purposes (Kirkham, 2009). Cost planning process begins at the briefing stage and extends to the design stage then to production and operation (renovations and maintenance works). However, there are certain pointers to a good cost planning process – the variation between the tender figure and the first estimate should be very close and any likely difference between the two should be anticipated and within an acceptable range. The funds available for the project should be efficiently allocated to the elements and sub-elements. A good cost planning process involves the measurement and pricing of quantities at some stage of the process and should strive to achieve good value at the desired projected cost for the project. Cost planning starts with the development of a cost bracket for a prospective project allowing client to make an informed investment decision regarding project feasibility. Cost planning deploys elemental method which involves the cost planning and control that enables the cost of a scheme to be monitored during the various stages of design development (Kirkham, 2009). Ferry and Brandon (2009) described the cost planning process in three phases:

Phase 1 – Defining the brief and budget setting which is called scoping and framing in order disciplines. Cost planning at the briefing stage influences budgeting correctly and to a desired standard.

Phase 2 – The cost planning and control of the design stages/process. Decisions made at this stage are vitally important since it has a direct impact on the whole life performance of the project. Cost planning at the design stage - designing to the established budget

Phase 3 – The cost control of the procurement and construction stages. It is essential that the cost planning advice takes into considerations the impact procurement decisions will have on design and construction costs. Cost planning and control at production and operational stages controls the designed cost. Cost planning techniques deploys two efficient broad approaches – Elemental Cost Planning/Target Cost, Comparative Cost Planning:

3.6.1 Elemental Cost Planning (Designing to a cost)

This cost planning approach involves breaking down building into component elements and sub-elements usually using the Building Cost Information Service (BCIS) cost structure. The elemental cost planning approach is a system of cost planning and control that enables the cost of a scheme to be monitored during the various stages of design development (Kirkham, 2009). Elemental cost planning process relies on sketch plans and initial approximate estimates, cost allocated to each element based on cost analysis of previous projects of similar type. The sum of elemental costs must not exceed the total estimated cost (cost limit or authorised budget). There are three parts to elemental cost planning – The preliminary estimate, the elemental cost plan and cost checking. There are four principal levels comprising group element, element, sub-element and component providing basis of a codified framework for elemental cost planning. This is used both as a frame of reference for cost checking cost targets as well as the overall cost limit as design information evolves (RICS, 2013). Work breakdown structure (elements) and cost breakdown structure (cost targets) for building project are also supported by elemental cost planning.

3.6.2 Comparative Cost Plan (Costing to a design)

This approach of cost planning process evaluates different options (evaluation of alternative cost – effective solutions) that satisfy clients brief. The main aim is to showcase the distribution of costs and what other alternative solutions are feasible and regulates no rigid cost control limits. With this approach clients, design team and the contractors will have market solutions from which to 'mix and match' for optimum design solutions. In comparative cost plan, cost plans are agreed and checks are carried out as detailed design progresses – QSs engage in this solution reflecting the agreed requirement of the client. (Kirkham, 2009).

However, traditionally cost managers and/or QSs produce an indicative cost plan at the outset of a project and update it once or twice as the project develops and only costing completed designs at the end of a long iterative chain when design consultants have completed design. This makes cost control functions extremely ineffective in generating accurate cost information. With this manual approach undertaken during cost planning, there is limited input or function of a QS or cost managers with increase in data drop as the design evolves (BSI, 2014). Design queries associated to elemental cost and an eventual total project sum are undermined. BIM cost modelling process is envisaged to engage the cost professionals right from the outset and on an equal player within the project team. Painstaking manual take offs at the project later stages is avoided and reporting a faster more accurate cost information effectively and upfront. This is perceived to have capabilities to maintain a living cost plan and potentially support project design team to design to a cost (target cost planning or elemental cost planning) rather costing a design (comparative cost planning) which has proven inefficient in helping clients save money and maintain cost ceilings at varying data drops – Figure 3.4 (BSI, 2013).

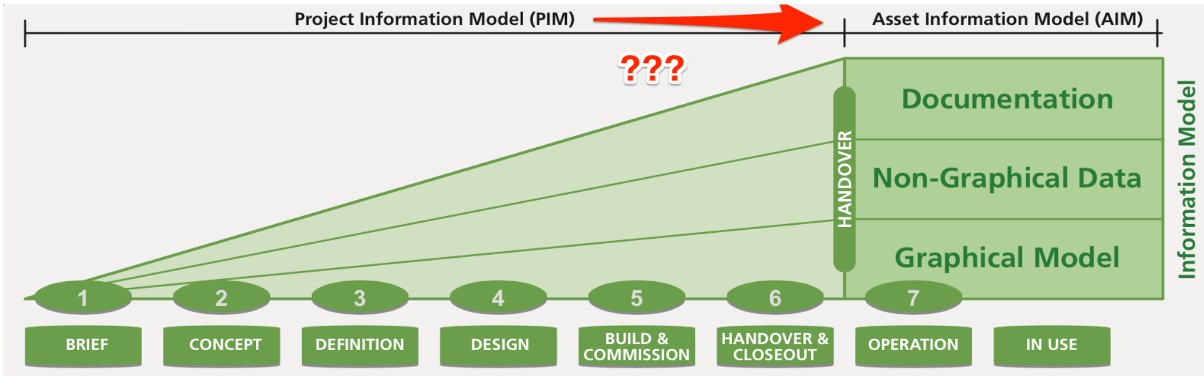


Figure 3.4: Information Delivery Life Cycle. (Adapted from BSI, 2013)

3.7 COST MANAGEMENT

Cost management provides value for money (VFM) for the clients. It is the total process which ensures that the contract sum is within the client's approved budget or cost limit, the process of helping the design team design to a cost rather than the QS costing a design. It ensures the planned development of a design and its procurement process for a project is within the expected client limits (Potts, 2008). Benefits are the major drive for construction projects. This benefit may be for public projects with justification based on a cost-benefit analysis or basically for private projects driven by financial considerations. Most clients work within tight pre-defined budget, which often are a part of a larger overall scheme. If budget is exceeded or the specified quality not met the scheme could fail. Pre-contract estimate sets the original budget, forecasting the likely project cost to the client. When defining a cost estimate of a project, many factors come into play ranging from – land acquisition and its legal costs, site investigation, enabling works, decontamination, insurances, consultations fees, contingency and risks (Nagalingam et al, 2013) etc. Cost control is to be exercised before any project commitment is established. If uncertainties are predominant in a project, cost estimate is more difficult.

Estimates of the cost and time are prepared and revised at many stages throughout the project cycle (Potts, 2008). Construction cost estimate should not be considered 100% accurate because it is all predictions but the accuracy is bound to improve as the design develops. The level of scope of work definition and the degree of uncertainties and risks will define the extent of realism and confidence achieved (Potts, 2008).

3.8 BIM AND 5D COST ESTIMATING

The cost estimating process involves performing Quantity Takeoff (QTO) and adding cost data to the QTO list. Traditional QTO process with CAD drawings is about selecting individual elements in CAD drawings, using the software to automatically determine the dimensions for the take-off, and inputting the quantities into the QTO list (Khemlani, 2006). This process requires estimators to spend substantial amount of time on generating the QTO of the entire drawing. Since the selecting and measuring processes are all based on manual operations, the errors and omissions happen during the QTO process. The construction industry is unique where contractors need to guarantee a price to owners before they know the actual completion cost. The calculations are conducted before the project actually starts and this will require a higher level of accuracy during the estimating process for contractors. On the other hand, BIM models are object-based model components with geometric information, it is therefore easier to capture the quantities of the objects in BIM and the QTO with BIM model will be more accurate with less errors and omissions. The QTO process is also expedited– it can require 50% to 80% of a cost estimator’s time on a project (Rundell, 2006). QTO process can be enhanced digitally with higher accuracy and less time using BIM process and appropriate software tools. With model mapping of generated item quantities aligned to cost database and linked to BIM models or a standalone external cost database, estimators can generate a more accurate and reliable cost estimate of the building with minimal effort.

BIM conveys two concepts: the process of a shared development of the design and the collective object components, and the 3D virtual model produced using BIM enabled technologies. This model is composed of objects that represent different elements of the building, and property data related to each object. These data could be linked to both produce and simulate construction programmes called 4D BIM application and work space planning or to produce 5D cost information for cost estimating. BIM-enabling software programs use parameters and rules to determine the geometry, as well as non-geometric properties and features of objects (Eastman et al., 2011). Type and cost of materials, cost of elements or assemblies are features which can be assigned to each object of a BIM (model). On the basis of the model, quantities and numbers can be extracted. But, according to Eastman et al. (2011): "No BIM tool provides the full capabilities of a spreadsheet or estimating package, so estimators must identify a method that works best for their specific estimating process. Three primary options to consider in an attempt to digital estimating functions are to export building object quantities to estimating software, use a BIM quantity take-off tool like CostX, CostOs, or Vico or link the BIM tool directly to the estimating software". Options present different levels of interoperability. In the first two options, data are extracted from the model by exporting them using a format that could be read by a cost estimating software, or on the second case, the estimating software has the ability to map BIM objects with the cost database. These offer little or no interoperability capabilities to automate the exchange of data between the model and the BIM-based estimating.

3.9 BIM ASSISTED COST ESTIMATING TOOLS

BIM has the ability to allow early cost estimation initiation in the design process and as well provide cost effects of additions and modifications with potential to save time and money and avoid budget overruns. A flexible process which allows designers to be aware of the cost effects of their changes early enough to help curb excessive budget overruns caused by modifications. Cost estimation using BIM focuses on more value adding activities in estimating (identifying construction assemblies, generating pricing and factoring risks) which are the essentials of high quality estimates, saving estimator's time to focus on more valuable issues in an estimate since take-offs can be automatically generated. The AEC industry has realized the importance and the hidden value that can be generated through collaboration and integration and as a result the construction industry is stepping into an era of construction process revolution spear-headed and driven by integration vision (Karasulu et al, 2013).

Consequently, digital cost estimating has become essential within the construction industry process and for a project to attain success, cost accuracy is critical. Quantification for building or infrastructural projects is time consuming when traditional cost estimation is deployed and there are inevitably human errors and poor coordination of information involved in this process (Sabol, 2008). The processes of estimating such as quantity generation and pricing of those quantities could be an integrated collaborative process at the outset of the design phase where a link to cost information within the model is established using relevant BIM and costing software (Sattineni, 2011). "BIM has proven to offer great advantages, over traditional estimating methods" (Nassar, 2012). The visual model of all the objects imported from a BIM model could be provided by technological tools like Innovaya, Navisworks, CostX, CostOS and this creates an easy to use version for estimators having to learn all of the features contained within a given BIM tool (Eastman, 2011). 5D BIM based workflow software like Vico supports data from other software including Revit, Tekla, MS Excel, etc. Vico possesses the ability to use quantity take-off data to define time and cost and it is very effective tool in project control phase (Vico Software, 2013).

As BIM becomes more prolific in its application, there is starting to become an increase in the usage for cost estimation. This in turn has led to an increase in the number of software tools available which utilize the BIM dataset for automated (or semi-automated) quantity take off and costing (Table 3.1). These tools are proliferated on the premise that BIM assisted costing generates accurate material quantities, allows necessary revisions, and stays within budget constraints (target costing) while design progresses. It engenders visual representation of project and construction elements that need to be estimated; provide cost information to the client on the early decision phase of design and explore different design options and concepts within the client's budget (Bloomberg et al., 2012). Several available software tools enable automatic quantification (Deutsch, 2011) and the production of schedules (Woo, 2007), which will largely eliminate the need for manual take-off of buildings during estimating. Wu et al (2014) presented an analysis of four of the most prominent tools used in the UK QS sector. Each of these tools were assessed against seven specific criteria including information exchange protocols, quantification processes and the output report created. One of the tools reviewed was Autodesk QTO and this product has since been discontinued and functionality included in the Autodesk Navisworks tools. The work concluded that whilst the tools provided a range of useful functionality, additional work was required to ensure that they supported the UK practice. To further build on the work of Wu et al (2014) and as the development of 5D focused tools continues to evolve, below is an overview of the tools currently available to support QS practice with BIM. Table 3.1 provides a snapshot of a comparative list showing current 5D costing tools as linked with BIM. This gives a good understanding of the technological tools available for use in BIM processes and includes a review of their data input approaches, classification approaches implemented and output data provided. Whilst it is acknowledged that this does not develop an in-depth analysis of the tools, it does provide an overview of tools available and their technical capabilities. From the review undertaken, it can be noted that the use of IFC is now becoming common place amongst 5D BIM tools. This follows the increasing use and acceptance of IFC as a critical approach in the BIM workflow.

Table 3.1: Current 5D costing tools as linked with BIM and cost data

Software	Input file format	IFC Compliant	Manual Take Off	Automated Take Off	2D QTO	3d QTO	Classification system	BOQ Creation	Cost Database	URL
Nomitech CostOS	Ifc, pdf, dwg	✓	✓	✓	✓	✓	NRM CESSM	✓	BCIS	http://www.nomitech.eu/cms/c/bimestimating.html
Innovaya	inv, ifc, dwg, dxf, dwf, rvt	✓		✓	✓	✓	NRM	✓	BCIS	http://www.innovaya.com/
Primus IFC	Ifc, excel.xlsx, word.docx, primus.dcf	✓		✓		✓		✓		http://www.accasoftware.com/en/bim-quantity-takeoff/
Exactal CostX	Dwf, dwfx, ifc	✓		✓	✓	✓	NRM	✓	BCIS	https://www.exactal.com/en/costx/page/us-estimating
BIM Measure	Dwf, dwfx, pdf, ifc			✓	✓	✓		✓	BCIS	http://www.causeway.com/BIM-Manager/BIM-Measure
Beck Technology (DProfiler)	Ddb, ifc, google earth	✓		✓		✓		✓	BCIS	http://www.beck-technology.com/product_dp.asp
Vico Software	Ifc, revit, Tekla, archiCAD	✓		✓	✓	✓	NRM	✓	BCIS	http://www.vicosoftware.com/
Bentley AECOsim	dgn, ifc	✓		✓	✓	✓				http://www.cadventure.co.uk/bentley/aecosim-building-designer
Navisworks	ifc, rvt, dwf, pdf, dgn, other popular card formats	✓		✓	✓	✓		✓	BCIS	http://www.autodesk.com/navisworks
Solibri model Checker	ifc,dwg, pdf, excel, rtf	✓	✓	✓		✓		✓		http://www.solibri.com/solibri-model-checker.html

3.10 CHALLENGES OF 5D BIM IMPLEMENTATION

3.10.1 Standards for Coding

One key issue that arose from a review of existing work in the BIM field focuses on the lack of standardized methods for coding within the BIM Environment. From a design point of view within the UK, the Uniclass standard from the NBS (NBS, 2016) is the most prevalent method of coding objects during the design stages of a construction project. This supports most aspects of construction elements, however, it is focused on the design aspect and there is no specific requirement at the moment to integrate the costing coding mechanisms within the BIM during the design phase. In particular, the New Rules of Measurement (NRM suite) needs to be fully integrated into BIM from an early stage of the design to support cost estimation from the initial concept stage throughout the life cycle of the project.

3.10.2 Lack of 5D BIM Protocols

BIM Execution Plan (BEP) is vital in delivering information uniformity from project inception (strategic brief and definition). The information generated is project specific reflecting Employer's Information Requirements (EIRs) and developed in conjunction with all project participants – internal and external. "By utilizing the RIBA-DPoW across all professions, we are better able to manage project deliverables, developing individual discipline models coordinated and guided by the BEP" (Kell and Mordue, 2015). The level of detail (graphical data) expected to be delivered at each workstage is largely defined by a key interdisciplinary guiding document – Design Responsibility Matrix

(DRM) which is a key resource in project and design development. The DRM is a guiding resource for outputs at different workstages, defining the level of detail needed at each workstage and the ownership of each building element. It is always a good practice to define the contractual deliverables early in the project as basic design requirements – constituting clear definition to the team on workstage deliverables, the time needed for the deliverable and the purpose of the information (Mitchell, 2012). All UK-centric developed project standards are with a single purpose of building up confidence, that design development, workstage outputs and project collaboration can be uniformly delivered. With advanced degree of "NBS Digital Toolkit" establishment, the QS and Cost Managers is expected to gain a good level of understanding towards digital cost information development and efficiencies in overall project lifecycle creating ultimate commonality across the industry. Developing an industry baseline for information delivery and checks will activate means of confirming compliance against a set of project defined deliverables, more coordinated data-rich information, aligned LODs and LOIs standards - driving efficiencies in the design, construction, and operation of built assets and increasing reliability on information quality (Mitchell, 2012). It is a good practice to define information requirement at each workstage throughout the design and construction phase for greater project and cost efficiency. The QS and Cost Managers can deploy LODs and LOIs as workstage baselines or check mechanisms to confirm compliance of various agreed workstage outputs (given agreed BEP), reflecting client's brief at the commencement of the project. The principle can be further engaged across disciplines to confirm the LODs and LOIs agreed requirements against each building element at various workstages for cost information. The graphical information represented in the design has a direct effect on the non-graphical information as the greater the graphical items, the more data are available when viewed within costing software (RICS, 2014). To populate design stages, with the required cost information and avoiding high LOD model objects; it is extremely important the QS and the cost managers understand the existing relationship between RIBA-DPoW stages and NRM classification requirements (Appendix E). The output of cost information at each stage is apparently the design inputs at that stage, therefore to avoid the common issues of designing to the correct level of detail in BIM projects – it is imperative for the QS and cost managers in collaboration with the design team to regulate information uniformity (LODs & LOIs) at each stage of the digital plan of work using agreed BEP that is project specific. Adopting a consistent early defined object naming protocol (like NRM object descriptors) allows successive developments in the model to align cost comparisons through the cost plan stages as well as benchmark costs across projects against held data (RICS, 2014). Once successfully implemented, digital quantity extraction is made easy then the QS and cost managers can have their value add in interrogating design deficiencies and queries with reference to client brief rather expending so much time in quantification. The BEP has to be tailored to address project needs.

3.10.3 Level of Detail / Definition

Level of Development is the degree to which the element's geometry and attached information has been thought through; that is the extent or degree of reliability of the project team members on the model information (project data) when using the model (reliable output), (BIMFORUM, 2013; RICS 2015). Level of Development as defined in the UK PAS1192 documents as a combination of Level of Detail – amount of graphical information included in the model element and Level of Information (LOI) - non-graphical information (such as spatial, specifications, performance, certifications, workmanship, standards etc) is the description of the model information throughout the project and develops alongside level of detail as the model progresses.

The UK Government drive towards BIM implementation did not alter to a greater degree the underlying principles required to effectively manage project designs and delivery processes. The changes are however embedded in the technological process which requires effective and proficient management skills to harness its overall benefits. The challenges of design management across individual disciplines do not vary significantly in comparison with BIM processes within existing design process; manual drafting, 2D, CAD and BIM – the communication requirement for information flow is still same but the technological influenced standards in BIM however delivers a more structured, managed and efficient information sequence with little or no risks and consequently improving outcomes (Kell and Mordue, 2015). Providing digital information that is consistent at same level across design stages; establishing a collaborative work practice among project stakeholders is the basic change required to achieve level 2 BIM. It then follows that standardization across design board and workstages will support equivalent information output for all project stakeholders (internal and external). The structured framework and organization for design deliveries and methodologies developed by RIBA called RIBA-DPoW is a vital resource to achieving uniformity of information across design development and/or design progression – thus engaged to optimize design/information outputs. The defined workstages (stage 0 – stage 7) and equivalent outputs at each stage reveals the intended level of detail (geometric or graphical data) to be delivered by each design discipline across workstages (Kell and Mordue, 2015). According to Kell and Mordue, (2015), there is far greater need for common, aligned geometric and information outputs if BIM benefits must be harnessed and achieved. Industry needs to agree on how to exchange data effectively and consistently throughout the project phases on a discipline to discipline basis – both geometric and non-geometric (level of information - non-graphical data). The geometric design development and resultant information output at various workstages must be aligned for other BIM uses like quantification parameters, digital measurement, and energy analysis to be achieved. The UK construction industry needs a robust and reliable means of exchanging digital information that is readable, easy to check and to validate at each stage of development since recent interviews with the industry practitioners revealed current issues around data exchange and interoperability (IFC) that must need to overcome and IFC's inability to serve as medium for all model file exchange and transportation due to file format variations. Developing an open system and standardized data libraries of knowledge for generic use for certainly support effective benchmarking and collaborations (Pittard and Sell, 2016).

3.10.4 Issues of Upskilling Existing QS Workforce

BIM has taken the construction industry towards a new paradigm and the education sector is catching up with the changes required. Initiatives such as the UK BIM Academic Forum and the UK BIM Task Group Learning Outcomes and the inclusion of BIM within a range of professional benchmarks have led to the inclusion of the concepts, philosophies and technical knowledge of the BIM process being included in curricula. However, this is somewhat ad-hoc at the present time based on previous research

(Underwood et al, 2015). In particular, there is little reference to how those involved with the cost and 5D element of BIM should engage through existing curricula. In order for the sector to develop the next generation of QSs' and Cost Consultants, more is needed to formalize the delivery of 5D both with existing courses. In addition, the collaborative nature of BIM also requires a shift in the teaching and delivery of all construction courses to ensure that subjects such as cost estimation and cost management are not taught in isolation but are seen as an integral part of the construction process and delivered via a collaborative mechanism.

In addition to teaching the philosophies, students currently engaging in academia and those already within the industry have a need to be upskilled in the use of the latest tools and technologies available. This will strengthen BIM education and awareness of digital demands in today's strategic and operational industry practice. This must be a strategic decision from higher level management who has an understanding of the benefits of 5D BIM integration into within a project life cycle.

3.11 EMERGING RESEARCH FOCUS TO SUPPORT SEAMLESS 5D BIM IMPLEMENTATION

As BIM becomes a more prolific methodology of working for the construction industry, so academic and industry led research develops. An extensive review has been undertaken on emerging research initiatives in the field of BIM usage for 5D costing activities within the construction sector. Overall, four broad research areas were identified, according to their particular areas of application:

- Quantity Take Off
- Industry implementation
- Cost Estimation and Management
- BIM and QS Education

3.11.1 Quantity Take off

One key area where BIM has been purported to provide a significant amount of benefit is allowing a more automated quantity take off from the 3D model. The use of BIM within a project will lead to less effort being required for quantity take off as more becomes automated from the 3D model (RICS, 2014; Goucher and Thurairajah, 2013), however others are more hesitant at the promises of the process due to the design models being unsuitable for the QTO process (Aram et al., 2014). The issue of automated quantity take off has received attention from researchers and is also an issue reported in industry based research as report later in this paper.

Cheung et al. (2012) discuss multi-level cost estimation and how this can be developed automatically from the 3D model. Focused on the conceptual design stages of a construction project, the proposed tools automatically extracts data based on the NRM format and provides the ability to deal with multiple levels of detail of the geometric model and thus provide more defined cost estimates as the design of a project develops. Wu et al., (2014) note that the level of detail of a model and the level of information can have a significant impact on quality of the cost estimate. The issue of the level of geometric data required to produce more accurate cost estimates is also considered by Monteiro and Martins (2013) who also discuss some issues surrounding automated extraction of quantities from the 3D BIM. Noting that the QTO process cannot be fully automated due to the model often not providing an 'accurate representation' of the building. It is noted that there is a fine balance to be established between the level of graphical detail of the model needed to produce accurate quantities and the usability of existing software tools as the data sets become more complex. These issues surround the use of 5D within the realms of QTO can therefore lead to inaccurate and thus cannot be relied upon for detailed cost estimates (Wang et al., 2014).

Automation of QTO through the implementation of the Industry Foundation Classes (IFC) and open BIM approaches has also received attention from research efforts. Noting that this can still be hampered by the issues surrounding the detail of the model objects (Monteiro and Martins, 2013). Choi et al (2014) propose the use of the ifc property sets such as ifcValue and ifcVolume to measure and deduce data from the 3D model, and these can then be input into systems to generate cost estimates. Whilst this supports the openBIM concept, there is still need for some significant manual input and this would increase as the complexity of a project and the subsequent model developed. To attempt to overcome the issue of manual requirements during the QTO process, Aram et al (2014) discuss the development of a knowledge based approach to implementing QTO from a Building Information Model. Noting that the geometric model itself often does not contain the correct level of detailed information to instantly automate the QTO process, this study discusses the development of a knowledge base, which allows rules to be applied to objects to develop knowledge about the product and how it can be quantified. Rajabi et al (2014) also concur with this approach and solve the issue of lack of model detail by allowing the user / estimator to take off where available and also add additional detail within the BIM authoring environment using logic based reasoning.

Wijayakumar and Jayasena (2013) highlight the issue that whilst there are a range of tools available to automate the QTO process from a BIM, the data that is derived is not always accurate or in the correct format. Citing examples of extracting linear wall lengths as an example, the wall can be measured from the centerline or the outside thus proving differing area calculations. If unchecked during an automated process this can present substantial inaccuracies in the costing further downstream in the process. However, Whang and Min (2016) claim that using BIM the results of the QTO are more accurate when compared to those undertaken via a traditional manual approach. However, this study was focused purely on building frames and thus the results could be isolated when compared with a more holistic take off from a complete model of a facility.

3.11.2 Industry Implementation

Just as BIM within the wider construction sector has received considerable attention with respect to strategies for implementation and methodologies for successful exploitation, the area of industrial based 5D research has been investigated by several authors. Smith (2014) postulates the 5D role of the cost manager with responsibility for managing a living cost plan which evolves as the project design and construction develops.

In a study by Smith (2014) highlighted that within the industry context, practitioners identified several issues which are hindering the implementation of 5D BIM. The quality of the Model, the ability to automatically take off quantities, lack of compatibility between software and the sharing of cost data were amongst some of the issues cited in respect to current approaches to 5D BIM implementation. This work was based on the review of the industry in Australia, however other studies such as (Plebankiewicz et al., 2015) have highlighted similar issues in Poland in addition to noting that a lack of classification systems in this region is also an issue in the application of 5D. The development of BIMestiMate (ibid) has been presented as a method to support the Polish construction sector in applying 5D to projects across the whole life cycle.

Tatt et al. (2016) identify the requirement of change in culture and current practice are required in order to manage the implementation of BIM within commercial Quantity Surveying practices. Using Kotters 8 stage change model as a mechanism to drive change in the Malaysian, it is proposed that the process begins with creating a sense of urgency for the implementation of 5D BIM. With this in mind it could be argued that in several countries where government initiatives have driven BIM this aspect has been provided, however often barriers are still in place that prevent proliferation of 5D usage. Often several of these barriers are cultural as previously highlighted, where other researchers such as Frei et al. (2013) have suggested that technological advances such as those presented by BIM threaten to reduce the role of the QS which could further compound this cultural issue. In a review of QS professional practice in South Africa, Monyane and Ramabodu (2014) note that whilst 5D is not widely used in the industry, a large number of those polled accept the potential benefit to managing cost throughout a project, however professionals still noted issues could arise from legal challenges and there was still some who believed that it could threaten the viability of the QS profession. The issue of cultural change within a company is also discussed by Sattineni and Macdonald (2014) who note that during a case study of 5D implementation in a US company citing reluctance to embrace a new methodology but also noted a lack of drive from the client side. The lack of client demand was also highlighted by Zhou et al (2012) who focused on the plight of SME's within the UK and Smith (2015) from an Australian perspective. This noted that at the company level demand, resource and training were key barriers to 5D BIM implementation but at project level, again highlight the issue of technological integration between tools and interoperability. Alongside company level demand, training for professionals is also a critical issue to ensure company implementation is appropriate and consistent (Keat, 2013).

In a survey of practitioners within the New Zealand Quantity Surveying, Stanley and Thurnell (2014) report that collaboration is deemed to improve when using BIM but many are less convinced that the application of 5D will lead to more efficient quantity take off or more efficient generation of cost plans. There is suggestion by those in the industry that the lack of software compatibility is an issue as is the lack of protocols for object coding within models and a lack of standard for use of 5D BIM implementation. Boon and Prigg (2012) also found that digital tools for QTO were not used in a New Zealand context but also that no systematic approach to coding is an issue when BIM is implemented.

Using automated quantity take off from a technological point of view, can sometimes lead to overestimation due to model accuracy, which can cause problems and suggesting early collaboration of the QS within the BIM process as a solution. Smith (2015) noted issues surrounding automated take off by practitioners noting that often the quality of the documentation was the biggest cause of problems in implementing automated methods. This is leading to a lack of trust in the cost based data derived from 5D BIM based on information reliability (Kulasekara et al., 2013). Early integration and constant collaboration of the QS into the project (Popov et al., 2008) and particularly the modelling aspect would allow input into the model development to ensure fitness for purpose and ensure that a reliable BIM database is available for cost estimates and cost management by the industry (Ismail et al., 2016; Taihairan and Ismail, 2015).

3.11.3 Cost Estimation and Management

Mitchell (2012) notes that whilst cost estimation is critical to any construction project, very often the concept of 5D BIM is purely seen as an approach to digitally take off quantities from models. This study notes that in following this approach definitive costs are not derived until later in the design / modelling process, no real time cost plan data is derived and fed into the design process and this still leaves the cost aspect as a separate entity which is contrary to the fully collaborative multi-disciplinary focus of BIM. Ma and Liu (2014) propose the development of a system that can automatically acquire construction information from a BIM data set and then subsequently use this in order to underpin construction cost estimation. This would require additional information such as construction methods and equipment to be derived from the BIM in order to develop the cost estimation. Whilst this gives a more holistic approach to the requirements to construct elements, it is still in need of a system which contains dynamic heuristic knowledge to develop construction approaches. Lee et al. (2014) further explain the development of an ontology based method to derive work items. The ontology approach utilized and IFC and xml approach to develop work items, which can then form part of the take-off procedure to develop a full bill of quantities. At the moment this approach was limited specifically to tiling activities however the approach was scalable.

Mitchell (2012) therefore suggests that costing and 5D is built in to the project from concept stage by building in elemental cost data into the lower level of detail BIM objects. Bukhary et al. (2015) support this approach noting that BIM requires a richer level of information at the early design / concept stage to allow more accurate cost estimates. It was also noted that the sharing of information underpinned by the philosophy of BIM would improve cost estimation at the early stage. The QS will therefore need to engage in the BIM process early in order to fully utilize the data available for early cost estimation. Popov et al. (2010) further this concept by presenting a computer aided evaluation system to allow construction cost to develop as the project progresses through design into the lifecycle management of the asset.

Managing cost throughout a construction project lifecycle is critical and often, as reported earlier, 5D BIM is focused on the cost estimation stage of a project. Lu et al (2016) argue that where BIM has been used for cost management, it has primarily focused on the outflow of cash during a project, however the actual outflow is not taken into account during 5D – leaving out many issues such as retention. The study argues that in order to be fully effective, a 5D model should include for inflow and outflow during the simulation. Thus a framework and prototype is presented that can incorporate other issues into the 5D model such as mobilization, payment lag and retainage.

Smith (2016) notes that one of the key issues surrounding cost management is the modelling standards for BIM, and how these impact cost managers. These are often overcome through the development of collaborative working relationships with project designers, however this is ad-hoc and there is not consistent approach for this. LOD is highlighted as a key consideration, as is the issue of the modelling of existing buildings and it calls for a global BIM standard to support cost management. Mitchell (2012) notes that post construction, cost data can still be utilized for the life cycle management of a facility by incorporating cost data (minus construction cost information) into the as built model in preparation for the operation and asset management process.

3.11.4 BIM and QS Education

As BIM is becoming more mainstream in its' global use within the construction industry, Academic programmes around the world are having to adapt to ensure that the knowledge and skills required are embedded within the curriculum. The application and emergence of 5D BIM is no different to this, with Quantity Surveying and broader management courses now needing to embed the subject of BIM and more specifically issues around 5D and digital quantity take off and measurement. The issue of how best to teach these topics are becoming an increasing focus of attention with major national initiatives such as the UK BIM Academic Forum Underwood et al. (2015). The UK BIM Task group (2012) developed a range of learning outcomes which include issues surrounding both capital cost and life cycle cost of an asset. In particular there are aspects focused on preparing estimates, use of BIM within tendering and cost control. Wu and

Issa (2013) noted that the QS profession and in particular estimators will be required to fully comprehend 5D BIM and this will start with the education

Monson et al., (2015) propose the use of a flipped learning methodology in order to engage undergraduate students in understanding 5D BIM and in particular the concept of digital quantity take off. The concept of flipped learning allows students to 'watch' lectures outside of the classroom setting and then take part in practical exercises during class contact time. In this regard students engaged in projects to undertake initial and then detailed cost estimates and virtual take off using Autodesk BIM tools. This approach and the focus on lab based working appeared to provide benefit and highlighted a greater level of understanding of the concept of 5D BIM. Kozlovska and Spisakova (2013) further the concept of teaching 5D as a distinct topic and propose an approach to teaching 5D within the framework of an integrated construction project. Bringing together different disciplines during the education stage will seek to help the better implementation of 5D as students will become more knowledgeable of this collaborative method and should seek to remove some of the obstacles identified during industry implementation of 5D in the previous sections

3.12 CHAPTER SUMMARY

This chapter is a comparative critical investigation of the traditional costing approaches for measurement, cost estimation and cost planning considering challenges and issues surrounding traditional processes vis-à-vis BIM based cost estimating and cost planning strategy. It investigated 5D digital quantification and implementation issues and found issues around non-coding standards, lack of 5D BIM protocols, level of details and level of information, issues of upskilling the existing working dynamics and working practises of cost professionals. It re-established that the emergence of BIM in the UK construction industry as a digital demand for workflow transparency and collaboration is changing and redefining the roles and working practices of a multi-disciplinary project team with particular reference to the changing role of cost professionals. Just as the cost estimating process involves performing Quantity Takeoff (QTO) and adding cost data to the QTO list to generate a competitive tender sum. A process that requires the quantity surveyors, cost consultants or experienced estimators to spend substantial amount of time generating quantities of the entire drawing using varying estimating techniques. Measuring and selecting processes as currently practised in the industry are all based on manual operations, hence consistent errors and omissions during take-off processes leading to inaccurate tender price.

With the uniqueness of the construction industry demanding the contractors to guarantee a price (a formal quotation) to owners before they know the actual completion project cost, it then becomes imperative to generate a higher level of cost accuracy during the estimating and planning process. Literatures reveal that digital cost estimation and cost planning with appropriate BIM tools are required to guarantee such high level of cost accuracy. Therefore, 5D BIM cost models on the other hand are object-based model components with geometric information (object properties) and it is easier to capture the quantities of the objects in BIM costing software with model take-off generating a far more accurate cost information less prone to errors and omissions. An expedited process according to literature findings converting 50-80% working time of cost professionals to a more efficient productive cost functions and improving collaborative workflow. Enhanced accuracy and less time using BIM process and appropriate software tools to increase cost benefit realisation. With model mapping of generated item quantities aligned to cost database and linked to BIM models or a standalone external cost database, cost professionals will be able to generate a more accurate and reliable 5D cost information from a design (dwg, ifc, dwf, rvt, pdf etc) with minimal effort. Literature also unveiled few other emerging research areas which when investigated has ability to support a seamless 5D BIM implementation. Based on the above literature findings, the research questions, aims and objective, the next chapter will look into the most appropriate research methodology and a suitable data analytical process to further the study.

CHAPTER FOUR

RESEARCH METHODOLOGY

4.0 INTRODUCTION

Having carried out an extensive literature review of existing work in the UK construction industry covering existing publications and articles in the field of Building Information Modelling (BIM), UK current industry practice relative to both traditional and digitization of construction practice, traditional cost estimation and cost planning and BIM based cost estimation and cost planning. This chapter is set out to explore research methods of inquiry and to choose the best strategy of inquiry capable of addressing the gap that informed the study under investigation.

4.1 RESEARCH PHILOSOPHY

Theoretical perception are underpinned and observed and this is evident in all research investigation (Jankowicz, 2005). Philosophical challenges are required to be given extensive consideration since it’s embedded in every research process (Coghlan & Brannick 2010). Douglas (2003) defined epistemology as the philosophy of knowledge. Further argument on the subject of epistemology from Johnson and Duberley (2000) expounds the settings and boundaries of a justified knowledge. Collis and Hussey (2003) had the opinion and paradigm stating that epistemological assumption stimulates reflexivity. Coghlan and Brannick (2010) believed that reflexivity is a theory that examines the relationship between the aim of an investigation and the investigation itself. This is used extensively by social scientists. Epistemology as a philosophical knowledge is used in the field of study - the stance of this philosophy of knowledge can be positivist, realist or interpretivist (Schwab, 2004).

4.2 APPROACHES TO RESEARCH INQUIRY

There are basically three different inquiry strategies according to Creswell (2009 and 2013, Creswell and Creswell, 2018) – Quantitative method (postpositivist worldview, experimental strategy of inquiry, and pre and post-test measures of attitude), Qualitative method (constructivist worldview, ethnographic design, and observation of behaviour, participatory knowledge claims) and Mixed method approach (pragmatic knowledge claims, sequential, concurrent and transformative); to doing a research considering what the intending research is due to address or what research problem exist or research questions to be answered. All these contribute to the strategy of inquiry adopted in a research study. In qualitative research study, according to Morse (1991) he argues that part of the characteristics of a qualitative study is a) immature concept due to an obvious lack of theory and previous research, b) a notion that the available theory may be inaccurate, inappropriate, incorrect, or biased; c) a need exists to explore and describe the phenomena and to develop theory; or d) the nature of the phenomenon may not be suited to quantitative measures. The approach in qualitative may be less inductive while relying on the perspective of the participants, they may further be written from a personal subjective point of view where the researcher positions himself or herself in the narrative (Moustakas, 1994) but the quantitative research study is more objective with less variation and addresses a research problem by understanding how variables or factors influence an outcome. Quantitative research strategy supports the investigator, or the researchers understand and explain the problem with the factors that explain or relate to an outcome. A quantitative research is written from the impersonal point of view to reveal objectivity (Creswell, 2009 and 2013). A mixed method deploys either the qualitative or the quantitative or the emphasis might tip in the direction of either of them and in some other cases the emphasis will be equal between qualitative and the quantitative strategy. To further examine the quantitative, qualitative and mixed method research strategies, it is necessary to justify the adoption of qualitative strategy as against the quantitative method of inquiry also in this chapter.

4.3 QUANTITATIVE RESEARCH

In the late 19^{th} and throughout the 20^{th} century, strategies of inquiry that associated with quantitative research were those that invoked the postpositivist worldview (Creswell, 2009). These include true experiments and less rigorous experiments called quasi-experiments and correlational studies (Campbell and Stanley, 1963). Quantitative research is described by the terms ‘empiricism’ (Leach, 1990) and ‘positivism’ (Duffy, 1985). It derives from the scientific method used in the physical sciences (Cormack, 1991). This research approach is objective in nature. It is defined as an inquiry into a social or human problem, based on testing a hypothesis or a theory composed of variables, measured with numbers and analysed with statistical procedures, in order to determine whether the hypothesis or the theory holds true (Creswell, 1994). By theory we mean ‘a set of interrelated constructs (variables or questions), that presents a systematic view of phenomena by specifying relationships among variables, with the purpose of explaining natural phenomena (Kerlinger, 1979). The systematic view might be an argument, a discussion or a rationale that helps explain phenomena that occur in the world (Creswell, 2009). They are formal systematic process in which numerical data findings are hard and reliable. The data are therefore not abstract they are reliable, measurements of tangible, countable and sensate features (Bouma and Atkinson, 1995). It describes, tests, and examines cause and effect relationships, using a deductive process of knowledge attainment (Duffy, 1985). Quantitative research is used when we want to find out facts about a concept, a question, or an attribute. It is also used when we want to collect factual evidence and study the relationship between facts in order to test a particular theory or hypothesis.

4.4 QUALITATIVE RESEARCH

Qualitative procedure demonstrates a different approach to scholarly inquiry than methods of quantitative research. It deploys different philosophical assumptions, strategies of inquiry and methods of data collection, analysis and interpretation. This method of inquiry possesses unique steps in data analysis, relies on text and image data, draws on diverse strategies of inquiry (Creswell J., 2009). Qualitative research is subjective in nature (Naoum, 2013). It emphasises meanings, experiences (often verbally described), and description and so on. Qualitative research can be classified into exploratory and attitudinal (Naoum, 2013). Exploratory research is engaged when the researcher has limited exposure to the amount of knowledge about a topic. In this method of qualitative, interview technique is usually adopted as a data collection method (Naoum, 2013). The purpose of explanatory research is intertwined with the need for a clear and precise statement of the recognised problem. Researchers conduct explanatory research for three interrelated purposes: diagnosing a situation, screening alternatives and discovering new ideas (Zikmund, 1997). The raw data provided in exploratory research is exactly what the people have said in an interview or recorded conversation or a descriptive of what has been observed (Creswell, 1994). Attitudinal research is used subjectively to evaluate opinion, view, or the perception of an individual towards a particular object. Object here is referred to as an attribute, variable, factor or a question.

There are characteristics of a qualitative research which includes but not limited to natural setting where the researcher tend to collect data from the site or the field where the problem under study is examined and the participants has a direct experience of the issue under study (Creswell, 2009). They have face-to-face interaction over time. In qualitative study, researchers are key instrument and they collect data themselves through observing behaviours, documents and interviewing participants. There is no reliance on questionnaires or instruments developed by some other researchers (Naoum, 2013). There are multiple sources of data like interviews, documentations, interviews rather than relying on a single source of data (Creswell, 2009). Emergent designs, participants' meanings, holistic account (complex picture of the problem or issue under study developed), interpretive, theoretical lens and inductive data analysis where the qualitative researchers build their patterns and themes from the bottom up, by sequencing the data into an increasing abstract unit of information (Naoum, 2013). Qualitative researches build their themes; patterns and categories, working back and forth between the themes and the database until the researcher have established a comprehensible set of themes (Creswell, 2009). They can interactively involve participants to create an opportunity to shape the themes and abstractions that emerge from the process. In this method of inquiry, it is credible for the researcher to maintain focus on learning the meaning that the participants hold about the research problem or issue under study and not the meaning the researcher brings to the research. The qualitative research process is emergent meaning that the initial research plans can vary or change once the researcher has entered the field for data collection. The questions may be altered, the forms of data collection may shift, target professionals or sites visited may need to be modified. According to Creswell (2009), the key idea behind a qualitative research process is to learn about the problem or issues from the participants and to address the research to obtain that information. It is also an interpretive inquiry where the researcher, the participants and the reader of research reports make interpretations relative to their background, history, context and prior understandings. Readers make an interpretation as well as the participants with a distinctive interpretation of the study. Multiple views of the problem under research can emerge through the readers, participants and researchers lens.

Whereas quantitative methodologies test theory deductively from existing knowledge, through developing hypothesized relationships and proposed outcomes for study, qualitative researchers are guided by certain ideas, perspectives or hunches regarding the subject to be investigated (Cormack, 1991). Quantitative research differs from qualitative approaches as it develops theory deductively. There is no explicit intention to count or quantify the findings, which are instead describes in the language employed during the research process (Leach, 1990). Bryman (1998) and Naoum (2013) tried to develop a useful list of a distinctive difference between the two research strategies since it’s rather like the difference between counting the shapes and types of design of a sample green houses as against living in them and feeling the environment. Bryman differentiated quantitative and qualitative research methods in terms of role, relationship between researcher and subject, scope of findings, relationship between theory/concepts and research and nature of data. For roles Bryman found quantitative fact finding based on evidence or records while qualitative is attitude measurement based on opinions, views, and perceptions measurement. He stated that quantitative is distant regarding relationship between researcher and subject while qualitative is close. Regarding scope of findings, quantitative is nomothetic and qualitative idiographic. In relationship between theory/concepts and research quantitative he concluded is testing and confirmation whereas qualitative is emergent/development. Finally, Bryman said in nature of data that quantitative is hard and reliable while qualitative is deep and rich.

4.5 RESEARCH METHODOLOGY OUTLINE AND LITERATURE REVIEW JUSTIFICATION

The phenomenological qualitative approach of inquiry adopted in this study looked into existing literatures in the field of BIM; the government construction strategy to implement BIM and the volumes of BIM literatures in various journals, books and online materials with a view to establishing its current use in costing. It extends to how the contractor's role can be integrated in BIM process and same time seeks to identify sources of information with regards to scope of costing activities (traditional costing approach and the New Rule of Measurement - NRM). It also looks into the existing procurement route and how they interplay within the BIM processes and the relevant project management concepts with intent to streamline construction methods and alternatives.

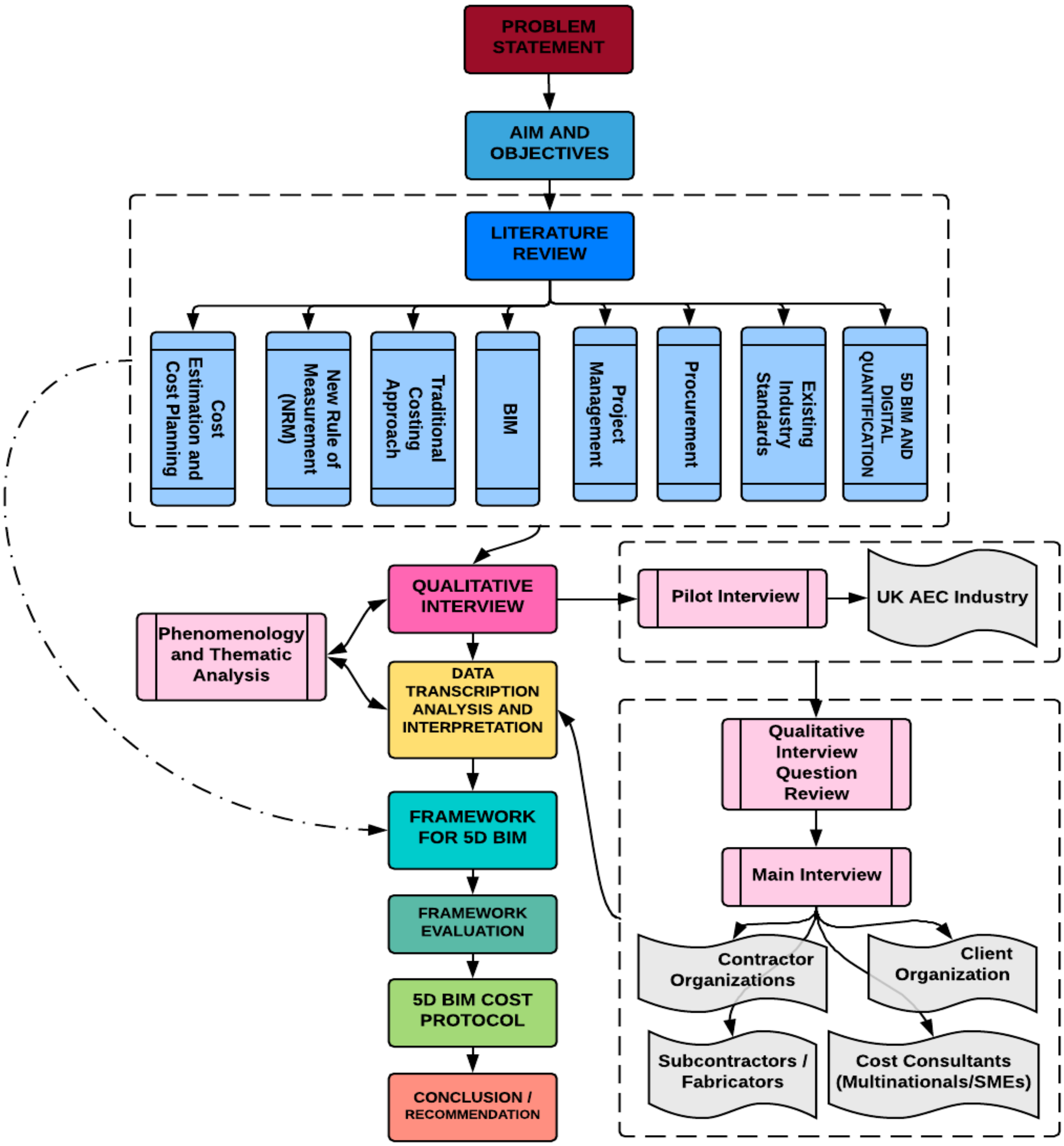


Figure 4.1 Methodological Flowchart

Among other things the research study will seek ways of incorporating cost data within the modeling environment and will explore the existing relationship between the existing construction industry standards and the proposed implementation BIM process. It will seek to collect data through pilot, semi-structured open ended interviews, and observations (if need be to strengthen interviews) from Tier 1 and 2 construction organizations, SME organizations, cost consultants, client organizations etc informed by their BIM practice and experiences; data collected will be transcribed, analyzed and interpreted for a research outcome (discussions and findings) – hence the research methodological flowchart as shown in Figure 4.1 above.

4.6 QUALITATIVE RESEARCH JUSTIFICATION (INTERVIEWS APPROACH)

Several research considerations led to the choice of qualitative method of inquiry – phenomenology method of inquiry to be specific. Looking at the research problem under study, no other method of inquiry would have been more appropriate or suitable than the stance for phenomenological qualitative research approach where the participants to the research are approached on face to face semi-structured open-ended interview. There is a relationship between the researcher and what is being researched and a social relationship with the participants. A look at the philosophical assumptions, paradigms or worldviews (Figure 4.2) would support the required justification for the research method of inquiry chosen.

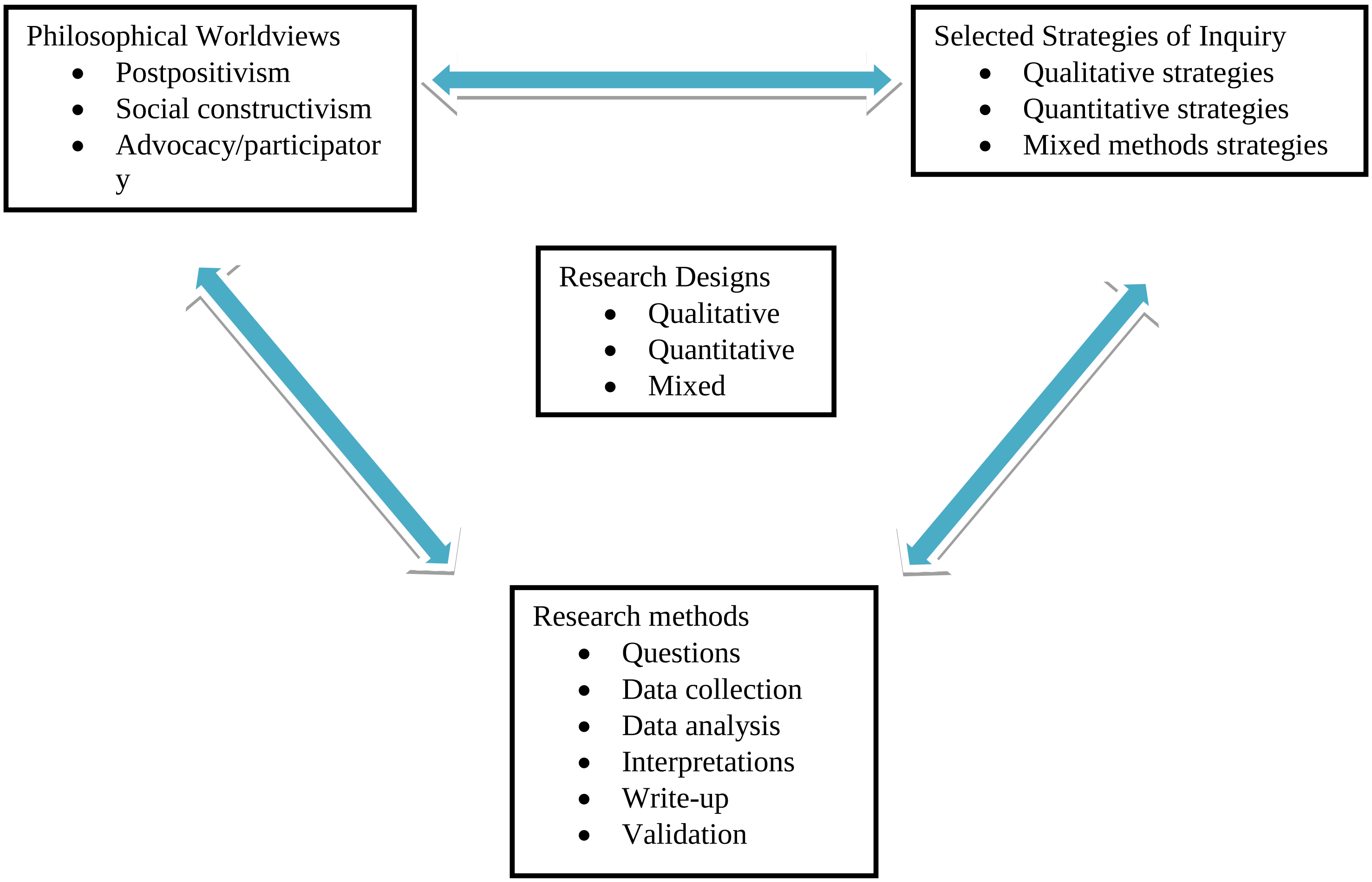


Figure 4.2: A framework for Design – The interconnection of worldviews, strategies of inquiry and research methods (Source: Creswell, 2009)

4.7 PHILOSOPHICAL WORLDVIEWS

To conduct qualitative research, there are worldviews or paradigms and frameworks, philosophical assumptions that shape and influence the conduct of an inquiry (Creswell, 2007 and 2013). The worldviews or paradigms and framework available in qualitative research and the diverse interpretive and theoretical framework shape the content of a qualitative project. Though these philosophical ideas are hidden in research yet they influence research process and therefore need identification (Slife and Williams, 1995). Worldview according to Guba (1990) simply means a basic set of belief system that guide action. Lincoln and Guba (2000) called it paradigms, Mertens (1998) also used the paradigms but Crotty (1998) called it epistemologies and ontologies; Neuman (2000) used the word – broadly conceived research methodologies. Creswell (2009) sees "worldviews" as a generic orientation about the world and the nature of the research that the researcher holds and that these views are greatly influenced by the students study background, past research experiences and faculty advisers of the discipline area of the student. He opined that the beliefs an individual researcher holds will influence his choice of research method approach – quantitative, qualitative and mixed method in his research. Amidst the worldviews, this research study limits the discussions to four – postpositivism, constructivism, advocacy/participatory and pragmatism. It will later look into the philosophical assumptions and their influence on research method decisions.

Table 4.1: Four Worldviews (Source: Creswell, 2009).

Postpositivism	Constructivism
- Determination - Reductionism - Empirical observation and measurement - Theory verification	- Understanding - Multiple participant meanings - Social and historical construction - Theory generation
Advocacy/Participatory	**Pragmatism**
- Political - Empowerment Issue-oriented - Collaborative - Change-oriented	- Consequences of actions - Problem-centered - Pluralistic - Real-world practice oriented

4.7.1 The Postpositivist Worldview

This is a traditional form of research with assumptions that hold true more for quantitative than qualitative research. It goes by various names spanning scientific method or doing research to positivist/postpositivist research, empirical science etc (Creswell, 2007). It is called postpositivism as a result of its challenge to traditional notion of the absolute truth of knowledge and its thinking after positivism (Phillips and Burbules., 2000). It does accept that studying human behavior and actions, we cannot be absolute regarding our claims of knowledge. It holds a philosophical belief system where causes have a deterministic effects or outcomes. Research problems under the lens of a postpositivists should therefore reflect the need to identify and assess the root causes that determine outcome (eg - experiments). It is deductive with intent of extracting unique traits rather than on broad generalizations about human behaviour and subjecting it to a small set of ideas to test like the variables that comprise hypotheses and research questions (Phillips and Burbules, 2000). The outcome of a postpositivists research is on the basis of careful observation and measurement of the objective reality that exist in the world. The study of individual behaviours and the development of numeric measures of observation are characteristic traits of a postpositivists research. According to Creswell (2007, 2009 and 2013), the acceptable approach with a postpositivists research is to begin with an existing theory, collects data that supports or refutes the theory and make significant revisions before additional tests are made. The key assumptions of this research proponent according to Phillips and Burbules is that absolute truth cannot be found and that research evidence is imperfect and tends to error. This is the reason researchers do not prove a hypothesis but indicate a failure to reject a hypothesis. Objectivism is a significant part of competent inquiry therefore postpositivist researchers examines methods and conclusions for bias. From the above key descriptions of the assumptions and stance of a postpositivist research, it does follow that the research problem under study will not adopt the quantitative method of inquiry as a strategy of inquiry.

4.7.2 The Social Constructivist Worldview

According to Lincoln and Guba (1995), social constructivist worldview is a naturalistic inquiry but Berger and Luekmann's (1967) book on "A treatise in the sociology of knowledge" calls it the social construction of reality. This perspective that is often combined with interpretivism according to Mertens (1998) is seen as an approach to qualitative research unlike the postpositivist worldview that defines an approach to quantitative research. This is a subjective and inductive worldview rather than objective and deductionistic where individuals seek meanings towards object or things. People tend to seek understanding of the world they live and work in. Researchers adopting this worldview deploy complexities rather than narrowing meanings into few categories of ideas. Social constructivist worldview deploys open-ended questioning listening carefully to what people say or do in their life settings. The use of broad and general questions supports the participants to construct the meaning of a situation which is gotten through an engaged interaction (Creswell, 2007). The researcher's focus here is to rely to a greater degree on the view of the participants regarding the situation under study. Although these derived subjective meanings are in most cases negotiated either culturally or historically, they are not imprinted on people but are generated through interactions, cultural and historical values that operate individual lives – hence social constructivism. Since cultural and historical settings of participants interplay in their views of situations, addressing the processes of interactions among participants and focusing on the specific context of their background becomes very significant for the researcher (Braun and Clarke, 2014). Under the lens of this worldview there is also a consideration of the researcher’s background and historical experiences and how it influences and shapes his interpretations. The researcher therefore positions themselves in the research to acknowledge how their interpretation flows from their experiences (Creswell, 2009 & 2013). The researcher’s goal is to be able to interpret or make sense of the views others hold about the world. In contrast to the postpositivist worldview that begins with a theory, the social constructivist worldview generates or develops a theory or pattern of meanings inductively. It is very obvious that the research problem under study will adopt the social constructivist worldview since it seeks to generate a meaning through the basis of interaction with the participant community and the data collected from the field.

4.7.3 The Advocacy and Participatory Worldview

In the 1980s and 1990s, another group of researchers with believe that the postpositivist assumptions imposed certain structural laws. They imposed theories inconsistent with the marginalized individuals in the societies or issues regarding social justice and therefore came up with a different view to the philosophical assumptions referred to as advocacy/participatory approach. This worldview is typically seen as a qualitative research but with a focus on group needs or marginalized or disenfranchised individuals within a society. It is also a foundation for quantitative research approach Advocacy/participatory worldview researchers recognize social constructivist stance but argued its incoherence in advocating for action agenda to support the marginalized group (Creswell, 2007). They believed that research inquiries should be tangled with politics or political agenda to instigate an action for reform with capabilities to changing the lives of people, the institution where they live and work and the researcher's life (Kemmis and Wilkinson, 1998). This worldview is of the opinion that specifics like issues relating to oppression, empowerment, alienation, inequality, suppression etc should be addressed. This worldview advises an integration of the researched sample/group into the research process to avoid further marginalization. The participants may support design questions, collect data, analyse information so as to provide a voice for the participants and advance an agenda for change to improve lives. It proposes a united voice for change and reform. There is some sort of integration of the theoretical views and the philosophical assumptions with a capability to deliver the required change and reform (Heron and Reason, 1997). Kemmis and Wilkinson (1998) summarized some key features of the advocacy/participatory worldview which include: helping individuals free themselves from the constraints of life and this is achieved by dealing with the root cause of the societal problems like the need for empowerment; emancipatory in that it helps unshackle people from the constraints of irrational and unjust structures that limit self-development and self-determination (Creswell, 2009).

4.7.4 The Pragmatic Worldview

The fourth of the worldview is the pragmatic approach which according to Morgan (2007) and Patton (1990) focuses attention on the research problem in social science research and deploying pluralistic approaches to derive knowledge about a problem. It is largely applied in mixed method of inquiry. Though there are many forms of this philosophical worldview according to Cherryholmes (1992) but for many it evolves out of the consequence of actions and situations rather than antecedent conditions. Major concerns revolve around applications, what works and solutions to problems. There is a less focus on research methods rather the emphasis is on the use of research problem and all approaches available to understand the problem (Rossman and Wilson, 1985). Pragmatism is not to any one system of philosophy and reality but to mixed method strategy of inquiry in that researchers engage both quantitative and qualitative method of inquiry in their research processes (Creswell, 2009 and 2013; Creswell and Creswell, 2018). There is a liberty of choice for researchers to choose methods, techniques, and procedures that addresses their research focus and needs. Researchers that submit to mixed method approach- a reflection of pragmatic worldviews engage many approaches for data collection and analysis and do not subscribe to one way strategy of inquiry. This worldview according to Creswell does not see the world as an absolute unity. Investigators deploy both inquiry approach (quantitative and qualitative) because they work to provide the best understanding of a research problem.

Having looked at the four philosophical worldviews (postpositivist, social constructivist, advocacy/participatory, pragmatism) considered to have a high degree of influence to a researcher's decision for a strategy of inquiry and their intent; it is very clear that social constructivist worldviews has influenced my chosen method of inquiry. Looking at the background of the research problem under study and the required interactive relationship with individuals and institutions in order to gain a meaning of their situation and interpret same. Social constructivism is deployed to gain such required understanding by asking open-ended questions and getting an unbiased feedback from the participants.

4.8 PHILOSOPHICAL ASSUMPTIONS

The process of research design in qualitative method of inquiry is underpinned by some philosophical assumptions that researchers make to carry out a qualitative research. The qualitative inquirer brings into the research study worldviews or paradigms as discussed above, assumptions, and sets of belief system to inform the research conduct (Creswell, 2007); with an awareness that the interpretive and theoretical frameworks supports to guide and shape the research work. These assumptions consist of a stance towards the nature of reality (ontology), the researcher's relationship with the researched - that is how the researcher knows what he or she knows (epistemology), the role of values in the research (axiology), the language of the research (rhetoric), and the methods used in the process (methodology) (Creswell, 2003). This research study would like to look at the existing philosophical assumptions that support a qualitative study having explored few worldviews or paradigms.

4.8.1 Ontology

This relates to the nature of reality and its characteristics. The idea of multiple realities is embraced by qualitative researchers. Researchers relate with realities as do also the individuals being studied and the readers of qualitative studies. These researchers conduct their study with intent of reporting multiple realities presenting different perspective from individuals. According to Moustakas (1994) "When writers compile a phenomenology, they report how individuals participating in the study view their experiences differently".

4.8.2 Epistemology

This is the relationship the researcher develops with the researched. It means the researcher gets very close to the participants under research focus. The researcher operates under a focal context in the field (where the participants live and work) to enable him understand the views of the participants. It's important the researcher gets firsthand information regarding the research focus by staying a bit longer in the field with the participants to support what he knows about the researched. According to Wolcott (1999), a good ethnography requires prolonged stay at the researched site. The objective separateness or distance is drastically minimized (Guba and Lincoln, 1988) between the researcher and the researched.

4.8.3 Axiology

The axiological assumptions prompt all researchers to contribute values to their study but the qualitative researchers make explicit those implicit values. The qualitative study in an effort to implement this assumption in practice recognizes the value-laden nature of the study and reports both their values and the biases of the information gathered from the field. Considering interpretive biography, the researcher is apparently present in the text and it's accepted that the stories is an interpretation and presentation of the author as much as the research focus, so it is said that the researchers positioned themselves in the study. When they position themselves in the research they definitely bring values to the research.

4.8.4 Rhetoric

This refers to the language deployed in a research study. There is a rhetoric that has evolved over time, qualitative researchers embrace its assumption that qualitative writings need to be personal and literary in form (Creswell, 2007). For instance the use of personal pronouns like "I' is engaged and stories are crafted chronologically as in the narrative research encompassing beginning, middle and end (Clandinin and Connelly, 2000). According to Lincoln and Guba (1985) they argued that qualitative research engaging this assumption does not use terms such as – internal validity, external validity, objectivity and generalizability but deploys terms as credibility, dependability, confirmability, validation etc. In writing purpose statements and research questions words like meaning, discover, understanding which all emerging qualitative terms come into play. The language of the qualitative researcher becomes personal, literary and is defined as research process evolves rather than being given a private interpretation by the researcher. The terms defined by the participants are of primary importance.

4.8.5 Methodology

The methodological process deployed in a qualitative research as outlined above is both inductive and emergent shaping the researchers experience in data collection and data analysis. The logical process entertained by a qualitative researcher does not follow a handed down theory or researcher's perspective but works inductively from ground up. The research questions may change influenced by the research evolving process to reflect better the type of question to be asked to support a good understanding of the research problem (Stake, 1995). This change for the question in the middle of the study has potentials to initiate a modification process of the data collection strategy. With this assumption, the researcher follows a path to analyzing data with intent to develop an increasing detailed knowledge of the research focus.

Table 4.2 is a summary of the philosophical assumptions discussed above making more explicit the questions the various assumptions put forward, their distinctive characteristics and their implications for practice.

Table 4.2: Philosophical Assumptions with Implications for Practice (Source: Creswell, 2007)

Assumptions	**Question**	**Characteristics**	**Implications for Practice (Examples)**
Ontological	What is the nature of reality?	Reality is subjective and multiple, as seen by participants in the study	Researchers use quotes and themes in words of participants and provides evidence of different perspective.
Epistemological	What is the relationship of the researcher and that being researched?	Researcher tries to reduce distance between him and that being researched	Researcher collaborates, spends time in field with participants and becomes an insider
Axiological	What is the role of values?	Researcher acknowledges that research is value-laden and that biases are present	Researcher openly discusses values that shape the narrative and includes his or her own interpretation in conjunction with the interpretations of participants

Rhetorical	What is the language of research?	Researcher writes in a literary, informal style using the personal voice and uses qualitative terms and limited	Researcher uses an engaging style of narrative, may use first-person pronoun, and employs the language of qualitative research
Methodological	What is the process of research?	Researcher uses inductive logic, studies the topic within its context and uses an emerging design.	Researcher works with particulars (details) before generalizations, describes in detail the context of study and continually revises questions from experiences in the field.

4.9 RESEARCH STUDY PARADIGMS

Paradigm is made up of the general theoretical assumptions and laws, and techniques for their application which individuals with a particular scientific community membership adopt (Chalmers, 1982). Paradigm in summary can be viewed as a concept that integrates inclusivity in its belief system, worldview, or framework overseeing research practice in a field (Willis, 2007). Paradigms function on ontological, epistemological and methodological assumptions. Ontological assumptions focus on the constituents of reality. It's the assumption that response to the question such as 'what is there that can be known?' or 'what is the form and nature of reality?' The epistemological questions majorly focus on 'how we know what we know?'

Epistemology establishes the relationship expected to be present between the knower and what is known or being sought to be known, supporting that formed knowledge is both sufficient and valid according to Denzin and Lincoln (2000). Methodological assumption ask such question as 'how can the inquirer go about finding out whatever is believed can be known?' (Guba and Lincolns, 1994; Crotty, 1998; Crotty, 2003). Methodology is the principles and ideas on which researchers base their procedures and strategies. According to Guba (1994), it could be deducted that both ontology and epistemology are concerned with the fundamental beliefs of the researcher. This research acknowledges the significance of the socio-cultural influence as a process rooted in the social behavioural community of the participants. The underpinning philosophical assumptions for this research which are ontological, epistemological and methodological assumptions are tied with the constructivist paradigms of inductive approach to inquiries. The positivist paradigm underlies what are called quantitative methods, while constructivist paradigm underlies qualitative methods (Tashakkori and Teddlie, 1998). The debate between the positivist and constructivist paradigms has sometimes been called qualitative-quantitative debate. Lincoln and Guba (1985) opposed that the beliefs of positivism and quantitative methodology that go with that paradigm have been questioned. The authors also oppose that constructivism and qualitative methods are in ascendance.

Quantitative purists (positivists) believe that social observations should be treated as entities in much the same way that physical scientists treat physical phenomena. Further, they contend that the observer is separate from the entities that are subject to observation. This school of thoughts maintain that social science inquiry should be objective. This school of thought however suggest that researchers should eliminate their biases, bracket out their interpretive inputs, remain emotionally detached and uninvolved with the objects of study, and test or empirically justify their stated hypothesis while the qualitative purists reject what they call positivism. They argue for superiority of the constructivism. This school of thought argue that multiple-constructed realities abound, that time and context-free generalisations are neither desirable not possible, that research is valued-bound, that it is impossible to differentiate fully causes and effects, that logic flows from specific to general and that the knower and the known cannot be separated because subjective knower is the only reality (Burke and Onwuegbuzie, 2004).

Both sets of purists view their paradigm as the ideal for research, and, implicitly if not explicitly, and incompatibility thesis states that the qualitative and quantitative research paradigms, including their associated methods should not be mixed (Burke and Onwuegbuzie, 2004). The social constructivist like the pragmatic views argues that the research methods and epistemological concepts are not linked in the real-word research and that research should continue independent of the worldview debates according to Bryman (2007) and Alshawish (2016). Clearly, the research problem as investigated will adopt the social constructivist worldview since it seeks to generate a meaning through the basis of interaction with the participant community and the data collected from the field. This establishes the relationship between the object of the research and the participant community.

4.10 FIVE QUALITATIVE APPROACH TO INQUIRY COMPARED

The research under focus having chosen, justified and established philosophically the rationale for the qualitative method of inquiry, has considered the five qualitative approaches to inquiry – The narrative, ethnography, phenomenology, grounded theory and case study. The five qualitative inquiry approaches have in common the general process of research with a research problem and question, data and data analysis and finally the research report. They share a similarity in data collection with varying degrees of interviews, documentations, observations and audiovisual materials with some in research design as well (Creswell, 2007; Braun et al, 2013). In a study of a single individual either narrative, ethnography or case study approach could be deployed for single unit analysis but the type of data and method of analysis would differ considerably. For instance a narrative research inquirer looks into the story of an individual and tries to arrange it chronologically, ethnography researcher focuses more on the culture context of the individual story while the case study researcher for a single case illustrates an issue and puts together a comprehensive description of the setting for the case.

The five approaches also have their differences which expresses itself in the primary objective of the research focus. Grounded theory originated from the sociological background, ethnography in anthropology or sociology while others have a broad spectrum of originating disciplines – interdisciplinary backgrounds (narrative and case study). Their variation is largely on the emphasis of data collection and extent of data collected. For instance, ethnography engages more observations and grounded theory and case studies more on interviews. Multiple case study research provides an in-depth case picture. Data analysis stage shows more explicit the variance within the five qualitative approaches. Like narrative research is less defined, grounded theory is most specific, few steps in ethnography, extensive steps in phenomenology and the final research report reflects the antecedents of the research process followed. When it mirrors the life of an individual is narrative, if a comprehensive description of an essence of experience is phenomenon. When the research report is portrayed in a visual model grounded theory emerges and if it involves a perception of how a culture sharing group works then is ethnographical and of course a detailed in-depth study of a bounded setting, case or cases is case study approach (Creswell, 2007 & 2009). Table 4.3 puts the above discussion in a general sketch to reflect the overall structure of each of the five approaches:

Table 4.3: Contrasting Characteristics of Five Qualitative Approaches (Source: Creswell, 2007)

Characteristics	**Narrative Research**	**Phenomenology**	**Grounded Theory**	**Ethnography**	**Case Study**
Focus	Exploring the life of an individual	Understanding the essence of experience	Developing a theory grounded in data from the field	Describing and interpreting a culture-sharing group	Developing an in-depth description and analysis of a case or multiple cases
Type of problem best suited for design	Needing to tell stories of individual experience	Needing to describe the essence of a lived phenomenon	Grounding a theory in the views of participants	Describing and interpreting the shared patterns of culture of a group	Providing an in-depth understanding of a case or cases
Discipline Background	Drawing from the humanities including anthropology, literature, history, psychology and sociology	Drawing from philosophy, psychology and education	Drawing from sociology	Drawing from anthropology and sociology	Drawing from psychology, law, political science, medicine

Unit of analysis	Studying one or more individuals	Studying several individuals that have shared the experience	Studying a process, action or interaction involving many individuals	Studying a group that shares the same culture	Studying an event, a programme, an activity, more than one individual
Data collection forms	Using primary interviews and documents	Using primarily interviews with individuals, although documents, observations and art may also be considered	Using primarily interviews with 20-60 individuals	Using primarily observations and interviews, but perhaps collecting other source during extended time in the field	Using multiple sources such as interviews, observations, documents, artifacts
Data analysis strategies	Analyzing data for stories, ‘restorying’ stories, developing themes, often using a chronology	Analyzing data for significant statements, meaning units, textural and structural description, description of the ‘essence’	Analyzing data through open coding, axial coding, selective coding	Analyzing data through description of the culture-sharing group; themes about the group	Analyzing data through description of the case and themes of the case as well as cross-case themes
Written Report	Developing a narrative about the story of an individual’s life	Describing the ‘essence’ of the experience	Generating a theory illustrated in a Figure	Describing how a culture-sharing group works	Developing a detailed analysis of one or more cases

4.10.1 Phenomenology

Phenomenological research is a qualitative method of inquiring a given concept, which involves exploring an in-depth understanding of a phenomenal experienced by different individuals (Creswell, 2007). The narrative study deals with the life of a single individual whereas a phenomenological study describes a concept or a phenomenon (a remarkable experienced process or state of development) of several individuals and their lived experiences (Creswell, 2007). Phenomenologists focus on describing what all participants have in common as they experience a phenomenon. The primary purpose of phenomenology is to reduce individual experiences to a phenomenon with the description of universal essence that is a strong grasp of the very nature of a thing (Creswell, 2007). Qualitative researchers here identify a phenomenon – the very object of a human experience and data is collected from persons who have experienced this phenomenon and with that develops a composite description (textural and structural description) of the essence of the experience for all of the individuals. This account relates what they have experienced and how it was experienced. In phenomenological research, respondents are carefully selected based on their experience on the phenomenal been examined (Creswell, 2007). Phenomenology has a strong philosophical component to it and draws heavily on the writings of the German mathematician Edmund Husserl (1859 – 1938) and all others who expanded on his views like Heidegger, Sartre etc. Phenomenological philosophical assumptions rest on some common grounds: the study of the lived experience of persons, the views that these experiences are conscious ones and the development of descriptions of the essences of these experiences, not explanations or analysis. The research study involves the suspension of the researcher's experience, knowledge or perception of a phenomenal (called ‘epoche’) (Husserl, 1970) to encourage or develop a deeper understanding of the concept been examined (Lester, (1999); Creswell, 2007). According to Stewart and Mickunas (1990), at a broader level there are four philosophical perspectives in phenomenology:

a) A return to the traditional tasks of philosophy (scientism – exploring knowledge through empirical evidence to the Greek conception of philosophy as a search for wisdom).

b) A philosophy without presuppositions (suspending all judgement about what is real ‘natural attitude’ till is founded on more certain basis).

c) The intentionality of consciousness (a relationship with the reality of an object to one’s consciousness of it. The reality according to Husserl is not divided into subjects and objects but into Cartesian nature of both subjects and objects as they appear in consciousness.

d) The refusal of the subject-object dichotomy (This is an extension from the intentionality of consciousness but opines that an object or knowledge is only understood within the meaning of the experience of an individual).

4.10.2 Types of Phenomenology

There are two major basic approaches to a qualitative phenomenological research. Van Manen (1990) highlighted what he called Hermeneutic or Empirical phenomenology while Moustakas (1994) spotted Transcendental or Psychological phenomenology.

4.10.2.1 Hermeneutic or Empirical phenomenology

Hermeneutic phenomenology describes research as oriented towards lived experience (phenomenology) and seeing texts as interpretative (hermeneutics). Van Manen does not approach phenomenology with a set of rules or methods but sees a phenomenological qualitative research as a dynamic interplay among six research activities. He sees researchers as first turning to a phenomenon where they have developed an interest and in the process reflects and develops on essential themes of what constitutes the nature of a lived experience; writing the description of the phenomenon while maintaining a strong relationship with the focus of the inquiry and balancing the parts of the writing to the whole. Empirical phenomenology does not constrain this approach of research to just descriptive but also judges it from the interpretive angle where the researcher makes an interpretation of a phenomenon, mediating between meanings of the lived experiences (Manen, 1990).

4.10.2.2 Transcendental or Psychological phenomenology

According to Moustaka (1994), transcendental or psychological phenomenology is focused less on the researcher's interpretations but more on the descriptive experiences of the participants. He also focuses on the bracketing ('epoche' – Husserl's concept) where researchers neglect their experiences as much possible to a fresh view towards the phenomenon under investigation. Hence transcendental meaning a fresh perception as though it's the first time though admitted this is seldom perfectly achieved. This concept involves an identification of a subject of motivation to study (phenomenon), bracketing out investigators experience and then collecting data from several individuals or professionals who have experienced the phenomenon under examination. Data analysis is by reducing the information to a significant statement of quotes and combining the statements into themes. Then the investigator or researcher develops a textural description of the experiences of the persons (what the participants experienced) and how they experienced it relative to conditions, situations or context which is referred to as structural description. The essence of the participants experience is conveyed through a combination of both the textural and the structural descriptions. Moustaka's approach (1994) has a systematic procedure regarding phenomenological research and data analytical steps with a more proficient guidelines for assembling textural and structural descriptions than few other psychological phenomenology authors like Polkinghorne (1989), Dukes (1984), Giorgi (1985,1994). The procedures for conducting a phenomenological research are outlined by Moustaka (1994).

4.10.3 Phenomenological Research Procedures

The investigator has a sole objective to determine the suitability of phenomenology towards the research problem under examination. The best research problem best suited for this research approach is one in which it is vital to understand differences in commonly shared experiences of a phenomenon by several individuals once a phenomenon of interest to study is identified. It is significant to understand these common experiences in order to develop frameworks, best practises, policies or guidelines or to develop a deeper understanding about the features of a phenomenon. It's imperative to recognise and specify in a phenomenological research the underpinning philosophical assumptions for instance, combination of objective reality and individual experiences. These lived experiences are furthermore 'conscious' and directed toward an object. To elaborate on the participants experiences of a phenomenon, researcher's experiences must be neglected (bracket out) as much possible.

The method of data collection in a phenomenological inquiry usually involves carrying out an in-depth interview or/and multiple interviews with participants tailored towards the phenomenon under examination (Creswell, 2007). Data are collected from individuals who have experienced the phenomenon which according to Polkinghorne (1989) recommended use of between 5 to 25 persons. Manen (1990) cited in Creswell (2007) suggested phenomenal data collection can also be carried out by using recorded conversations, accounts of vast experiences covering spectrum of activities or events, formally written and documented. Other forms of data may also be collection like observations, documentations, poetry and other forms of art. Participants are interrogated to know what they've experienced regarding a phenomenon under investigation, how they experienced it (Moustakas, 1994). What conditions, contexts or situations influenced or affected their experience of the phenomenon. Open ended structured interview questions are engaged to interrogate experiences of the participants on the phenomenon with a streamlined focus for data collection to ultimately support both textural and structural description of their experiences providing an understanding of the balanced/common experiences of the participants.

4.10.4 Phenomenological Data Analysis Procedure

Similar methods devolve with psychological phenomenological data analysis procedures (Moustakas, 1994; Polkinghorne, 1989). Building on the data from the research questions, data is analysed and significant statements, quotes or sentences highlighted or underlined which provide an understanding of how the participants experienced the phenomenon under examination and this is referred to as ‘horizonalization’. From the highlighted or underlined significant statements, sentences or important details, the researcher develops clusters of meaning from these into themes. These significant statements or sentences are then used to fully describe the participants experience (what he experienced) which is called textural description. Same is engaged in describing the context or setting that influenced how the participants experienced the phenomenon and this is referred to as imaginative variation or structural description (Moustakas, 1994). Moustakas further adds in situations where it’s practically impossible for investigators to bracket out their experiences, they should write it describing the context, settings and situations that have influenced their experiences. The textural and structural descriptions aids the researcher to write up the composite description that presents the ‘essence’ of the phenomenon called the essential, invariant structure (or essence). This largely focuses on the common experiences of the participants.

4.10.5 Challenges of Phenomenological Research Strategy

Phenomenological qualitative research approach provides an in-depth understanding of a phenomenon as experienced by the participants or research respondents. It can involve a streamlined form of data collection by including only single or multiple interviews with participants (Creswell, 2007). Moustakas (1994) helped provide a more structured data analysis guideline for novice or early qualitative researchers. A broader understanding of an underpinning philosophical assumption to a research strategy (phenomenology) is required to be demonstrated by a researcher. The participants in the study need to be carefully selected to be individuals whose experiences are relevant to the study (phenomenon) under investigation to support the researcher in the end to forge a common understanding. Bracketing personal experiences may be difficult for the researcher to implement. According to Manen (1990), an interpretative approach required to generate patterns or themes in a qualitative research would signal an impossibility to bracketing out researchers personal experience (or separating the researcher from the text) while engaging phenomenology. Le Vasseur (2003) argues perhaps the research community might need a reviewed definition of ‘epoche’ or bracketing, such as suspending the researchers understanding in a reflective move that cultivates curiosity. Thus, it becomes the researcher’s prerogative to decide how and in what ways to determine the input of his/her personal understanding into the study under investigation. Figure 4.3 shows a coding process for interpretative phenomenological investigation where meanings, significant statements of that which is experienced are described using textural and structural descriptions to generate composite data which is called the essence.

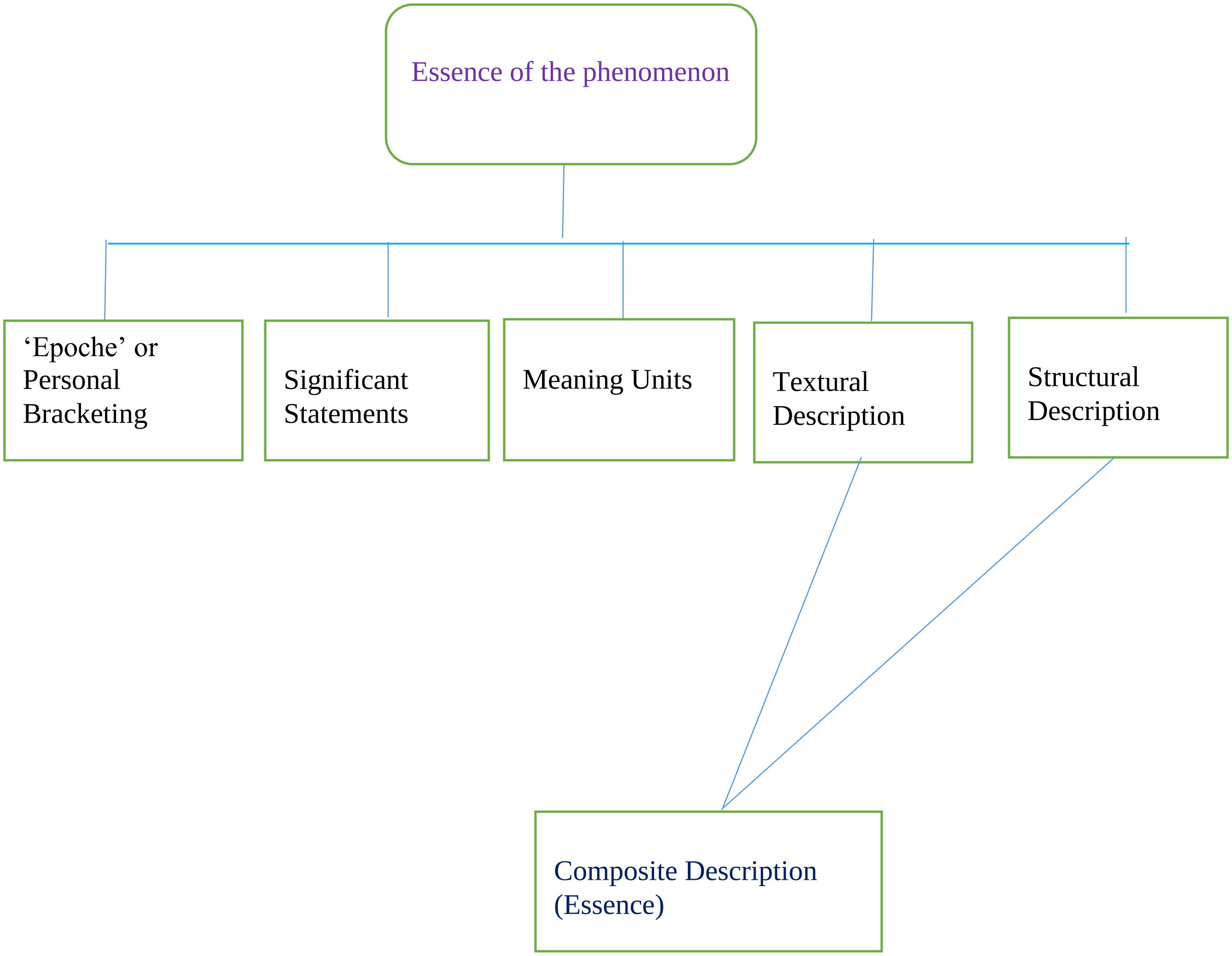


Figure 4.3: Adapted template for coding a phenomenological investigation or study (Source: Creswell, 2007).

4.11 INTERVIEW DESIGN – PILOT INTERVIEWS, SEMI-STRUCTURED OPEN-ENDED INTERVIEWS

Interviews are perhaps the most common data collection tool for both qualitative researchers and participants. It is undoubtedly one of the most familiar methods of data collection within the social and health science (Briggs, 1986). There are various kinds and styles of qualitative interview and that includes narrative, active, grounded theory and feminist approaches but approaches for qualitative interviewing can be adapted to reflect specific requirements. According to Kvale (2007), interviewing is defined as a professional conversation with the aim of capturing participant's language and concepts in relation to a determined research focus to reflect their perspectives and experiences (Rubin and Rubin, 1995). The interview guide approach which is also called semi-structured interview will be adapted in this research focus to be able to cover or capture a diverse range of participant's view/responses in their own words. There are also structured and unstructured interview styles. The structured interview has a quantitative research orientation where the questions and the response categories are predetermined by the researcher (Braun and Clarke, 2013). This is seen as a standardized or closed (yes/no) form of interview where the ideal interviewer is a 'robot' asking each participant exactly the same questions, in exactly the same way and in exactly the same order. Questions are prepared in advance and stringent effort is made to minimize the impact of the interviewer on the participant's response unlike the semi-structured interview where the interviewer plays an active in the interview, co-constructing meaning with the participants. The interviewer's role in semi-structured is not minimized but is given the opportunity to reflect how participants practices and value would shape the data outcome. The unstructured interview is supposedly in some way structured because all the three styles are all social encounters (Braun and Clarke, 2013). The interviewer mostly asks questions and the interviewee mostly responds to them.

In this study, the interview guide was pre-developed before the actual interview in this approach, the interviewer did not rigidly adhere to it with respect to the question sequence or the precise wording of the questions. The reason is that the wording and sequence or order of the questions was contextual and developed through the participant's responses. According to Rubin and Rubin (1995), the ideal qualitative interview is on target while hanging loose. There was flexibility with the researcher's approach allowing participants the opportunity to delve into issues that are critical to the research focus and was not anticipated by the researcher nor covered in the interview guide. According to Oakley (1981), the qualitative interview came up as a method of response to critiques about what he called 'depersonalisation' of the then standard social scientific methods of data collection, therefore face-to-face contact has been held as the ideal context for interview data collection between researcher and the participants- the 'gold standard' (Novick, 2008). Semi-structured interview was adopted for data collection, open-ended questions were used in contrast to the closed ended question approach for the quantitative method of inquiry. This allowed the participants enough response room to provide in-depth and detailed responses and also to discuss what is considered critical to their practice reflecting the research intent. The participant's responses to the open-ended questions mirrored their own words. One of the benefits derived from this approach in this study was the spoken conversation (face-to-face) between the interviewer and the participants which was typically audio-recorded and further transcribed into a text for data analysis. A qualitative interviewer is not a programmed robot who conducts an interview according to some set of inviolate rules but a human who deploys social skills, distinctive personal styles, potentials and abilities with certain degree of flexibilities (Braun and Clarke, 2013). The interviewer draws on good interview practice guides to conduct an interview that reflects the needs and is appropriate to the research questions, objectives and methodologies, the context of the interview and the individual participant.

4.11.1 Inclusion/Exclusion Criteria

This was deployed to enable the researcher gather informative data that will best answer the research questions and meet research objectives (Easterby-Smith et al, 2012) and as a result inclusion and exclusion criteria was used to select participants with related experience to the research topic. With the eligibility criteria in mind, potential sample participants who met the criteria as decided were used and those who did not were not included in the study. Criteria for the interview eligibility were involvement in BIM projects where 5D BIM was utilised, basic or in-depth experience in executing BIM Level 2/BIM projects or associated projects, cost management skills/experience, ability to use BIM tools to generate cost information. The understanding of BIM process and technological application with respect to accurate cost modelling, cost planning, generation of quantities and integrated cost solutions. Finally, the participants' willingness to participate in the interview session. Once the above criteria were established through verbal and email conversation, the potential participant was chosen - interview date, location and time scheduled.

4.12 QUESTION DEVELOPMENT

The non-probability sampling method was employed for this study. The participants were recruited for this study using purposive sampling technique. Palinkas et al (2013) noted that qualitative investigation usually emphasizes in-depth on comparatively small samples that are purposely chosen. Collection of data from a total population is not practiced; nevertheless, it is attainable if the population size can be managed.

Thomas et al (2014) noted that an advantage of this technique is that the collected data are usually richer and it provides an in-depth knowledge of the subject under study. According to Easterby-Smith et al (2008) stated that this method helps the researcher draw the most significant and strategic information for the study. Manso, (2002) however, added that this approach is used in selecting research informant on the basis of their relevance to the research questions as well as the argument or explanation that the researcher is developing.

The participants in this study were carefully selected to be individuals whose past and current experiences are relevant to the research problem. This was to aid the researcher's understanding in the end to develop a common solution in the form of a framework to streamline industry process and impact cost saving culture within industry practise. Prior to conducting the main study, two main Tier 1 contractor organisations were chosen for the pilot study involving twelve (12) target participants. The number of participants used from each of the organisation was six (6) out of the total of twelve (in six comparable roles). These were professionals from UK AEC industry who possessed relevant construction backgrounds in BIM, cost management, project management, design and operational management practices. The organisations for the pilot study was outside the seven chosen construction organisations used for the main study and to remove bias, the participants used for the preliminary studies was not included in the main study. The two pilot organisations used had similar design, construction and cost management activities/experience. The pilot study was used to pre-test the instruments (semi-structured open-ended questions) for data collection and subsequently reviewed/modified due to question ambiguity before engaging the wider construction practitioners. Drafted interview questions were redefined and further developed to address research aim and objectives. In general, the pilot study helped the researcher to modify interview questions to be subject specific, improve on interview skills, know estimated time of interview and also developed process management skill for the main study.

4.12.1 Data Collection Instrument Development

Identified research gaps from literature review, researcher's experience and also the research aim and objectives guided the development of the research instrument. The scope of the questions reflected content that were sufficient to address the research problem under investigation. Individual industry experiences shown below (Table 4.4) and overall knowledge in the generic use and implementation of Building Information Modelling (BIM) with respect to costing (5D) in various construction roles were cardinal in developing the final interview questions. The table shows organisation categories with stars (*) indicative of relationship between participant's portfolios, their professional membership and level of experience associated with design and cost competences. Green colouration as indicated emphasises where participants within an organisation category demonstrates vast industry proficiency and strength of proficiency opinion. The interviews conducted supported an in-depth interrogation and apprehension of the challenges and issues surrounding a seamless 5D BIM implementation than could be obtained using quantitative questionnaire surveys. The reason being that questionnaire survey approach would not offer a one on one in-depth interrogation on the issue under investigation and again there is no guarantee that the responses will be from the targeted individuals or anticipated job roles. The firms represented a good indicative sampling of sub-contracting, client organisation, main contractors, cost consultants (SMEs and Multinationals) and design consultancy sized firms in the UK AEC industry.

Table 4.4: Participants' Profile

CATEGORY		Participants' Portfolios				
SUB CONTRACTORS/ FABRICATORS ORGANISATION	Predominant Experience (s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator
	RICS Membership			*		
	Experienced in BIM tools	*			*	
	Experienced/ Limited experience in 5D	*			*	
	Experienced in 4D		*			
	Experienced in CAD	*	*	*	*	*
	Experienced in 2D/3D	*	*	*	*	*
	Limited BIM experience		*	*		*

		Participants' Portfolios		
MAIN CONTRACTOR ORGANISATION	Predominant Experience (s)	BIM Director	Head of BIM	Traditional QS
	Experienced in BIM tools	*	*	
	Experienced in 5D	*	*	
	Experienced in CAD	*	*	*
	Experienced in 2D/3D	*	*	*
	Limited BIM experience			*

		Participants' Portfolios				
	Predominant Experience(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager
CLIENT ORGANISATION	Experienced in BIM tools	*	*	*	*	*
	Experienced in 5D	*			*	*
	Experienced in 4D				*	*
	Experienced in CAD	*	*	*	*	*
	Experienced in 2D/3D	*	*	*	*	*
	Limited experience in 5D BIM		*	*		

		Participants' Portfolios			
	Predominant Experience (s)	Traditional/ 5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS
COST CONSULTANTS ORGANISATION – (SMEs)	Experienced in BIM tools		*	*	
	Experienced in 5D		*	*	
	Experienced in CAD	*	*	*	*
	Experienced in 2D/3D	*	*	*	*
	Limited BIM experience	*			*

		Participants' Portfolios			
COST CONSULTANTS ORGANISATION – (Multi-Nationals)	Predominant Experience (s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager
	RICS Membership	*			*
	Experienced in BIM tools		*	*	*
	Experienced in 5D		*	*	*
	Experienced in CAD	*	*	*	*
	Experienced in 2D/3D	*	*	*	*
	Limited BIM experience	*			

4.13 SAMPLE SELECTION

The process of recruiting research participants takes into account the importance of identifying appropriate participants who can best inform the study to successfully address the research question. As Webb (2002) emphasises, establishing homogeneity is very important when setting up in-depth interview (IDI) as it allows participants to capitalise on their shared experiences. Selecting the sample size for the qualitative data was a concern due to small sample size used (Marshall, 1996). The sample size in qualitative research normally depends on the researcher's consideration of these related variables; usefulness, purpose of the study, credibility of the selected cases, resources and time available to the researcher (Patton, 2002).

The researcher purposively selected participants naturally from sampling seven UK based organisations with varying involvement with BIM related construction activities and virtual environment. This is a procedure of selecting research informants because of their relevance to the research questions, theoretical position and analytical of the study as well as the argument or explanation that the researcher is developing (Mason, 2002). Purposive sampling was used as it could offer informants who could provide data that could help in the understanding of the development of 5D BIM framework facilitating costing in contractor-led projects. In the recruiting process, the researcher earlier set predefined inclusive and exclusive criteria to select participants for the interview. One of the basic criterion for being a participant in the interviews was basic or in-depth experience in executing BIM projects, designing with BIM digital capabilities, exposure to virtual projects, linking of model information to generate non-geometric data, involvement with digital quantification and associated projects with respect to cost estimation and cost savings (5D BIM) and finally, the participants' willingness to participate in the interview session. Potential interviewee who matched the sampling criteria were approached to seek both verbal and written consent and their availability to participate in the interview.

4.13.1 Limitation of purposive sampling

Purposive or judgemental sampling technique which is a commonly used non-probabilistic sample design where samples are selected based on judgement (Saunders et al, 2016). The use of this sampling which the researcher may have introduced selection biases to this study as participants were selected based on the subjective judgement of the researcher. The main source of data collection was self-report of respondents. Samples are not easily defensible as being representative of populations due to potential subjectivity of researcher.

4.14 INTERVIEW SETTING

Once the participants' willingness to participate in the interview session through both verbal and written consent and their availability to participate in the interview was established as highlighted in section 4.13, the participants were asked for the preferred interview location. All participants preferred their respective offices since availability was within week days. At the interview, the researcher extended greetings to the participant and created a soothing welcoming environment by exchanging pleasantries and this was to make the participant very relaxed in anticipation of free and open responses to interview questions. After the researcher was invited into a private enclosure to reduce distractions from normal office activities, an overview of the interview structure, process, procedures and ground rules was established. An overall overview and the importance of the research was also reiterated in addition to the email and phone conversations while assuring them of ethics and any confidentially concerns. The researcher commenced the interview by asking background questions relative to BIM projects (see Appendix H for data collection instrument). The researcher's responsibility was to keep the participant on track and to make transition to the next question when considered appropriate. Where the researcher thinks further questioning was necessary for clarity of what was said or to ensure responses addressed interview questions, there was a follow up question. Once the participant had responded to all questions, the participant is given further opportunities to share further information if there is and then the interview comes to an end. Each interview session lasted between thirty minutes to one hour.

4.15 DATA ANALYSIS PROCESS

Data analysis is very important in a research, since it changes the raw data into data obtained from the data collection tools into meaningful information if the procedures used for answering the research questions is adequate. Data can provide a baseline to explore what learning has taken place (Waterman, 2007). The analysis for this study was done using thematic analysis. Thematic analysis can be defined as a systematic yet flexible and accessible approach to qualitative analytics - providing an orderly and logical approach to analysing qualitative data (Saunders, Lewis and Thornhill, 2016). It is not tied to a particular philosophical position and could be used irrespective of an objectivist and subjectivist position the researcher has chosen to adopt. Thematic analysis involves coding qualitative data to identify themes or patterns for further analysis related to research questions (Saunders et al., 2016). Data analysis involves taking the data apart, understanding the components and how they relate to each other (Stake, 1995). The research philosophical assumptions which in this case is subjective was reflective in data interpretation with a consideration that thematic approach is a standalone analytical technique. According to Creswell (2009), regardless of the qualitative methodology used in the analysis, a common process to qualitative data analysis involving six steps is discernible, though the steps may not necessarily be linear. The steps are as follows: organisation, reading through the data repeatedly to get the general sense of the data (familiarisation with data), coding, using coding process to identify categories or themes and to generate description, contextualising and interpretation of the data.

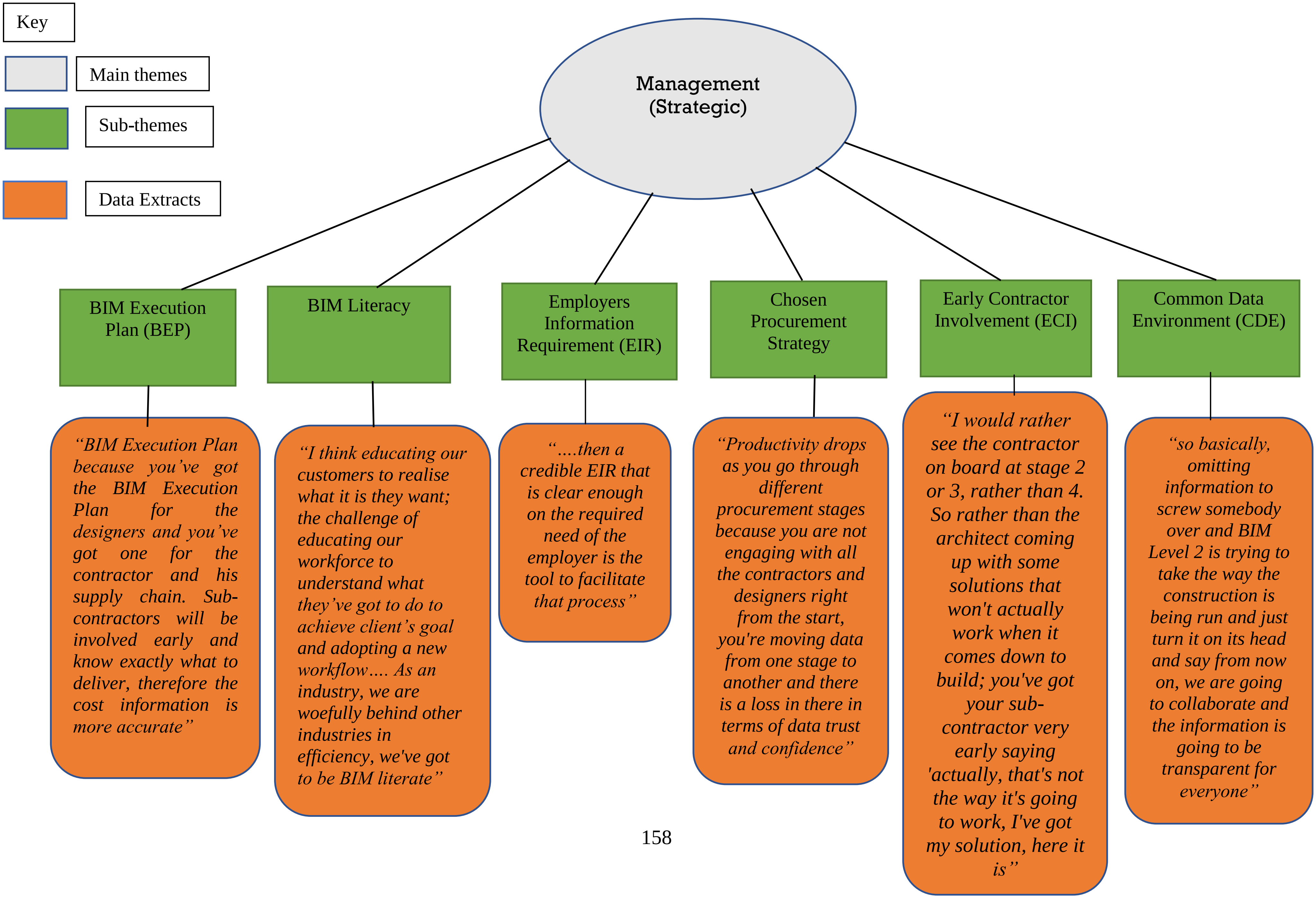
Data for this study was collected from five sectors of construction organisation covering the spectrum of construction business in the UK - Sub-contractors/Fabricators, Main Contractors, Client Organisation, Cost Consultants (SMEs), Cost Consultants (Multinationals). These varying sectors constituted seven different organisations with design, construction and cost management integrated activities/experiences (more details in section 5.0). The audio recordings were transcribed verbatim by the researcher before the analysis was carried out. The analysis mirrored the six steps as outlined above and was done manually. With some colour-coding making it possible to list codes accurately (see appendix G for sample transcript) using inductive approach to derive themes. This was done by searching for themes to explore relating to research interest and questions and grouping the themes and sub-themes from the collected data using bubble diagram (see appendix A). Significant statements, sentences and important units of data extracts were highlighted and developed into clusters of meanings forming themes (see appendix G and Figure 4.4).

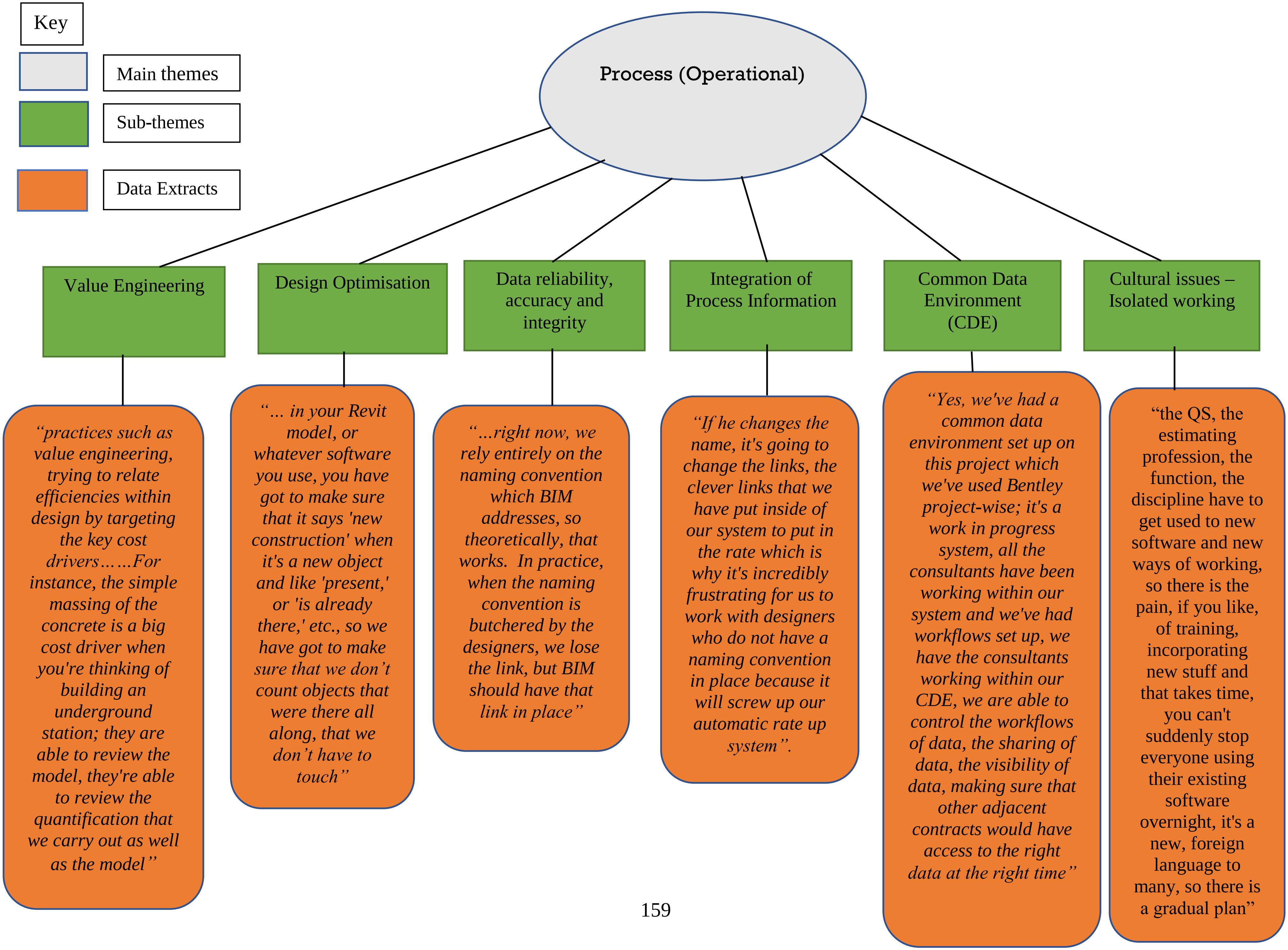
The whole transcribed data set was explored for occurring and reoccurring themes, thus the bubbles used to collate themes were further represented in a tabular form and scored (see appendix B) to both identify and select dominant themes relevant to the phenomenon under investigation. Three main themes were identified using extracted data units, significant patterns and clusters. A total of 16 sub-themes were identified (Figure 4.4) and used in the final analysis of the study which were both relevant and important to the research questions. The developed themes were used to discuss participants experience covering context and settings that influenced how the participants experienced BIM and 5D BIM workflow. This leading to the development of 5B-CF (Figure 6.2) and 5B-CP

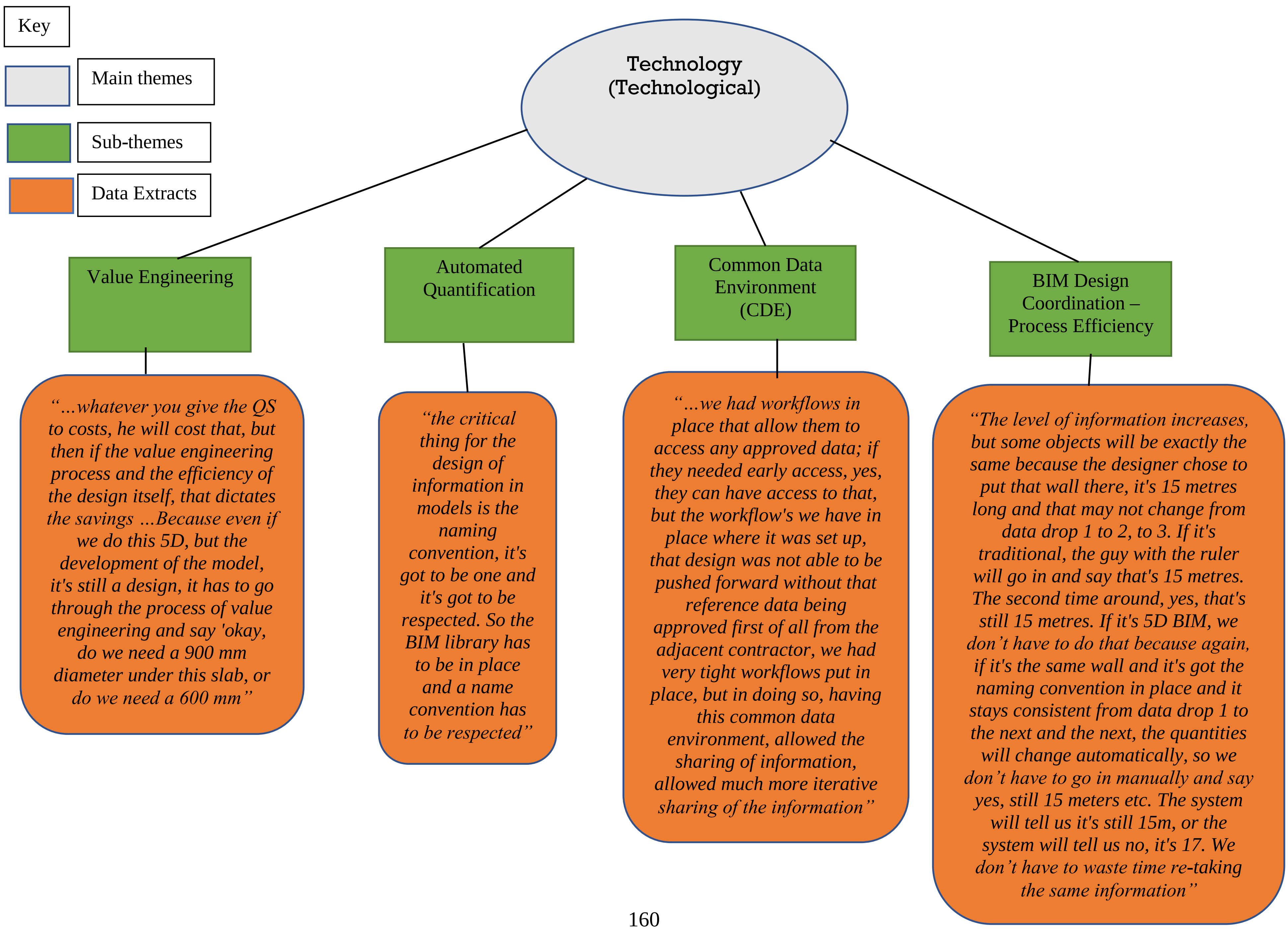
(Section 6.3). The other sub-themes identified (as seen in appendix D) could not be used as they were mirrored in the 16 sub-themes (data condensation process) that was used for the final analysis and discussion of the findings.

Participants were given pseudonym (represented by portfolio) for confidentiality purpose and adherence to ethical procedures. The initial analysis was done by engaging in reflection, identifying and using colours to highlight key words. The researcher read repeatedly through the transcribed data to get the general sense of the data (familiarisation with the data) - line by line to make sense of it and to ascertain that what has been transcribed is a true presentation of participants responses. This helped the researcher to stay true to the data and paying attention to see what themes, relationships or patterns were emerging as mentioned by Bringer, Johnson and Brackenridge (2006), while interpreting and explaining the findings. Relevant data to research interest was coded forming the foundation to the reoccurring theme across transcribed dataset. A systematic coding reflective of key phrases, research question and objectives was performed manually as earlier mentioned to categorise data with similar meanings (labelling each unit of data within a data item), generating concepts, establishing data autonomy as well as category connections (see appendix G for transcripts). According to King (2004) software can help the researcher with complex coding schemes and coding large amount of text, however it is also important to emphasise that although computer programmes may be supportive to organise and examine large amount of data, intellectualing and conceptualising processes required for data transformation is still left to subjective human judgement (King, 2004; Thorne, 2000). This gives credit to manual coding and interpretation of coded units of data as agreed by Saunders et al (2016). Welsh (2002) also argues that software may not prove as helpful as one may expect with respect to addressing issues of validity and reliability in thematic ideas that emerge during data analysis process. Welsh further said, this is as a result of "fluid and creative way in which these themes emerge". According to Ibrahim (2012) it may be better to use manual analysis in instructing data sets rather than computer based-methods. Using computer software to analyse data could help identify family of words and patterns but may not capture developing coding trend, context, and settings reflecting contextualised assumptions that is evident or underpinning the data. 5D BIM being is a relatively new concept in a virtual environment hence, to make sense of significant statements, meanings and patterns from collected data requires intense familiarisation of transcribed data. Without close and careful interpretations of data extracts, meanings could be lost in the process of intrusting coded data. As a result, coded extracts or unit of data were gathered manually as mentioned to generate different themes that emerged from the dataset ensuring validity and reliability of themes. According to Saunders et al (2016) manual approach is an analytical process with effect on reducing and rearranging research data into a more manageable and comprehensible form. Figure 4.4 below illustrates how the main themes and sub-themes were generated following data analytical process as described above:

Figure 4.4: A Flow Chart for Data Analysis Process




Key
Main themes
Sub-themes
Data Extracts
Process (Operational)
Value Engineering
Design Optimisation
Data reliability, accuracy and integrity
Integration of Process Information
Common Data Environment (CDE)
Cultural issues – Isolated working
"practices such as value engineering, trying to relate efficiencies within design by targeting the key cost drivers……For instance, the simple massing of the concrete is a big cost driver when you're thinking of building an underground station; they are able to review the model, they're able to review the quantification that we carry out as well as the model"
"… in your Revit model, or whatever software you use, you have got to make sure that it says 'new construction' when it's a new object and like 'present,' or 'is already there,' etc., so we have got to make sure that we don't count objects that were there all along, that we don't have to touch"
"…right now, we rely entirely on the naming convention which BIM addresses, so theoretically, that works. In practice, when the naming convention is butchered by the designers, we lose the link, but BIM should have that link in place"
"If he changes the name, it's going to change the links, the clever links that we have put inside of our system to put in the rate which is why it's incredibly frustrating for us to work with designers who do not have a naming convention in place because it will screw up our automatic rate up system".
"Yes, we've had a common data environment set up on this project which we've used Bentley project-wise; it's a work in progress system, all the consultants have been working within our system and we've had workflows set up, we have the consultants working within our CDE, we are able to control the workflows of data, the sharing of data, the visibility of data, making sure that other adjacent contracts would have access to the right data at the right time"
"the QS, the estimating profession, the function, the discipline have to get used to new software and new ways of working, so there is the pain, if you like, of training, incorporating new stuff and that takes time, you can't suddenly stop everyone using their existing software overnight, it's a new, foreign language to many, so there is a gradual plan"


Key
Main themes
Sub-themes
Data Extracts
Technology (Technological)
Value Engineering
Automated Quantification
Common Data Environment (CDE)
BIM Design Coordination – Process Efficiency
"…whatever you give the QS to costs, he will cost that, but then if the value engineering process and the efficiency of the design itself, that dictates the savings …Because even if we do this 5D, but the development of the model, it's still a design, it has to go through the process of value engineering and say 'okay, do we need a 900 mm diameter under this slab, or do we need a 600 mm"
"the critical thing for the design of information in models is the naming convention, it's got to be one and it's got to be respected. So the BIM library has to be in place and a name convention has to be respected"
"…we had workflows in place that allow them to access any approved data; if they needed early access, yes, they can have access to that, but the workflow's we have in place where it was set up, that design was not able to be pushed forward without that reference data being approved first of all from the adjacent contractor, we had very tight workflows put in place, but in doing so, having this common data environment, allowed the sharing of information, allowed much more iterative sharing of the information"
"The level of information increases, but some objects will be exactly the same because the designer chose to put that wall there, it's 15 metres long and that may not change from data drop 1 to 2, to 3. If it's traditional, the guy with the ruler will go in and say that's 15 metres. The second time around, yes, that's still 15 metres. If it's 5D BIM, we don't have to do that because again, if it's the same wall and it's got the naming convention in place and it stays consistent from data drop 1 to the next and the next, the quantities will change automatically, so we don't have to go in manually and say yes, still 15 meters etc. The system will tell us it's still 15m, or the system will tell us no, it's 17. We don't have to waste time re-taking the same information"

4.16 CHAPTER SUMMARY

Following a critical analysis of investigation in the field of Building Information Modelling (BIM) and its current deployment for measurement, cost estimating and cost planning in previous chapters, different strategies of research inquiry have been examined to ascertain suitability for appropriate methodology. To further the research, three major approaches to research inquiry have been considered covering quantitative, qualitative and mixed method. The researcher considered many factors that informed the choice of selected qualitative strategy of inquiry and phenomenology approach to be specific having justified and established philosophically the rational for chosen the method of inquiry and the research sample size.

The research problem under investigation, literature findings, research questions and the aim of the study confirmed the suitability of a phenomenological qualitative inquiry to be the most appropriate for the study. Four other qualitative approaches to inquiry (narrative, ethnography, grounded theory and case study) were carefully interrogated before phenomenology was chosen. This is a method of inquiry where face-to-face semi-structured open-ended interview is used establishing a relationship between the researcher, the participants and what is being researched. An approach of inquiry that carefully selects its participants based on defined inclusion criteria and the phenomenon experienced. It expresses itself in the primary objective of the research focus, describing the commonality of a phenomenon as experienced by all participants and developing a composite description of the essence of the participant's experience using thematic data analytical process to analyse collected data to generate themes. It deploys subjective interpretivism informed by research questions and aim. Philosophical assumptions and relevant worldviews to the study were considered and integrated into the methodology chapter development. Based on the data collected, analysed and the themes generated, the next chapter will present the research findings and discuss the generated main themes and sub-themes.

CHAPTER FIVE

FINDINGS AND DISCUSSIONS

5.0 INTRODUCTION

This chapter presents the findings of the study set out to achieve the research aim (section 1.4.2) and was carried out using semi-structured open-ended interview. A total of 21 participants were interviewed from seven construction organisations with design, construction and cost management activities/experience as evidenced in Table 4.4. The interviewees were asked a range of questions (see Appendix H for data collection instrument) relating to issues, problems, benefits, procurement challenges, integration of contractor's knowledge during design phase, engagement of 5D costing, incorporation of cost data as design evolves. Impact of identified challenges, involved risks, best practices and future direction of 5D costing associated with the implementation of BIM and digital quantification (automated). Scope was intentionally provided for extensive discussion to identify issues beyond the literature findings and also that which is conceived by the researcher. Transcribed recorded interview data were analysed and coded manually to generate predominant themes, significant statements, strong sentences, important details and relevant quotes from the respondents as highlighted (Appendix G).

Each interview question was analysed under five (5) various organisational categories – Sub-contractors/Fabricators, Main Contractors, Client Organisation, Cost Consultants (SMEs), Cost Consultants (Multinationals) – Appendix A. The output predominant themes of each question (Figure 4.4) were the views of different participants occupying various roles within the construction organisational categories. The generated predominant themes (analytical outputs) were again put in a Table under same defined categories to determine theme score and then highest scoring theme(s) as shown in Appendix B. This helped the researcher to critically analyse collected data under organisation categories, interrogate issues to investigate initiatives being undertaken, to summon solutions with extensive positive impact towards the industry and to identify future needs. Highest scoring themes through data condensation process (section 4.15) became dominant sub-themes for the development of a 5B-CF with potentials to facilitate costing in a contractor-led project. The outcome of the framework evaluation by key industry practitioners is used to develop 5B-CP. Building Information Modelling (BIM) is about Management (Strategic), Process (Operational) and Technology (Technological). The responses from the interviewees are either referring to the management strategic decision regarding BIM implementation and processes, the influence of strategic decisions on process implementation at the operational phase or the technological tool to support the process implementation at the operational level. Thus, the three main themes - Management (Strategic), Process (Operational), Technology (Technological).

5.1 RESEARCH RESULTS

Following a phenomenological data analysis procedure of a qualitative method of inquiry, transcribed semi-structured open-ended interview data was analysed using thematic analysis, - generating three major predominant themes and sub-themes relating to issue of cost and BIM as shown in Figure 5.1:

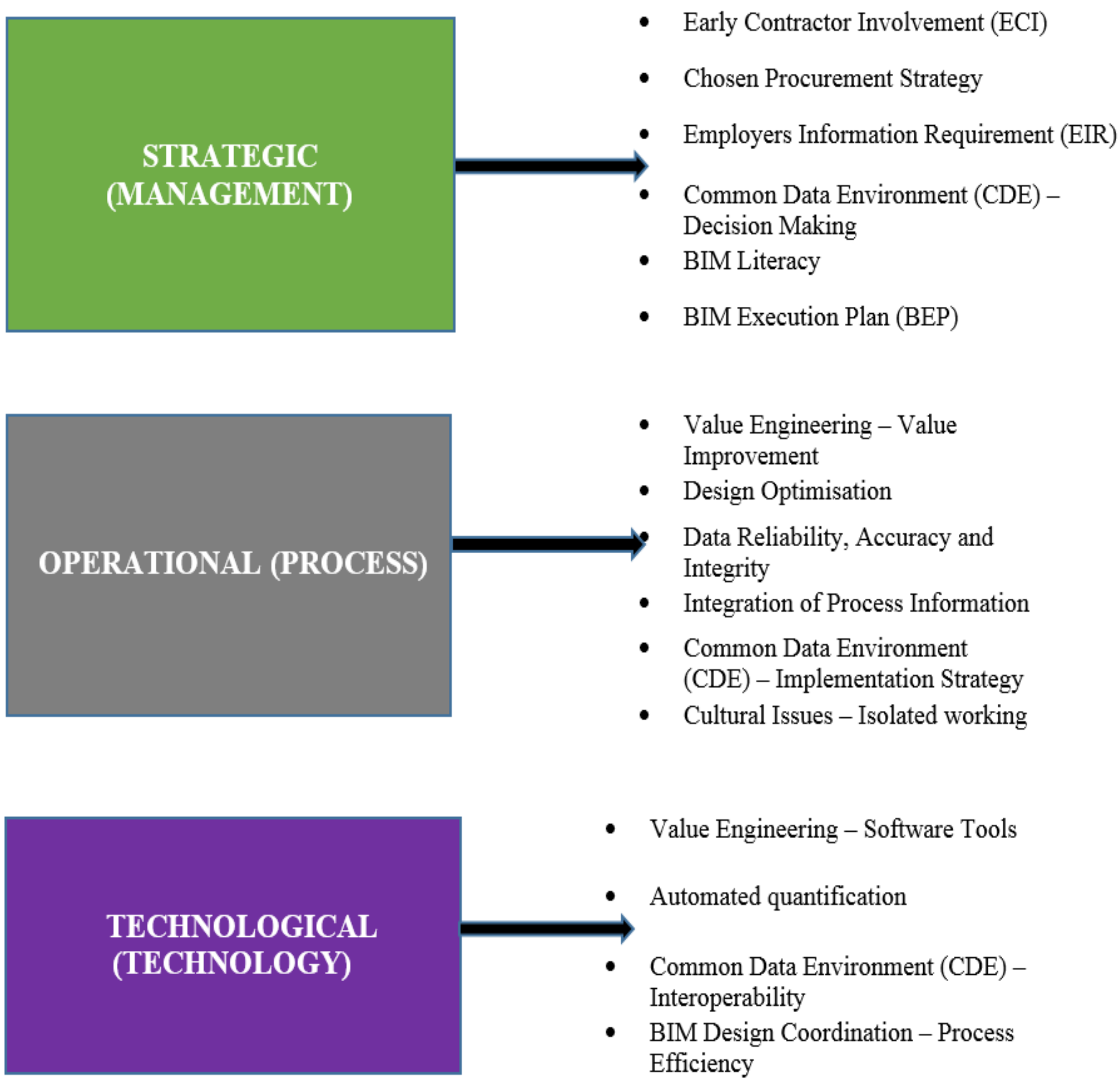


Figure 5.1 Main themes and Sub-themes

Building on the data as transcribed and analysed from various conducted interviews across a spectrum of relevant organisations with experienced participants across various BIM functions regarding the phenomenon under investigation - significant statements, quotes and sentences were underscored which provided an understanding of how the participants experienced the phenomenon under examination. A cluster of meanings from the underlined significant statements, sentences and important details, themes were developed by the researcher. Leveraging the significant details or underscored sentences of the participant's experience captured within the interview data, themes and sub-themes is fully described engaging textural and structural description. This looks at the context or settings that influenced how the participants experienced the phenomenon and is referred to as imaginative variation or structural description according to Moustakas (1994). The textural and structural descriptions aid the researcher to write up the composite description that presents the 'essence' of the phenomenon called the essential, invariant structure (or essence).

Organisations within the UK construction industry (sample population) who participated in the research study through interviews were a selection within the construction supply chain that engaged in virtual environment. This ranges from Main Tier 1 and Tier 2 Contractor's Organisation, Client Organisation, Sub-Contractors/Fabricators (Offsite Manufacturers), to Cost Consultants (Multinationals) and Cost Consultants (SMEs) as shown in the data analysis Figures and Tables comprising small and medium sized firms, large contractor firms, client organisation (delivery partners) and multi-disciplinary design consultants. Some of the firms had global experience on how BIM was being implemented in other countries of the world which puts the findings of this study at the vanguard of extensive industry impact and application though the research scope was confined to the UK construction industry.

5.2 MANAGEMENT (STRATEGIC LEVEL)

Research has shown previous studies to have focused much on the technical aspects of BIM while neglecting the role or the perspective of management towards enforcing smooth implementation process through clarity on project and data requirements (Arayici et al, 2012; Stasis et al, 2012). BIM as the suggested panacea to addressing construction inter-disciplinary challenges and inefficiencies – integrating business processes of various construction stakeholder's practices is seen to have huge positive impact on projects if requirements are clearly defined and enforced in contractual process by the organisational management. Organisational informed perspective will adopt early contractor involvement, address procurement issues on digitised infrastructure and building projects (standards, repositories and required technical information), define organisational information requirements and employers' information requirements (EIR), with impact on common data environment, BIM literacy and BIM execution plan. It will also enhance construction productivity, reduce lifecycle cost, lead times and duplication, improve building and infrastructural value, quality and efficiency and sustainability aspirations.

5.2.1 Early Contractor Involvement (ECI)

Early Contractor Involvement (ECI) is an aspect of the growing trend for early project collaboration across the industry allowing contractor's early involvement within the project team at the outset of a scheme bringing expertise in planning, buildability, cost estimating and value engineering (Garlick, 2016). ECI allows the contractor to be engaged in a project under a two-stage Engineering and Construction Contract (ECC) before project details regarding what is to be constructed is fully developed and priced. This enables the contractor to be involved and integrated within the design development and construction planning stages of a project early enough to make a valuable expertise input. This approach promotes team working, collaboration, innovation and good construction planning through the whole project and sharing benefits gained through such team working. NEC has recently developed an additional clause to be used with the NEC3 Engineering and Construction Contract (ECC), options C and E where ECI approach is required. The traditional approach within the construction industry in a single-stage procurement and contractual models has only involved the contractor and its subcontractors only at the construction phase. However, such a model is not likely to obtain the best contributions of all parties to a successful project due to the exclusion of the main contractor and subcontractors from the early design and project planning. As a result innovative solutions, constructability, cost saving benefits, overall project timescale, health and safety planning into the design has been adversely affected. Experience has shown that value for money is not achieved in either the final cost of construction or the whole life and operational costs (Pittard and Sell, 2016).

One of the interview questions was on the respondent's perspective on contractor's involvement in a design phase or design model development of a BIM process. Respondents from various organisational categories – Sub-contractors/Fabricators, Main Contractors, Client Organisation, Cost Consultants (SMEs), Cost Consultants (Multinationals) and majority of the respondents had the opinion that getting the contractor involved early in the project has a huge cost benefit impact on the overall cost of the project and also generates a better value for money. One of the respondents who is a 5D BIM Information Manager from a cost consultancy firm had this to say when asked his views from his current work experience regarding contractor's involvement on projects. The respondents view was the following:

"Currently in a D&B project, the contractor comes in at stage 4 which is the last stage of design in RIBA Plan of Work stages and carries it to completion which is not good

enough. I would rather see contractors coming in earlier than stage 4 in a two stage D&B tender - having a contractor involved with the project earlier than stage 4 has benefits in terms of earlier buildability analysis, earlier supply chain sub-contractor procurement solutions, advice on buildability, advice on value engineering, the whole supply chain of sub-contractors and their solutions, health and safety issues, early advice on costing and programme etc; I would rather see the contractor on board at stage 2 or 3, rather than 4. So rather than the architect coming up with some solutions that won't actually work when it comes down to build; you've got your sub-contractor very early saying 'actually, that's not the way it's going to work, I've got my solution, here it is. The biggest advantage of an early contractor involvement in the project is the transfer of risk from the designer and the client over to the contractor. The advantage will reduce the design errors passed to sub-contractors" (5D BIM Information Manager – Cost Consultancy Firm (SME))

Another respondent from a cost consultancy firm – a 5D BIM QS also agrees with early contractor involvement and said; *"I tend to think that getting a contractor involved as early as you can is generally a good idea. It's not something that's necessarily done in the industry and I guess it depends on the type of contract as well; if you're using a traditional type of contract, in theory, the contractor wouldn't need to have any input until post-tender. D&B would be slightly different, particularly if you've got Value Engineering (VE) items where you want to get the contractor's input to try and drive down costs, or make things simpler. So I would say as early as possible"*.

A BIM Information Manager from a sub-contracting firm was also in agreement and has this to say when asked the same question *"Every project should be like a joint venture* *almost, like an integrated project delivery (IPD). Nobody's there at the moment, but that approach where the contractors or the sub-contractors are brought in early for their design knowledge is as soon as possible. I've always asked the question 'why aren't we there earlier?' Is that not going to be the thing that increases the advantages, having our expertise at the outset stops them designing something incorrectly. So if we're talking 'where do they come in initially? It should be right at the very outset, I'd say even once the brief has been given, that's where contractors should come in. I think for it to work well, you have to involve the contractor straight away, at the end of stage 1/start of stage 2".*

Another participant reiterated this perspective further *"We've got a transition to move from silos activities still into a shared environment and federated models and so on; the benefits will be for a 5D QS, you would be involved a lot earlier in the process, you would have more opportunity to add value to the process because your valued cost advice would be able to influence the project at the earlier stage and everyone understands the earlier in the process, the bigger changes you can make and I think it will just integrate the cost into the early stages of project development from where it had been relegated to, traditionally".*

Early Contractor Involvement and the supply chain is exclusively a management decision with positive impact on project outcome. The strategic protocol on project initiation should be such that supports design process to be linked to contractors cost and schedules reflecting contractor's BIM Execution Plan. Contractors initial design response to the client if involved early in the project development should integrate the clients agreed programme of schedule and cost to their internal programme linking design, cost and schedules. 5B-CP as developed using the key findings of 5B-CF should be part of the competency assessment for generation of accurate cost information and should be submitted alongside BEP. Leveraging on the contractors professional input at the early stages supports a 5D BIM costing approach rather than the late stage traditionally led approach that is error prone. It supports the 5D BIM QS to interrogate a 3D model for early cost estimate and cost planning advice and strengthens the internal gateway processes of the client to achieve design stage cost targets. It is an early decision that empowers the clients with knowledge, skill and appropriate exposure to streamline design and construction processes. The participants views on ECI is very clear regarding the early project benefit of getting the contractor very early on board. One of the respondents who is a BIM Strategy Manager from a client organisation gave this response when asked same question

"*Right from the start, it has to be done from the conception, or from planning stage because from a client perspective, we need to make sure we've got clarity on data, so it's not just about the physical assets, but also about what information, or what digital data we need in order to design that asset, build it and operate and maintain it at the end, especially because I worked in TfL as well, from an operator's and owner's perspective, that clarity on requirements and communicating it right from the start is key".*

At the moment contractors are involved at a later stage during design model development, and at this stage the benefits of contractor's vast experience and inputs within the design processes are lost. Late stage involvement reverts the entire digital initiation to a traditional costing approaches and destroys client's feasibility studies. The procurement strategy chosen by the client for the project largely affect what input and benefits could be realised from the vast experience of the contractor and the supply chain as flagged by the respondents. Contractor's inputs and benefits in terms of buildability analysis, procurement solutions, health and safety advice, building systems performances, engineering systems performances, supply chain input and assessment on supply chain competences, sustainability aspirations and checkpoints, performance criteria, and energy conservation are positively impacted. Stage design checks with respect to elemental cost limits, performances, project objectives and varied strategies are carried out, design data verified and validated before passing on to the next stage. Late involvement creates lots of myriad cost issues within the construction phase where opportunity to design changes are very minimal and even if it occurs, the high impact cost of change at a later project stage affects the overall project budget. But early contractor involvement does not only provide benefits within the design development, basically the contractor takes the risk for all of the design early on which is great for the client and the design team, it is one of the biggest advantage. This both challenges and mitigates the impact of design errors that is passed to the sub-contractors.

A design manager from a subcontracting firm also subscribed to the same views as above and also cited a project case: *"So most of our projects that we get involved with are extremely complicated and we are only looking at maybe 10 per cent of the overall project. Most projects are design and build of a whole facility, we don't do whole facilities, we provide ventilation systems. Complicated ventilation systems probably only equate for about 10 per cent for the cost of an overall project. So most of our projects,* *there is a main contractor and he will do a concept design, he may do a detailed design. When he's finished the detailed design, he may produce a technical specification and go out to tender to ductwork manufacturers like our groups"* (Design Manager - subcontractor firm).

On further questioning, the design manager from a sub-contracting firm continued to say this:

" ……. at that point, you're given a model, it could be in any software that's available, it could be Solidworks, it could be PDMS, it could be Revit, it could be anything and the client, all he wants you to do is add a level of manufacture design, so you're not responsible for the design, i.e. will those fans work? Will those air handling units work? Is the size of the ductwork correct? That's all his responsibility and our responsibility is to turn that into a manufacture design, manufacture and install it and then he will commission it and make sure that his design works.

The design manager further narrated the opposite as experienced while working on design phase of a project by saying *"….Then you have the total opposite contract of where we do the concept design, so all the way through. We come into these contracts in any of the phases from the beginning of the design until almost the end of the design and it's up to the individual, main contractors to determine where the cut-off point is and where we add value to their scope. We're trying to convince them that we can add value earlier on because quite a lot of the time, if they do a model in PDMS, we can't convert PDMS, so they spend three years doing a design and it arrives in a software that we can't convert, we almost have to trace over that information and re-draw that information, to put it into a software that we can use, and that's not adding value, you're repeating the* *work all over again. What we try to encourage clients and demonstrate to them is that we can add value by getting involved sooner on some of these projects".*

The respondent cited a project case where early contractor involvement had impact on cost efficiency, collaboration, and information sharing and time savings. Early involvement of the products manufacturers and integration of the sub-contractor manufacture experience, knowledge and expertise solutions in the design phase added both cost and time value throughout the project design and manufacture duration. The below project case further consolidates the positive impact of early contractor involvement in achieving project cost limit, process efficiency and overall timescale.

5.1.1.1 Project from SME Organisation

The project cited focused on a single high value project within the host organization whereby clients design consultant had identified early within detailed design, that their traditional design team had little experience in coordinating traditional building services and ventilation systems. The design consultant was using BIM clash reports to manage the detailed design layout, but was not controlling coordination or access requirements which can then move the problem further down the programme and into manufacture design. This approach would have brought about considerable reworks of the HVAC systems after the coordinated model for detailed design had been approved. In embracing the manufacture design team early and embedding the team into the traditional detailed design, enhanced the teams overall capabilities to deliver a rounded solution. The manufacture design teams brought practicality into the routing, coordinated support structure, which will save on installation time and cost.

The value transition point for this project was much earlier than has become traditional, as the drawing and routing design works was led by the manufacturer rather than the clients design consultant, as it is them that has this practicality and knowledge of the product. The early involvement of the manufacture designers added 5D cost value to the design scope at that early point of entry, challenging design liabilities, and design details that come in excess of what's required at that design phase. Again, receiving a completed design model in a file format that cannot be converted (like solidworks, PDMS) by the manufacture designers is not value add, it means retracing that design information and redesigning it for appropriate use. 5D BIM automated processes with this approach brings confidence in the detailed design output and cost information; this confidence allows the project to move directly into manufacture once the detailed design gate has been achieved. Having a huge cost and time savings on the normal costly tender exercise / contract placement and quality assurance documentation/ manufacturer familiarization period as could be seen in Figure 5.2 and 5.3. The study highlighted exemplar usage of 5D BIM and ECI. The early contractor involvement of the design-manufacturer company eliminated the tendering process since the cost is being derived in collaboration with the client design consultants alongside the manufacture designers. The project case highlights ECI supported the client's design consultants in designing to a correct level of detail for use in the manufactures and positively impacting on the overall project cost.

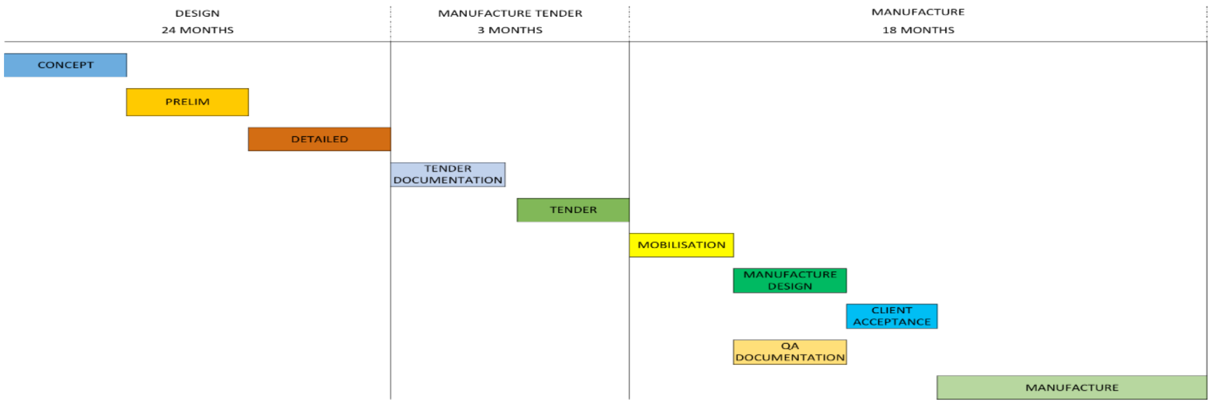


Figure 5.2 Traditional Costing QS Approach

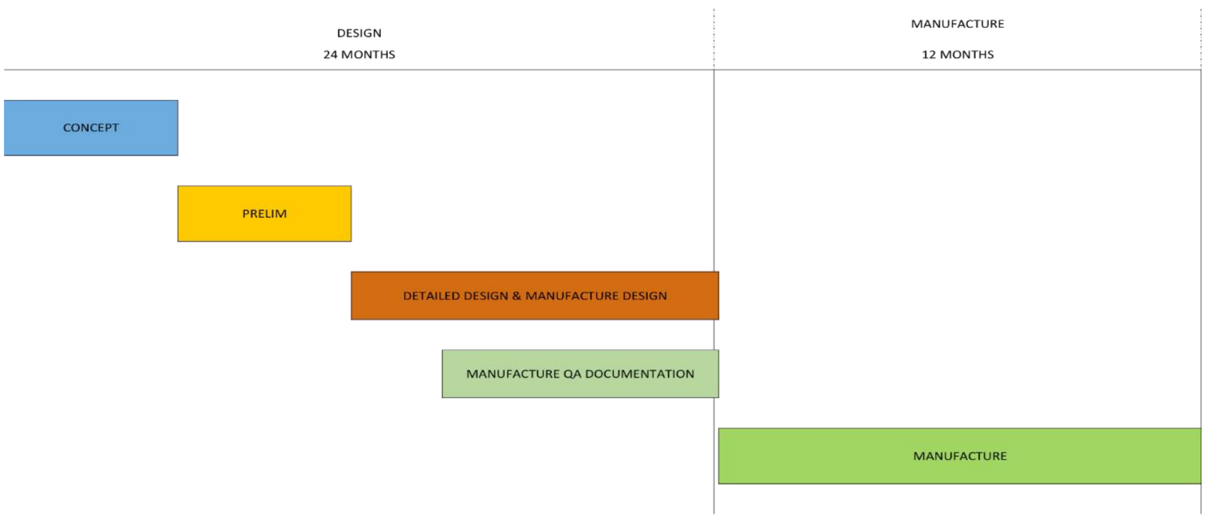


Figure 5.3 Early Contractor Involvement Project Case

The traditional approach involved the team much too late in the project development and therefore providing limited scope for innovation, cost considerations, knowledgeable inputs into the design phase and the consideration of constructability issues. It is expected that the designer's team, consultants and contractor's team work together from the very beginning upon which the premise of the ECI is based. ECI supported through the BIM process is a credible means for cost savings and rewards cost-benefit ratio with respect to initial process investment for the manufacturers. It offers potential project merits in avoiding and managing project risks, predicting cost and project time, encouraging innovations and better project. As a consequence, the industry should embark on a sustained campaign to cushion the effect of performance problems through a number of initiatives and radically different approaches to the procurement and management of construction projects to enable ECI. Employers should leverage on the valuable expertise of contractors from the brief definition stage right through commissioning to ensure a maximised streamlined process and a support for automated quantification process in order to deliver a reduction in overall project cost. Emerging project delivery methods should increasingly rely on collaboration between the client, designer and contractor together with their supply chain, and are aimed at developing longer term positive relationships for the benefit of all involved parties.

5.1.1.2 Benefits of Early Contractor Involvement and 5D BIM

- Removes the normal costly time consuming mid-term tendering process.
- Knowledge retention through-out the whole project delivery.
- Visualisation of cost information by all parties involved
- Ability to interact with the design model with reference to cost and programme schedule
- Enhancement of project team collaboration through modelling of 5D information and generating the suitability of 3D design information.
- Project conceptualisation as 3D design information facilitated the costing of design options through ECI

- Efficient generation of quantities for cost planning as compared to the traditional QS processes during the manufacture design detailed cost plan stage
- Contract arrangement more likely to encourage a fit for purpose solution.
- Increased ability to resolve RFI's in real time, potential risks identification and clash detection possibilities
- Substantial time and cost saving exist for the project, as the Quality assurance documentation and manufacture design detail can be completed earlier - during the detailed design phase, further enhancing the benefits identified in item one above.
- Commencement of the Quality Assurance documentation can only commence in manufacture design, this documentation is quite likely to take longer than the manufacture design and in some instances delays manufacture.

ECI is very beneficial, the contractors build the facility. Designers sometimes do not have an oversight in what can actually be built and this is the reason early engagement model of involving contractors very early on to inform and influence buildability is critical at the moment. They construct the facility and therefore having a decision from the management for early contractor involvement and getting the contractor and the supply chain on board early makes sure that there are no surprises. When the contractor doesn't get involved until very late in project stages, they get to site and flag non-buildability, extended design errors and clashes. Thus the reason for a shift in the approach in terms of procurement. The buildability and options, appraisals, contractors and supply chain coming up with the solutions that they are certain they will be able to build and that would then feed into the estimating process and aligned to what can be built. When people bring in contractors, infrastructure projects and clients, contractors and the supply chain should be on board from stage 1 of the RIBA Plan of Work 2013 to make sure that the 5D cost information generated with design progression and buildability is assured.

5.2.2 Chosen Procurement Strategy

The Procurement Strategy chosen to deliver either a public or private sector project is critical to the project success with respect to meeting client's requirement in procuring that project-capturing and developing 5D model information effectively from the start to ensure that design, regulatory, construction and supply teams are able to collaborate efficiently, making use of well-structured and integrated cost information. Considering Government Construction Strategy to implement BIM Level 2 within the UK construction industry, it has therefore become imperative to ensure BIM requirements are embedded in the procurement processes from the early stages of RIBA Plan of Work guidelines – tailored to suit project needs and specifications as outlined in Figure 5.4. All construction supply chain should contribute to the information that answers the employer's Plain Language Questions (PLQs) in terms of cost outputs. A 5B-CP has been developed in this research to act as part of BEP.

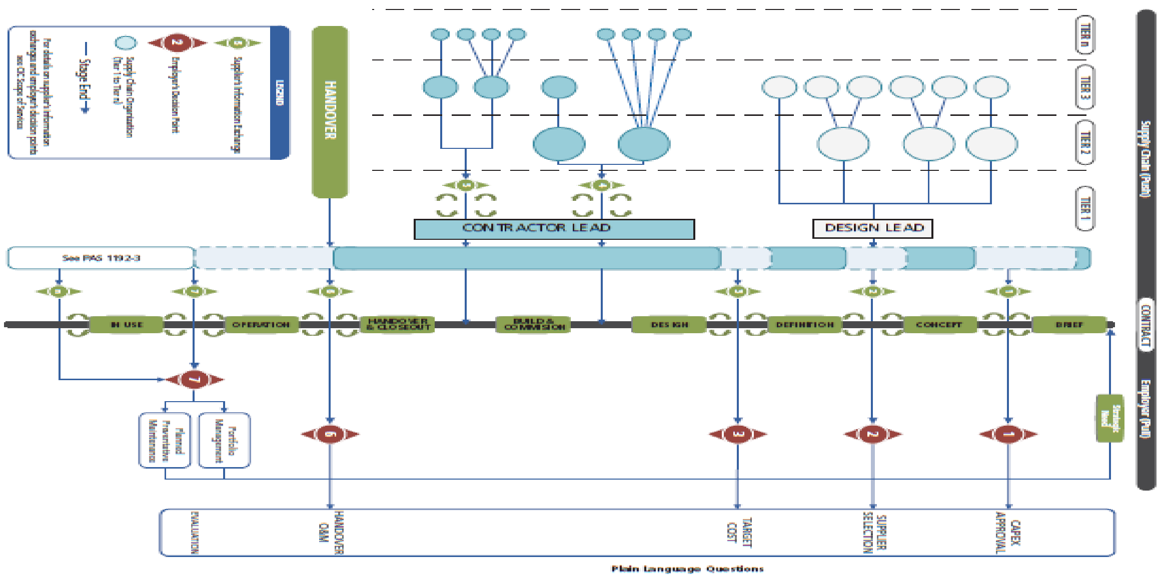


Figure 5.4 Supply chain information contribution to answer Plain Language Questions (Source: BSI, 2013)

A well outlined and defined procurement strategy by the client should reflect a fundamental principle of client's specific idea upfront of the information required from the supply chain showing protocols that meets cost targets and when this must be delivered Figure 5.4. This enables BIM deliverables to be adequately priced and accepted by suppliers of construction products. Procurement creates an opportunity for early evaluation and assessment of capacity, capabilities and competence (resource assessment, information technology assessment, building information management assessment) of the suppliers (eg Main Contractor, specialist trade etc) and their supply chain together with the details of their approaches. It demonstrates how sufficient the suppliers proposed approach is to meeting the client's Employers Information Requirement (EIR) and the cost limits of building components at different stages. It goes a long way in testing the compatibilities of suppliers approach to delivering the contents of the EIR as contained within the Information Delivery Life Cycle (IDLC). The CAPEX (capital expenditure) and the OPEX (operational and maintenance expenditure) strategy are set within the procurement strategy and provides a real time feedback platform to the clients for realistic evaluation of their projects with respect to whole life costing and decision making.

Some of the research interview questions were tailored to examine the impact of procurement position with respect to contractor point of entry or involvement in BIM model development considering RIBA Plan of Work 2013 stage gates and in accordance with PAS 1192-2 and what the cost implication could be. The overall client asset strategy and project life cycle (CAPEX and OPEX), the link between contractors and their supply chain, the important role effective procurement strategy play for a seamless BIM Level 2 implementation throughout the whole life cycle costing (WLCC) reflecting correct specification of information requirement was discussed. Further interaction on the strategies adopted within a chosen procurement model to meet the set cost target of an employer and the real time feedback mechanism to monitor and control cost limits of components as data drop increases were initiated. Respondents across the spectrum of industry practitioners engaged for the research purpose had their views regarding interferences a fragmented procurement approach or model could bring into BIM processes. A respondent who is a BIM Strategy Manager with a Client Organisation said the following when engaged with a question on procurement position and how it affects the contractor's point of entry and value add:

"In order for us to get to Hybrid Bill, we had to work with a bunch of designers and now design has been developed to a level of maturity and we are going out again for a D&B

contract, so now the contractors are coming in, a different bunch of contractors, different to the designers; so they've had no involvement in the previous design stage and we are, effectively, just handing over that information that's been developed during Hybrid Bill to the contractors, to develop it to a scheme and detailed design. Procurement has always been an issue; we need to have early engagement, we need to make sure the data that's coming back we have confidence in the integrity of that data, then at least that could resolve some of the issues, but because we don't have any integrity, or we don't have confidence in the provenance of the data that's been delivered during the first stage, effectively, the contractors might have to start from scratch. Productivity drops as you go through different procurement stages because you are not engaging with all the contractors and designers right from the start, you're moving data from one stage to another and there is a loss in there in terms of data trust and confidence"

The respondent who at the time was dealing with loads of challenges given their chosen procurement model chosen and the effect on the generated cost information for initiated projects. In the views of the respondent, going for procurement at each delivery stage gate became problematic to already defined project cost and had a negative impact on the overall project outcome. Absence of continuity and consistency in procurement solutions in their BIM processes affected already defined data requirement set by the employer, interfered with 5D cost expectations and contract programmes at different stages. This created risks within the process, lack of data trust, lack of confidence and integrity in data provenance and made the entire process very inefficient. In other words, procurement methods certainly need to change, because for a process to be efficient, it does not only have to be with BIM but continuity in available information. One of the standards which

is BS11000 is a good example of establishing those relationships right from the start of the project and keep those relationships with the same designers and contractors. It has to be alliancing and partnering and those type of contracts, but right from the start of the project avoiding different procurement solution at every project stage which currently affect the integrity of BIM processes and the 5D output of cost information. Absolutely 5D BIM solutions is a lot of value in meeting project objectives with respect to cost targets, cost certainty and for quantity extraction accuracy. However the adopted procurement model would need a more bespoke definition for those values to be realised.
Looking at the RIBA stages, procurement solutions need to be consistent and run through all stages without changing it every time a stage gate is reached, it has to be a procurement that runs through all the way through the plan of work. Currently organisations go out to procurement every time they reach a design stage and then a new bunch of contractors and supply chain come on board without any prior understanding, or knowledge of what has previously happened in data and design development. Clarity of client's requirements reflecting consistent procurement solution through design and construction stages is critical to projects success. If the employer is clear right from the start what information requirement is needed, clear on exactly how to deal with data drop increase, clear on how to assure it and how to govern that data as they develop - possibly some of the issues existing currently with the procurement method could be eliminated - procurement issues and clarity on client requirements and planning. Take for instance, you are going out to procurement for different contractors and different designers, the procurement model should be able to offer early visibility of what contractors and their supply chain are proposing to do, outline their internal processes and identify the systems

they will be using through pre-contract execution plan. This way processes between the client, contractors, designers and supply chain that takes into account the cost information generation “5D model” during design and construction phase, the contract programming “4D model”, health and safety issues, asset strategy, performance criteria etc will be integrated and synchronised from the common data environment (CDE) viewpoint. So the procurement solution that enables consistency from early contract stages will support automation of workflow facilitating the use of 5D BIM within the processes. The underpinning factor here is early visibility of construction suppliers BIM Execution Plan (BEP), early visibility of suppliers Project Implementation Plan (PIP), early visibility of Information Delivery Plan, early visibility of information management plan, commercial management plan, competence assessment of suppliers supply chain, collaborative production plan. The clarity on clients information requirements and how suppliers BEP answers the clients Plain Language Questions at different stage gates of the Plan of work.

A consistent procurement strategy that will ensure early engagement of the construction suppliers and their supply chain, an internal assurance processes of data procurement, Project Information Model (PIM) deliverable strategies, project milestones and programmes that improves productivity and how that sufficiently meet the Employers Information Requirement (EIR). According to BS11000-1:2010 which is British Standard that provides a framework specification for creating collaborative business relationships, there is need to maintain a consistent procurement relationship model that runs all through various project stages without going to procurement at every stage gate. The BS11000 requires a greater management structure and processes in the management of workflow relationships, sets out framework for best collaborative practice principles, improves the way collaborative business relationships are created and managed. It offers measureable benefits in a collaborative working environment. To successfully demonstrate the capabilities of its collaborative strategy and to objectively generate 5D cost information within the BIM level 2 processes, appropriate procurement solutions would need to support that. Figure 5.5 below shows a UK Government Digital Plan of Work with stage gates; these project stage gates should see a consistent procurement to enable the stages deliver the needed collaborative benefits and values consistent with BIM Level 2 implementation strategy enabling 5D automation workflow.

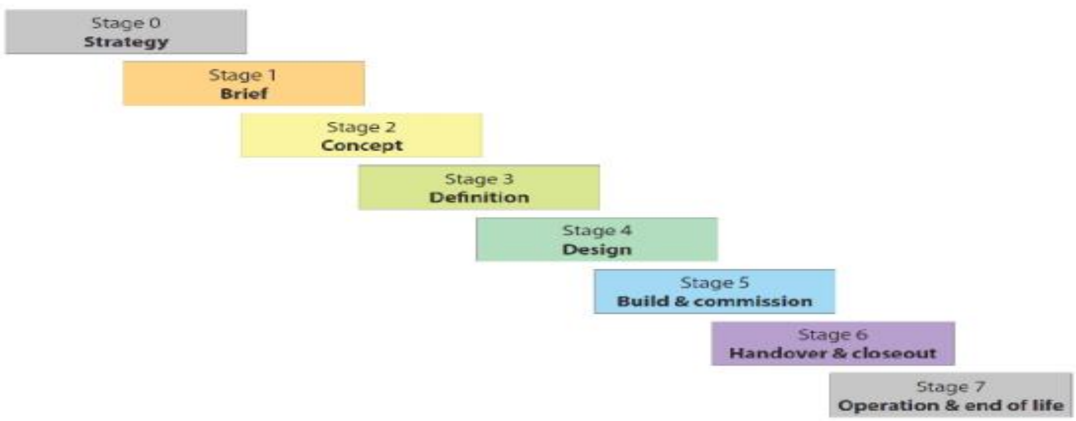


Figure 5.5: UK Government Digital Plan of Work (Source: RIBA 2013)

Working in partnership with other organisations or project disciplines allows you to share knowledge, skills and resources effectively – helping all involved to meet mutual goals but the current procurement adopted by the employers as found by this research does not engage or encourage consistency and reliability of processes from the suppliers (contractors, designers, specialist trades, supply chain etc). This is a barrier to the implementation processes of BIM level 2 with its specification and standards. It is an impediment to the ambition of the Government Construction Strategy to improve productivity, efficiency and reduce waste and operate a very cost effective asset maintenance. The soft landing strategy and the construction lean approach of the UK construction frameworks, specifications and expected process efficiency will be compromised with the existing procurement methods.

Another respondent from a client organisation had this view, *"At our big project level, there are two issues with procurement strategies of public sector procurement. You are constrained by the rules that are laid down by the cabinet office, the government in general - and they have a very rigid and robust process you have to go through, so you are constrained, to a certain extent, by the rules and procedures, but it is a problem in that if your procurement strategy is based upon how you've always done it, then you will lose out on innovative approach coming in from the supply chain. I would procurement in the industry is very traditional at the moment and as a consequence, might/might not give you the best value for money for what you end up with; it will give you a good value for money, but might not be the best because you are restricting on how people can do certain things, but it's more problematic looking at BIM process and BIM should allow you to engage with the supply chain early enough to have a seamless transfer of data and information at a contractual level … an accurate level of data as well"*.

From the respondents view, if the procurement strategy is not asking for early involvement of construction service suppliers, or it is not very clear on consistency through all project stages, then BIM Level 2 implementation might be difficult to achieve. What this suggest is that the employer's information requirements which should be supporting the procurement strategy and the procurement documents that go out need to be very clear on how things should be done on BIM projects or information and data, then analysis of information at contract level/programme level could be properly followed. At the moment, the clarity of what the contractors should provide is ambiguous. If the design part of the procurement strategy and the commercial viable procurement strategy are not all aligned and not structured in a way that sets of procurement model criteria questions are answered, then it becomes extremely difficult to do certain required analysis. The current procurement issues hinders analysis of the schedules of services for the right cost and affects risk management protocol. Once data is not procured and governed in the correct format for easy use, lots of time is wasted on a constant review of poor data. Getting the data formats correct contractually between the supply chain and the client organisation generates an integrated BIM process and cost information extraction.

Another respondent's view from a Cost Consultancy said *"If we're taking a traditional method, the contractor is going to come in at stage 5 which is way too late to do any design work, so all he's going to literally do is take the model and build it. There's no design solutions from the contractor, he's just got to build what is handed to him; there's no advice of any kind, to me that's bad because the contractor knows better than the design team, how to build an asset and so if he doesn't have any design input because he came in at stage 5 which is construction phase, you don't benefit from his inputs and experiences. The use of BIM is going to encourage contractor-led procurement rather than traditional. Traditional is the way things are being done right now and I think it's going to slowly transfer to D&B being the major way of doing things because it encourages the early involvement of the contractor through the transparency of* *information, so to me, that's where it is going to go ... more D and B rather than traditional"*.

Looking critically at the respondents' views above, it is very clear that currently the client defines the procurement strategy which is mostly traditionally led projects. The strategic decision for an effective procurement model to be used in 5D BIM projects will shift to the contractors who know better how facilities are built. The decision for a contractor-led project team will be in conjunction with the client because of its impact on the procurement of project party members. A core Stage 0 function of the RIBA Plan of Work 2013 should decide whether a procurement model is to be traditionally led or contractor-led as it impacts on the assembling of the project team for later stages and output of 5D cost processes looking at the pros and cons of either approaches. Where a traditional approach is proposed or a traditional team that converts to a contractor-led approach through novation of the design team to the contractor, contractor's involvement should still influence and to a great extent dictate the roles and functions of certain project parties at different stages of the project. A contractor-led procurement will support a seamless implementation of BIM Level 2 strategy, consistency in procurement through different stage gates, data integrity and reliability and to gain massively in terms of waste reduction, productivity hike, time and cost savings.

However clients should be equipped with upfront ideas of their BIM expectations, recognising the value of having BIM strategy in place from the outset to better start the process. Adopting a procurement model that engages Early Contractor Involvement (ECI) reflects the UK Government Construction Strategy (2011) stating that "BIM is a way of working that facilitates early contractor involvement, underpinned by the digital technologies which unlocks more efficient methods of designing, creating and maintaining our assets". Currently, advice on the selection of procurement models focuses majorly on identifying which team member(s) are liable for design risk and how to alienate that design and construction risk away from the employer. However, to achieve a more collaborative integrated approach, a BIM focused procurement model should incorporate means to obtaining early enough BIM model contributions from the supplier and the supply chain without causing delays or impacting negatively the warranties relied upon by the employer. Procurement models should be designed to achieve cost and time efficiencies which do not submit to the temptations of market forces (low pricing) but rather focuses on the collaborative Government objectives through Early Contractor Involvement (ECI) and Building Information Modelling (BIM). This research is strongly advocating a contractor-led procurement for a seamless Level 2 implementation and consistency of procurement model throughout the project stages. This allows for earlier involvement of supply chain and specialist subcontractors, ensures buildability, provide solutions for associated health and safety issues in the design process, considers earlier site logistic issues, assists in minimising contractor's allocation of any risk allowances and facilitates quicker start on site. A contractor-led procurement solution is better positioned to advice the client on the information requirements for different stage deliverables in a BIM process and how that influences a 5D cost output in achieving project outcome.

5.2.3 Employers Information Requirement (EIR)

Employers Information Requirements (EIRs) are produced as part of a wider set of documentation for use during project procurement (procurement of the design team and the contractor) and is developed to constitute part of employer's requirements or tender documentation. Reviewed literatures as showed in Figure 5.6 revealed that a clear assessment of upfront client need is key to seamless implementation of BIM level 2 strategy and accurate generation of cost estimate (RIBA, 2013; BSI, 2013). The information contained within the employer's requirements facilitates well-informed decision making from the contractor and the supply chain, and that means greater clarity of design information, better visual communications, and ultimately better cost efficiency. Cost savings of around 33% across CAPEX and OPEX are possible by following a Level 2 BIM process (NBS, 2016).

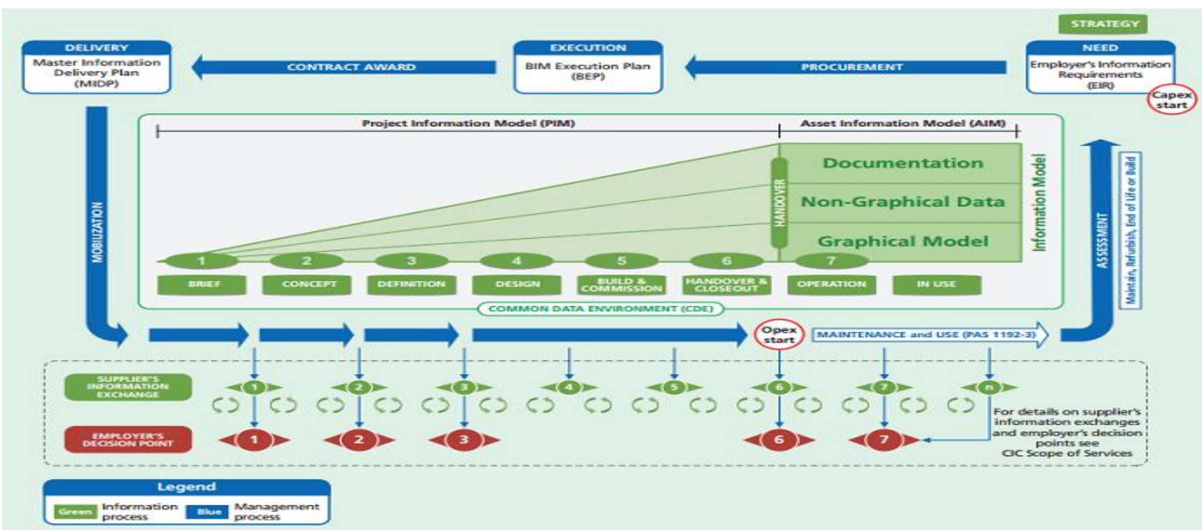


Figure 5.6: Information Delivery Life Cycle. (Source: BSI, 2013)

The assessment of client's need and the development of EIR which starts by either assessing the existing asset leading to development of client's need or directly with the client's need if no existing asset model information is to be considered is clear from the Figure above (CAPEX Start). This will guide and inform the contractor in developing a bespoke Project Implementation Plan and BIM or Project Execution Plan. Compliance with the employer's requirement and developing a BEP that interacts with the Plain Language Questions (PLQs) support contractor's implementation of 5D model in a digital environment and process efficiency approach from the strategic definition right through to hand over and close out. According to NBS (2015), "This approach is underpinned by a range of documentation. The fundamental principle being that the client should have a specific idea upfront of the information required from the supply chain and when this must be delivered. The demands a client make will dictate the level of BIM maturity that participants should adopt with the 'maturity wedge' diagram visually representing the kind of increasing demands that might be made. Level 2 BIM is focused on the end deliverables (and who is required to deliver what and when) with specific requirements set out in the contracts used to engage participants".

The contractor as a major participant player in delivering employers key project requirement with his supply chain will need to grapple with the content of EIR. To achieve this requirements and cost saving targets, the contractors BIM Execution Plan (BEP) will have to answer all the PLQs of project stages as contained in the EIR. However, the client and his project team need to be very clear and unambiguous with requirement needs, avoiding unclear technical requirements, unshared process assumptions and commercials as well. In RIBA Plan of Work 2013, Strategic Definition stage (Stage 0) identifies client's business case and strategy brief with other core project specific requirements while the Preparation and Brief stage (Stage 1) develops project objectives, quality objectives and project outcomes (overall stage outputs/deliverables), identifies sustainability aspirations, project budget (target cost), constraints and other project parameters. Robust initial project brief is developed while feasibility studies and review of site information are undertaken. It is at this stage that collaborative and integrated working are initiated. The EIR and other project specific documents are developed to enable seamless BIM implementation strategy, assessment of contractors and the supply chain competency. Assessment and evaluation of BEP and how each stage project requirement are being met, cost information trends, assessment of capacities and capabilities in terms of available resources and ability to verify such information as provided, details of delivery approach, assessment of information technology management and commercial management, definition of information exchange and collaborative working requirements, approach to data procurement, development of construction programme and approach to managing risk factors, cost efficiency and waste reduction etc. In PAS 1192 (2013), "information requirements shall be specific, measurable, achievable, realistic and time bound against, for defined project stages and information exchanges". The contents of the EIR is reflected within the suppliers Project Execution Plan and are aligned to employer's decision points which obviously will agree with project stage requirements.

Respondents from the field research across a vast spectrum of construction organisations agree with the above position of literature findings on EIR and reinforces vigorously the need for employers or their advisors to clearly identify what they need to be included or excluded in BIM Level 2 requirements which informs the EIR development and influences contractor's BEP. This is not very clear at the moment and very ambiguous as many clients lack required BIM literacy. Some respondents cited contractual documents with no reference to BIM generally or EIRs while fewer respondents made reference to working with unambiguous EIR though acceding to general conception of lack of

Client's BIM education in preparing EIR documents. The EIR does not specify at the moment how the 5D BIM cost information will be generated or what digital BIM protocols should be applied as credible solutions to meeting with overall project budget and yet cost remain a critical component for any project's success.

The lead designer together with the Architect has a responsibility to understanding the set out cost criteria just as the QSs or the cost consultants do. This will also influence an appropriate choice of the procurement route, a clear understanding of client's need and who should be part of the project team to support the 5D BIM expectations. In a more BIM procurement solution (let's say design and build) contrary to a traditional type of procurement, clients can request cost certainty at very early stages in a BIM process and this will have a positive significant effect with respect to stage cost checks in design outcome. 5D cost information with the developing design details should remain within cost parameters and with suitable design development allowances. Construction cost estimate in a 5D BIM is predicated on indexed or historical elemental cost data of previous projects but is strongly challenged by lack of unification of industry coding standards. For instance RICS New Rule of Measurement 2 (NRM 2) codes elements but the NBS coding techniques is in objects. The cost consultant is looking to automate quantities with a software system that does not recognise the designers coding techniques. Non-reconciliation of the coding differences hinders automated quantification and attachment of rates. The EIR should be very clear on the coding standards to be used to facilitate the uptake of 5D BIM process in a BIM project. The level of cost detail gathered from product manufacturers, design meetings and other ancillary cost related information may vary, the design team should therefore collaborate to provide the best possible cost solutions. Where details of certain elements are less robust, an integration of designers and QSs/cost consultant's functions will be significant in creating estimate allowances that are both realistic and appropriate.

Some respondents noted the incorporation of BIM requirements in their contract documents but with less contractual implementation emphasis. They stated that the management's decision from the employer's front – knowing project specific requirements and means of evaluating how the BEP satisfy those requirements contained in the EIR, will support 5D BIM model approach. Cost is a critical priority within the project criteria as set out in the robust initial project brief. Processes that both define and support to actualise cost objectives should therefore be integrated within the initial brief. The relationship of cost to time and design quality will dictate some of the construction sequencing tasks. Designing to stage and overall project cost is a key benefit in a 5D BIM process having a design-cost relationship that is critical in delivering an accurate information exchange strengthening client's confidence towards delivering a project to cost.

The respondents also agree to the fact that working to BIM Level 2 process brings huge benefits to the supply chain. However, to generate better outcome for the client with respect to cost savings, it is the function of the client to be very specific in populating the EIR and also to define the most credible means to evaluate suppliers and/or bidder's capacity and capability to deliver and manage digital information throughout the project – meeting key project stage requirements. Particularly a respondent who is a BIM director in a Tier 1 Main Contractor organisation said, *"to harness BIM Level 2 requirements from a contractor's construction workflow viewpoint and to integrate the organisations*

16,000 supply chain across the UK to further interact with other business data sets and meet the employers project benchmark, then a credible EIR that is clear enough on the required need of the employer is the tool to facilitate that process".

One of the most important element for Level 2 BIM implementation is EIR as it is used to communicate to tenderers practice requirements to BIM model processes and the intent of the models at different project stages. In compliance with PAS 1192-2 document for the CAPEX delivery of the project, BIM Execution Plan (BEP) prepared by the designers and the constructors should demonstrate how the requirements outlined in the EIR will comply with the technical, management and commercial details. BEP should also demonstrate compliance with the processes for the production of 5D cost information using agreed technical platforms - software platforms, definitions of levels of detail, cost information deliverables at various stages, agreed information exchange and common standards, timing of data drops within a Common Data Environment (CDE).

5.2.4 Common Data Environment (CDE)

When organisations worked in silos focusing on their own practice outputs, common standards or collaborative working offered fewer benefits. However the advent of BIM is a game changer in terms of how project teams deliver functions, common standards differing from isolated working culture in organisations should be utilised. Providing a more certain way for working in a Common Data Environment might be rather difficult at the time of this research given the evolving nature of emerging industry common standards and guidance. Common standards facilitates the automation of 5D processes and collaborative working, agreeing on certain workflow upfront on a project.

Application of common standards and guidance improves processes and productivity in a CDE, avoid practices disagreements and continuously improves BIM processes. BIM is altering industry isolated working culture, changing procurement routes designed to improve 5D cost estimates and timescale issues. Dynamics in changing procurement approaches, increase in the amount of design work undertaken by specialist subcontractors, constant evolving software innovation and use has resulted in different processes being adopted from project to project. A 5D BIM information manager from an SME cost consultancy firm talked about sharing of information, data transparency and collaboration to support seamless project delivery and improve accuracy of cost information. The participant said *"To me, there's a few things. Where BIM Level 2 starts is basically just everyone acknowledging that sharing information and collaborating is the best way of doing things because in my mind, in the construction industry pre-BIM Level 2, the way things were run was trying to omit some information for somebody to bid too low and lose some money - to me that's how it was before - so basically, omitting information to screw somebody over and BIM Level 2 is trying to take the way the construction is being run and just turn it on its head and say from now on, we are going to collaborate and the information is going to be transparent for everyone. No one gets screwed over and we all know where this is going. To me, that's it, collaboration in terms of sharing information, so that's where it comes from"*(5D BIM Information Manager – Cost Consultancy Firm (SME))

From the participants viewpoint, adopting common standard approach agreed by all project parties in a CDE has potentials to reduce the significant impacts of variable working practices and associated risks. For instance, the BEP will outline how a BIM model and its attributes will be created and conveyed at different stages of the project life. The different authoring tools to be used by the design team and the format of usage for clash detection purposes, data validation, 4D sequencing and programming and how the role of the QSs/Cost consultants evolves at project stages.

5.1.4.1 Interoperability and Information Exchange Compliance

Information exchange formats need to be agreed by the project parties and the QSs and cost managers as data recipients will state what formats and versions of data is required such as IFC, PDF, DWG, DWF etc. For the Cost consultants and QSs to initiate suitable adjustments to quantities, rates, other ancillary costs and automate modifications as appropriate, compatibility issues needs consideration and possible determination of tools, software and exchange formats that suits particular service delivery. Inability of the BEP to address the use of suitable software platforms would hamper information sharing and file exchange. Varying software platforms will have different implications to a QS or cost consultants. A respondent from a client organisation gave this practical narrative which was happening at the time of the interview in one of their projects *"Yes, we've had a common data environment set up on this project which we've used Bentley project-wise; it's a work in progress system, all the consultants have been working within our system and we've had workflows set up, we have the consultants working within our CDE, we are able to control the workflows of data, the sharing of data, the visibility of data, making sure that other adjacent contracts would have access to the right data at the right time -any approved data - so one area may have been doing some design, they may need to co-ordinate with the adjacent contractor, or consultant's design work, so we had* *workflows in place that allow them to access any approved data; if they needed early access, yes, they can have access to that, but the workflow's we have in place where it was set up, that design was not able to be pushed forward without that reference data being approved first of all from the adjacent contractor, so we had very, very tight workflows put in place, but in doing so, having this common data environment, allowed the sharing of information, allowed much more iterative sharing of the information"*. Working in a CDE requires a neutral data exchange format like IFC to interact with the majority of the measurement software. The 5D BIM QSs or cost manager would need to understand how the measurement tool will process the building elements and objects in a CDE to avoid compromising data integrity which one of the respondents referred to as "loss of data intelligence" – that is comprising the integrity of the electronic data being exchanged.

Exchange workflows in a collaborative working should be tested early in the design process to curb a later compromise of data integrity. The associated issues relating to the variance of the level of details and information especially between design disciplines at different project stages/work stages should also be noted. The QSs, cost managers and cost consultants should also be aware that data drop increase as design progresses does not necessarily mean that all elements or design objects of same discipline will be at same level of detail though at the same stage of project lifecycle. The 5D BIM QSs or cost consultant should then need to compare the output required with the provided model detail at each work stage when measuring as supplementary quantification may be needed. Communicating BIM deliverables early enough to all parties and getting all project members to agree on data drops and definition of information to be produced at different work stages would enhance 5D BIM processes and would support accurate generation of cost information in a digital environment. Any non-compliance to the earlier agreed information sharing protocol among the design team should be highlighted and recommended modification reflected to support the 5D measurement and pricing automation processes.

5.1.4.2 Object Naming Protocols/Coding

In another instance, one of the respondents talked on their object naming strategy deployed within the BIM process. It was a process system tailored to deliver a common naming convention among project parties. From a design point of view within the UK, the Uniclass standard from the NBS (NBS, 2016) is the most prevalent method of coding objects during the design stages of a construction project. This supports most aspects of construction elements however, it is focused on the design aspect and there is no specific requirement at the moment integrating cost coding mechanisms within BIM process during the design phase. Particularly, New Rules of Measurement 1&3 (NRM) need to be fully integrated into digital BIM process from an early stage of the design to support cost estimation from the initial concept stage. In the words of a respondent, *"The other process we had in place, for example, for naming convention, we had a document naming wizard set up in our common data environment, so they could not name something incorrectly, they were forced to name something the way we wanted it named. So having that naming convention strategy in place well defined made it much more efficient and much easier for us, as a client, to do the data, but also the sharing of data with other consultants"*. Naming convention should be captured and agreed on by the project team during the preparation of the BEP creating an efficient automated process during the project life cycle and interrogating the efficiency of the design with clear reference to requirement of the client. This should encapsulate files and layers and should be explained in detail especially its impact on export requirements at work stages and software support. A BIM object defined by geometry, specified data and visual appearance can be imported into a model by the designer and objects can be scheduled and compared when they have a common naming convention.

Though naming convention of BIM objects seem to have been standardised by the NBS following a specific naming structure (object library) and can be used for design inputs into models but the NRM codification is by elements rather than objects which creates difficulty in generating accurate cost information once design inputs (objects) are coded using NBS conventions and standards. Ratification between the NBS coding and that of the NRM is required to resolve the naming variances enabling setting up a robust naming protocol during early stages and retaining it throughout the project life costing. If for instance a 3D model that is not optimised for costing using NRM coding standards is imported for cost functions, it will be incoherent and interrogation of the model and identification will both prove difficult and time consuming as well. Standard naming protocol including clear descriptions of plain language questions is very important for 5D BIM processes. This will make cost analysis within the model very easy – supporting automated extraction of quantities and rate attachment. There are also other existing standards for naming objects like those that exist in Revit software products (Autodesk packages), it is particularly important to adopt a unified agreed naming strategy from inception of the project allowing effective use for the whole design team. As one of the key roles of a QS or cost manager is the collation and sorting of data to create usable cost plans, object naming agreement will support 5D processes extensively and will smoothing the running of project on site with less construction cost risks. The QSs or cost managers as part of the design team and in agreement with the design parties should find means of unifying or incorporating NRM coding system into BIM object parametrics at the BEP stage. This will resolve the naming conflict that exist with BIM objects and will drive seamless developments in the evolving design BIM model, aligning cost comparisons through various stages of iterative cost plans as well as maintaining cost benchmarks. Even when a client's demand for a bespoke presentation of cost output (cost modelling preferences) is to be respected and followed, a clearly agreed naming conventions identified and adopted from the outset of the project definition will support the process.

5.1.4.3 Linking Design Changes to Cost and Risk Impact

At the moment there are no established means of linking the cost of design changes to symmetrical cost and risk impact. Linking a BIM model 3D design to a cost database, construction programme and associated risks would a drastic reduction in the amount of design changes during design developments. In the words of one of the respondents, *"If you can get people who are on the same page working towards one set of data from CDE that everybody knows is correct and then you start hitting your milestones earlier than planned, you're going to have a common data environment and a common set of information that everybody can use. This is an important point, on one particular project we spent 12 months - we were over budget - we spent 12 months reducing that budget but in real time reviewing 3D models, or 2D models of the design of the underground areas and in real time, we would be able to change those designs and look at the impact of what* *that change might be, like you would change the width of a tunnel where it connected with another tunnel and so on. The issue there was, we then had to go to the cost base and we had to go to the risk base to see the impact of those changes we wanted to a design level. If that 3D design is already linked to its cost and its schedule and its risk associated with it, you could have gone through that review - which took us 12 months - probably in three months because in real time you can see straightaway what that impact is and that's the benefit of what we should be trying to get to. I've seen it almost there, the Olympics gave us a really good version of the truth sort of approach; Crossrail gave me, particularly, how to do that work and now we should take that and actually put it in our current project".* That link that shows in real time the cost of design changes, associated risks to those changes in terms of liabilities, resource wastage, rework, schedule delay and impact on contract programme should be established and agreed at the outset. Huge design liabilities and errors passed to the supply chain and specialist subcontractors will be reduced and would cut down review times. Early risk identification to design changes and the potential impact on cost is a vital factor to a project success. Therefore to save time and adverse cost consequences, part of the QS or cost managers function while design evolves will be to use an established cost link to run cost and risk analysis for effective advice to the design team on the effect of change decisions. This will generate adequate design response to support 5D processes at various work stages, re-estimating the developing design a substantial number of times and providing feedback on the estimate variances and corrective suggestions.

Most respondents acknowledged collaborative working through a Common Data Environment (CDE) as a key solution towards the fragmented construction industry.

They decried the adversarial impact of the traditional approach where project participants' work in isolation to deliver design responsibilities, cost advices, consultancy and construction functions. In their opinion they demonstrated systematic savings in cost and time that could take effect if all project parties would work from what one of the respondents referred to as a "single source of truth" – the Common Data Environment (CDE). The respondents reiterated that to meet cost reduction and improve productivity which are the key drivers of Government Construction Strategy, information sharing among project parties and mapping that approach to RIBA Plan of Work stages in practice remains the only substantive solution. This also extends to the post construction period of the project with respect to operation and maintenance cost savings (OPEX) and the Construction Operations Building Information Exchange (COBie) data. They agreed that Government ambition towards a 20% public sector project cost savings of CAPEX and overall waste reduction is possible but not without educating construction sector clients and sector employees on the processes that supports BIM implementation strategy. They agree that if CDE protocols are strictly followed by the design team, suppliers and the supply chain, spatial coordination will be a by-product of using CDE processes and will deliver production information that is right first time. That information could be used for construction programme (4D) information, cost information – estimating and cost planning (5D), facilities management (6D) and other ancillary project deliverables. Working collaboratively in a CDE they acknowledged gives greater control over revisions and versions of project information. This aligns with PAS 1192-2:2013 statement on CDE stating that "The structured use of a CDE requires strict discipline by all members of a design team in terms of adherence to agreed approaches and procedures, compared with a more traditional approach. The benefits can only be realized with a commitment to operate in a disciplined and consistent manner throughout a project".

The respondents agree that working in a CDE collaboratively will generate cost and time benefits, support integration of project interfaces, streamlined construction approaches, improves risk management systems, resolve conflicts and mitigate contingencies. Their views reflect integrated project delivery approach, contractor driven processes as opposed to consultants driven approach, visibility of data and improvement in communication, effective management of design changes and reduction in construction waste and reworks, reduction of errors passed to other construction discipline members. It will activate high level of confidence in clients and suppliers regarding expected project output and overall success, data assurance, uniformity of data and consistency in naming convention, non-site modification of products and processes, increased trust and reliability of sequences and visual construction programmes.

5.2.5 BIM Execution Plan (BEP)

BIM Execution Plan (BEP) is pre-contract based and answers Plain Language Questions as contained in the EIR through Project Implementation Plan (PIP), Project Information Model (PIM) deliverable strategy, capacity and capabilities to fulfil project goals for collaboration and information modelling, and strategy to deliver project milestones consistent with project programmes (BSI, 2013). To achieve project goal and a successful project outcome in a BIM project, it is essential to communicate project expectations, objectives and requirements to the suppliers and their supply chain for best practices. BEP key objective is to strengthen collaborative working approaches, adopting uniformity for naming conventions, descriptions and responsibilities. Approach for collaborative working incorporates project BIM standards, project coordinates, modelling standards, communication and meetings, data exchange protocols, model data validation protocols, model data sub-division (verifications and approvals), modelling units, BIM mock-ups, area calculation methodology (AEC, 2012). Practices that address key components of BIM project objectives, mode for data and model formatting, full compliance with PAS 1192-2 reflecting EIRs, agreed descriptions on varying party functions and roles, creating a clear unambiguous vision for executing a BIM project seamlessly. BEP identifies key project tasks, reflects supply chain competencies and resources that meets Employer's Information Requirements, outputs and model configuration. Each potential supplier with their supply chain bidding for a project will submit to the employer alongside quality assurance documentation a building information management competencies, information management competencies and commercial management competencies.

BIM Execution Plan (BEP) is critical to delivering information uniformity from project inception (strategic brief and definition). The information generated is project specific reflecting Employer's Information Requirements (EIRs) and developed in conjunction with all project participants – internal and external. "By utilizing the RIBA-DPoW across all professions, we are better able to manage project deliverables, developing individual discipline models coordinated and guided by the BEP" (NBS, 2015). The level of detail (graphical data) expected to be delivered at each work stage is largely defined by a key interdisciplinary guiding document – Design Responsibility Matrix (DRM) which is a key resource in project and design development. The DRM is a guiding resource for outputs at different work stages, defining the level of detail needed at each work stage and the ownership of each building element. It is always a good practice to define the contractual deliverables early in the project as basic design requirements – constituting clear definition to the team on work stage deliverables, the time needed for the deliverable and the purpose of the information (Mitchell, 2013).

All UK-centric developed project standards is with a single purpose of building up confidence, that design development, work stage outputs and project collaboration can be uniformly delivered. With advanced degree of "NBS Digital Toolkit" establishment, the QS and Cost Managers is expected to gain a good level of understanding towards digital cost information development and efficiencies in overall project lifecycle creating ultimate commonality across the industry. Developing an industry baseline for information delivery and checks will activate means of confirming compliance against a set of project defined deliverables, more coordinated data-rich information, aligned LODs and LOIs standards - driving efficiencies in the design, construction, and operation of built assets and increasing reliability on information quality (Mitchell, 2012). It is a good practice to define information requirement at each work stage throughout the design and construction phase for greater project and cost efficiency. The QS and Cost Managers can deploy LODs and LOIs as work stage baselines or check mechanisms to confirm compliance of various agreed work stage outputs (given agreed BEP), reflecting EIRs at the commencement of the project. The principle can be further engaged across disciplines to confirm the LODs and LOIs agreed requirements against each building element at various workstages for cost information. The graphical information represented in the design has a direct effect on the non-graphical information as the greater the graphical items, the more data are available when viewed within costing software (RICS, 2014). To populate design stages, with the required cost information and avoiding high LOD model objects; it is extremely important the QS and the cost managers understand the existing mapping relationship between RIBA-DPoW stages and NRM classification suites (Appendix E). The output of cost information at each stage is apparently the design inputs at that stage, therefore to avoid the common issues of designing to the correct level of detail in BIM projects – it is imperative for the QS and cost managers in collaboration with the design team to regulate information uniformity (LODs & LOIs – increase in data drops) at each stage of the digital plan of work using agreed BEP that is project specific and by answering PLQs for different stage tasks. Adopting a consistent early defined object naming protocol (like NRM object descriptors) allows successive developments in the model to align cost comparisons through the cost plan stages as well as benchmark costs across projects against held data (RICS, 2014). Once successfully implemented, digital quantity extraction is made easy then the QS and cost managers can have their value add in interrogating design deficiencies and queries with reference to client brief (EIRs) rather expending so much time in quantification. The BEP has to be tailored to address project needs/objectives.

The above discussed solutions as discovered through this research will support collaborative working, however collaboration within the industry practice using an established industry standard (common BIM standards/common modelling standards) or project specific standards is a huge challenge presently due to organisational cultural conflicts. Various cost databases, software packages, conflicting disciplinary approaches to model development, varying standards organisations are familiar with and have developed to increase their business profit margins is creating a stronger barrier in efficient collaborative working. This fragmented industry practice contradicts literature assertions of Eastman et al (2011) and Aranda Mena et al (2008), stating two valid approaches to achieving collaboration as using one model software from one vendor containing all relevant design information and cost information or using a proprietary or open-source software from different vendors but contains mechanisms to ensuring full interoperability. Model within the software could be transported across a spectrum of design disciplines without losing intelligence and yet allows electronic real time design updates, cost information and construction changes. The cultural transformation is constituting a greater challenge than any technological issues arising from BIM adoption. Secondly, the respondents' highlighted lack of BIM education among project stakeholders as core to transformational resistance to collaborative working and BEP full scale application in delivering projects. This is a great limitation that requires further attention. Organisational management occupied by dinosaurs are not willing to test the waters neither ready to succumb to the 'threats of BIM' as defined by them nor allow younger optimistic employees to advance processes technologically.

One of the respondents echoed *"Our estimators are used to measuring jobs in certain ways, it's having the confidence that the BIM model is correct, that's the issue at the moment, until certain times that that confidence exists, then we'll probably end up running the two in parallel, so traditional and a BIM process; but in time, I think that should make us more efficient, as in easier to take off the quantities and then get our estimators coming up with the best solution, rather than spending all their time doing take offs and the like".* One respondent spoke specifically on the importance of BEP clarity in supporting accurate cost information for the 5D QS saying *"To have the most* *accurate cost information you need to have a very, very clear and defined picture of what the information will look like at different data drops. So if it is incredibly clear in the BIM Execution Plan, what detail will be delivered at each data drops, QSs will know what's going to come in and we can prepare for it and can immediately see whether some information is lacking. BIM Execution Plan because you've got the BIM Execution Plan for the designers and you've got one for the contractor and his supply chain. Sub-contractors will be involved early and know exactly what to deliver, therefore the cost information is more accurate"* (5D BIM Information Manager – Cost Consultancy Firm (SME))

Industry practitioners are still embedded within the traditional way of isolated working. They are not collaborative yet because of non-BIM interest or lack of confidence that BIM inputted data and generated estimating information is correct or that BIM has proficient solutions to developing issues. People default to their standard way of doing things once they find a problem with a newly developed approach. Thus, they are stuck with their traditional strategies of cost information generation, relaxed with their non-technological approaches and not willing to bend. However, BIM legislation is gradually getting them off their comfort zone to both learn and apply new BIM tools in delivering cost efficiency. Management decision to execute projects through BEP and implementation at the operational level deploying relevant technological tools will be hampered except employees are upskilled to function effectively in BIM digital processes. Information management, commercial management, and building management competences possessed by the QSs, cost managers and cost consultants will generate expected cost efficiencies and productivity within BIM processes. Collaboration among project stakeholders will breed a stronger trust and confidence in the process and will support 5D BIM QS and Cost Consultants to effectively deliver their estimating and cost planning functions at different stage gates. It is therefore imperative to equip both clients, construction suppliers and supply chain with the knowledge requirement to engage with the virtual construction environment.

5.2.6 BIM Literacy

One of the key findings in this research that has impacted negatively on the 5D BIM implementation is that clients may want BIM (in fact some are bent on it), but do not know what exactly they want neither the processes to engage to actualise it. From architects to contractors, the construction industry has become increasingly frustrated that clients ask for BIM, but don't seem to understand what it is, or what exactly they want. The problem is that, while most clients understand what BIM is in general terms especially if they have read any construction-related publication or online content for the past decade. However, they do not understand the value it will offer during the design and construction phases and throughout the management of the lifecycle of the building. As value is subjective, the end generic BIM value especially the 5D BIM processes generating cost estimations and cost planning of work stages needs to be communicated to clients. The contractors can only communicate the benefits of utilising BIM to clients if they understand their bespoke value indicators and engage with them effectively to communicate how BIM can improve the 5D BIM delivery process. *"For example, the benefit of BIM for one client as sited by a respondent may be to improve the design and coordination of building services in a particularly complex scheme. Conversely, another* *may see greater accuracy in cost validation of specific building systems and components based on model data, and another might derive most value from the operation and maintenance data contained within the model"*.

Whatever their value criteria, it is the architect and delivery partner's responsibilities to aid clients apprehend how working in BIM environment will support and facilitate realise their goals; helping them articulate the requirements within the EIR to accomplish their objectives. Again, early client engagement must include all parties - owner representatives, end users and facilities management, design team, 5D BIM QS, Private QS, consultants etc. Each has a critical role to play in formulating the goals to determine how BIM process will be developed and managed by the delivery team to produce the required project outcome. The architects, consultants and contractors driving the BIM project have a role in addressing any misconceptions about BIM so that required deliverables or project proposed outcomes can meet the client's objectives. A respondent from a main Tier 1 contractor organisation highlighted these important lines *"I think educating our customers to realise what it is they want; the challenge of educating our workforce to understand what they've got to do to achieve client's goal and adopting a new workflow. As an industry, we are woefully behind other industries in efficiency, we've got to be BIM literate. The benefits of becoming an efficient industry which you can look to other industries and say 'yeah, the construction industry is efficient, we're not wasting time, resource, money, materials which at the moment we do far too easily"* (BIM Director - Main Contractor Organisation).

This underscores a need to integrate both the client's representative and the industry workforce who are engaged with learning with adequate BIM knowledge with special reference to 5D BIM processes. A more skilful iterative cost processes within BIM environment will be adopted to strengthen industry workflow. BIM is not an off-the-shelf solution, nor does a single approach work for every project, so an appropriate level of understand is required to generate an ultimate end value. While one client may be interested in objects embedded with data, another may be more interested in using virtual reality as a marketing tool. If these goals are established from the outset, it enables the design team to take an appropriate approach to meeting these objectives. The key measurement of success in a BIM project should reflect how the potential 5D and other 'nD' models are implemented to realise and benefit client expectations. Though the most imperative critical issue to the design team and the contractors is that clients most often than not do not know their BIM needs, which is why advocacy for early contractor engagement is so vital for interrogating the brief and developing an understanding of value criteria and processes. Only then can the BIM model uses be tailored to meet the needs of the client during the delivery phase and ultimately, throughout the lifecycle of the building. It then follows that the Project Implementation Plan (PIP) developed from the project outset will include 5D BIM implementation requirements to support in meeting cost limits and achieving cost efficiency. Implementing BIM is not just about delivering a data-rich model to impress the client but about providing added cost value and process efficiency to the client. To that effect, design programmes should strongly consider an integration of 5D cost functions of the QSs/Cost Managers at design stage responses.

From the education angle, BIM has taken the construction industry towards a new paradigm and the education sector is catching up with the changes required. Initiatives such as the UK BIM Academic Forum and the UK BIM Task Group Learning Outcomes and the inclusion of BIM within a range of professional benchmarks have led to the inclusion of the concepts, philosophies and technical knowledge of the BIM process being included in curricula. However, this is somewhat ad-hoc at the present time based on previous research (Underwood et al, 2015). In particular there is little reference to how those involved with the cost and 5D aspect of BIM process should engage through existing curricula. The respondents agreed that in order for the sector to develop the next generation of QSs' and Cost Consultants, more is needed to formalize the delivery of 5D both with existing courses. Consequently, the collaborative nature of BIM also requires a shift in the teaching and delivery of all construction courses to ensure that subjects such as cost estimation and cost management are not taught in isolation but are seen as an integral part of the construction management process and delivered via a collaborative mechanism.

In addition to teaching the philosophies, students currently engaging in academia and those already within the industry have a need to be upskilled in the use of the latest tools and technologies available. This must be a decision from strategic management level who have an understanding of what benefits 5D BIM can bring to a project. Another respondent also agrees with the above views regarding the need to educate both the client and the workforce and in his words said, *"From a personal opinion, the key is the level of detail that you do early on in the design because the biggest cost, always, is poor design.*

If you go into a contract, or project with anybody where you haven't really bottomed out exactly what you want to deliver, how you want it delivered and when, you'll go wrong - so BIM will just help that. If you've got BIM already built into your design process, your requirements capture and design process of any contract, you will identify very quickly what the problems are which take a long time at the moment. If you know the cost impact of changing a design based upon BIM model, that this is going to be the outcome, then you can say 'I'm not going to do it. If you can straightaway see it's going to be a six-month schedule slip if you do it a certain way, you won't do it, you mitigate that schedule slip. That means that clients more than us, or big private companies who are managing the whole raft of the project cycle, need to be BIM educated because they're the drivers, otherwise, you still get the contractors doing what they want to do each time. Everybody's got to be educated and at the right level".

A cost consultant also agrees with the BIM literacy notion with his response for upskilling industry workforce *"I suppose up-scaling, people aren't able to use softwares, it's something that we're trying to do at the moment, we've taught few QSs how to interpret software data and how to use it and we're running training sessions, but until you really use it, it's a difficult thing to get your head around, so there is a small risk in up-scaling and getting people trained and ready for it. But again, it won't be 'oh good, I've got some new design information, I'll print it off and get out my scale rule,' it will be 'I've got some new drive design information, let's get into CostX and make up the model map, see what we can find. Another part of the inertia (upskilling downtime) that stops people from adapting towards the upcoming trend. Yeah and getting people up to speed* *and that's always going to take a little bit of time, but I think being left behind is not the right way to go"*

Respondent's perspective regarding BIM literacy, the need to upskill project team members is obvious. This includes empowering the clients with required knowledge on the appropriate use of BIM for collaborative working with special reference to the QS, cost consultants and cost managers who are the first users of design data (concept design data). The fact that 5D BIM depends on 3D BIM design information, the accuracy of QS functions is therefore reliant on the input of the design team. For instance, if a client's design consultant is not BIM educated or BIM literate to understand certain convention as contained in the EIRs and BEP, that design consultant will certainly not respect object naming conventions in the design model and once that agreed convention is not in place, the 5D BIM element will have issues. One notable fact flagged by the respondents constituting major limitation in BIM education is the unavoidable upskilling downtown. The management of contractor and client organisations would have to come up with training solutions to strengthen the technological skills of the employee community and to enable adequate understanding of required BIM processes. The UK Government as the key driver of BIM implementation mandate also has a responsibility to develop an upskilling support system for the industry workforce. BIM literacy is an absolute prerequisite to seamless Level 2 BIM implementation.

5.3 PROCESS (OPERATIONAL LEVEL)

The process as identified in the analysis allows all project team members (owners, architects, engineers, contractors, subcontractors and suppliers) to collaborate in a virtual environment more accurately and efficiently than the traditional process. BIM model information undergoes constant refining and adjustment process to ensure project requirements and specifications including any alteration arising from design changes are reflected as accurately as possible before actual physical execution of the construction on site. Designs are constantly optimised for value improvement (value engineering), quality, aesthetics, constructability, cost (affordability), timelines and milestone schedules and a seamless flow of construction information transfer into the operation and maintenance phase.

5.3.1 Value Engineering (VE)

Royal Institute of British Architects (RIBA) Plan of Work 2013 provides a framework mapped to Level 2 BIM strategy to guide design development, constructions and asset strategy (operation and maintenance) and overall client's decision. Considering the framework, the client after due consultations sets the project budget at stage 1 (preparation and brief) with an expectation that the design team working through concept and developed designed stages will produce a design that meets the project budget. Early cost estimate is developed by a 5D BIM QS, cost managers or cost consultants and fine-tuned at later design stages to support the design team in meeting stage cost outputs. At the end of each stage gate, output of 5D QS advice being the latest cost estimates is reconciled by the project information as agreed from early stages and signed off by the client. With increase in data drops at different stages of the project, design development reveals hidden building components like materials and chosen finishes and that changes the area (m^2) calculations used at early stages to elemental cost plan (stage 3). This enables the 5D BIM QS or the cost consultant identify elemental items that impact negatively on the project budget as set by the client – those expensive items when compared with the elemental cost plan of past or similar buildings. Advising the client and the design team to focus on elements with impact on cost information output and ensuring the design team designs to a target project cost (elemental or target cost) rather costing to a design. The 5D QS helps the design team interrogate BIM model and limiting design to agreed initial project budget. Once the price of construction estimate is in excess or goes over stage/overall budget (could be previous estimate), then value engineering could be undertaken with the preferred contractor to produce optimum value substituting materials and methods without compromising functionality.

This is where the roles that function at the operational level of BIM projects in construction industry believes the need for value engineering. Especially with consideration to whole life costing that compares options and their associated cost over a period of time – having a benchmark for elements that fulfils the required asset performance with respect to operational and maintenance cost. Value Engineering according to RIBA (2015) is defined as "a systematic and organised approach to provide the necessary functions in a project at the lowest cost. It is said to promote the substitution of materials and methods with less expensive alternatives, without sacrificing functionality". It reviews and monitors design development to remove unnecessary cost without reducing value. Two respondent cost consultants from SME and Multinational consultancy firms communicated a 5D BIM approach on value engineering of a design progression.

"From a cost perspective, using BIM and implementing BIM processes is a far earlier challenge on the design; practices such as value engineering, trying to relate efficiencies

within design by targeting the key cost drivers. For a contractor, it's a lot more beneficial by undertaking BIM as a methodology of carrying out the work on this project. For instance, the simple massing of the concrete is a big cost driver when you're thinking of building an underground station; they are able to review the model, they're able to review the quantification that we carry out as well as the model - and they are able to use their pricing data which is based on the local rates in Saudi Arabia, the contractor is able to do that utilising BIM to identify concrete as a cost driver in the first place and then to challenge and push back against their design team and say 'let's have a look at where we can start to find some efficiencies or let's see where we can squeeze a bit of cost out of the project. For example, thinning the concrete walls, reducing the amount of concrete and rebar within the columns which a design agency might put in a bit of extra for comfort when they're doing their calculations on what is needed to hold the building up, or hold the building from imploding under the weight of all the soil around it. I can imagine the contractor's benefit would be therefore they're not buying more concrete than they need to, more rebar than they need to, so they can get savings which either affects their profit margin, or they could pass that on to the client as well, in order to make the overall cost of construction come down"

Ultimately the respondent is saying that deploying BIM methodology for value engineering in a design and construction development creates a digital environment where the contractor can ask questions on generated cost information and have ability to relate design with efficiency. This is because they have a lot more visibility of the design and stage cost output earlier in the process enabling them to challenge the design and therefore drive out inefficiencies - challenging things such as contingencies. Visualisation of the design process has a lot more potential for value addition while design evolves and the 5D digital process could also interrogate inputs early on before it gets too late in the stages. Working collaboratively in a CDE as discussed above enhances this practice streamlining difficulties and embedded risks associated with traditional process. Information sharing and file transportation are carried out seamlessly across design functions supporting value improvement of the entire process while achieving milestone objectives.

The second respondent reiterated the above view from another supporting angle *"Currently, you've got a better chance of making savings at that very early stage of your design where you do value engineering. I expect the model to be very efficient and lean in the design and therefore….you've made all the savings from the actual design using BIM because that's where all the savings are, the question of cost, whatever you give the QS to costs, it will cost that, but then if the value engineering process and the efficiency of the design itself, that dictates the savings. Because even if we do this 5D, but the development of the model, it's still a design, it has to go through the process of value engineering and say 'okay, do we need a 900 mm diameter under this slab, or do we need a 600 mm?' because by the time you decide that it's a 600 mm diameter, that's it, that's your value engineering gone and the QS doesn't cost that, so there's no saving. It says in the design, if you give me a 900mm diameter pipe instead of 600, I will cost the 900mm, but the value engineering should have been done during the process of finalising that model dimension or its design, therefore the system needs the 5D QS still for value engineering cost advice in BIM while the design progresses. You need the QS or 5D BIM QSs as you call it, to be able to challenge the solutions that are put to you and try to inform the costing. I could* *turn around and ask the question, do you really need a 900 mil diameter pile for this solution or a 600 mil diameter pile, which could give you a 20% cost saving and the engineer might say that might work, that's the kind of intelligence from the costing QS profession".*

Effective management of the design process and development is where most value engineering cost saving capabilities are embedded. Once the 5D QSs/Cost Consultancy functions are downplayed or not well integrated at the brief stage in a design programme for a collaborative design evolution and cost management, then the value engineering solutions cannot be of much benefits. The cost information generated will be as designed which mirrors the traditional regime of design processes. The respondents have a view that early involvement of the 5D QS will deliver cost benefits and efficiencies that later stage involvement cannot deliver. They also possess skills and competences that challenge fragmented solutions, optimise cost functions, avoid risks and reduce cost liabilities of later project stages; working through the process of that development at different stages and managing value engineering options and also making certain the solution put forward is the most efficient and perhaps, the most cost effective. Thus, Value Engineering as perceived by the respondents should be an integral 5D BIM approach to effectively harness value improvement of end product or services where clients receive greater value for money in a BIM project. Their views aligns with the RIBA definition of VE which is to identify and eliminate unnecessary elemental design cost without loss of function in a nutshell – producing significant savings in both cost and time. This is why design optimisation processes becomes the key function in a design process validating cost outputs and value engineering options.

5.3.2 Design Optimisation

Design responses to initial project information (project objectives, project outcomes, project budget and project programme and any site information with potentials of constraints) support project team members to contextualise project development, socio-economically capable of achieving set out project strategies (RIBA, 2015). Design optimisation reviews design inputs within developing model (geometric) and challenges decisions made through early stage design assumptions. To meet up with the client's cost target, performance requirements and sustainability aspirations, design needs to reflect production parameters that generates best design solution. Though there could be multiple design alternatives with cost efficiencies but the optimal solution is to be identified. Value Engineering is an organised systematic approach for value improvement of end product or services without loss of function but design optimisation requires a more critical evaluation of modelling material products to not only minimise cost but also achieve best performance. Design variables are to be determined to achieve the optimum performance and to a desired client's standard irrespective of any given constraint. Optimised design takes into account the basic raw materials, how much concrete, how much steel, cladding, windows, basic material cost (materials and construction products) based on the geometry and the size of the building. Considers how object components and elements are modelled and automate a design response to address any non-conformance issues and standards. The roles at the operational level would need to keep an eye on design model inputs with respect to how the QS and cost consultants visualises that object within the model to enable a proper cost function and quantification automation responsibilities. For instance an issue was identified in the narrative of one of the respondents who had this to say on the impact of wrong identification of model design inputs/objects;

"We've got issues around designers using the wrong object in their 3D models. For example, a simple column is sometimes drawn on the 3D model as a wall, so instead of having a square column, the designer will just put a very small wall in order to represent that column. Now, if he sends me the file and I open it on 'CostX' and without looking at the model, export or do my quantity export, I will have a wall instead of a column, but it should be a column, so it should go in to two different sections in the NRM 1 cost estimate.

There are issues when something is modelled using the wrong tool, for example, a flat roof is sometimes modelled as a slab, obviously in the NRM 1 cost estimate, you've got two different lines for the roof and all the slabs and if I'm not careful and I just run the system automatically, the roof will go into the slab line, so we've got to be careful around the designer's information because sometimes it's simply wrong.

There are issues around, for example, excavation for civils works. For example, drainage, you've got pipes below the ground and the NRM 1 will ask you information around the excavation volume of earth and mud that you need to dig out and put in your drainage and put back in - that information is not strictly intra-object property - so simply having the pipe modelled does not give me any information around excavation volumes, so that's something that we need to work out and that's not based on the object itself, it's based on where it's based. So that's something that we cannot do automatically, we have to do some clever coding around that.

We've got issues around, for example, if it's a refurbishment project, there's obviously a big difference between the wall that you have to build and the wall that's been there all along and you don't have to touch. So in your Revit model, or whatever software you use, you've got to make sure that it says 'new construction' when it's a new object and like 'present,' or 'is already there,' etc., so we've got to make sure that we don't count objects that were there all along, that we don't have to touch.

The respondent who is an experienced cost consultant and has worked in several BIM projects highlighted an issue where designers use wrong objects in their design models making identification of objects for cost activities difficult and automation responsibilities almost impossible. Highlighted also are non-intra object property that cannot be modelled like excavation volumes and existing/non-existing components in a refurbishment work, attention during design activities should be prioritised to develop an output that will not undermine cost accuracy in terms of quantities and tender sum. 5D BIM QS should in consultation with the design team and specialist subcontractor designers create a clever coding system that support design optimisation process. The cost consultant should possess the ability to do CAPEX cost analysis and then the life cycle costing analysis for the building – weighing options and adjusting the design to make sure that the upfront cost for operation and maintenance is not too high. There are strong indicative perceptions among the respondents that assembling developed design from all members of the design team at the earlier project stages will provide the client and suppliers of construction products and services with a coordinated design and robust 5D BIM cost plan. The client develops confidence in the design output for planning permission procedures. One of the respondents with lots of BIM projects around the UK, shared an opinion given the multi-disciplinary nature of collaborative BIM working that if design processes are optimised, cost savings through progressive cost estimate and cost plan will be huge.

5.3.3 Data Reliability, Accuracy and Integrity

This has been discussed under chosen procurement strategy (5.2.2) and how it is implemented at the operational level.

5.3.4 Integration of Process Information

This was discussed elaborately including the views of the participants under automated quantification (5.4.2).

5.3.5 Common Data Environment (CDE)

This applies to the implementation of management decision on collaborative approach to processes enabling 5D cost estimation approaches. This was discussed elaborately under Management (Strategic Level) including the views of the participants (5.2.4).

5.3.6 Cultural Issues – Isolated Working

To exploit full 5D BIM capabilities and benefits towards a more accurate and quicker cost information generation, contractors and the supply chain, QS practices and cost consultants are required to re-evaluate and re-engineer their business processes. As BIM evolves, industry practice in many construction organisations will typically rebrand to meet the changing requirements of clients. In the words of a BIM Director from main contractor organisation when issues of cultural challenges towards 5D BIM implementation came up during the interview, the director said:

"….the QS, the estimating profession, the function, the discipline have to get used to new software and new ways of working. There is the pain, if you like, of training, incorporating new stuff and that takes time, you cannot suddenly stop everyone using their existing software overnight, it is a new foreign language to many, there is a gradual plan. That is where we are and as I have highlighted in some of the examples, we are using it for some purposes on some projects. My hope is that we will expand that capability across the whole business, but it will take time. The software is already there and available, that is not a blocker, it is the people, culture and training" (BIM Director – Main Contractor Organisation).

An emerging trend of lager scale businesses and operations are gradually developing alliance and synergy to enable a maximum delivery of 5D BIM offers according to Peter Smith (2014). However, the study discovered the biggest barrier facing QS and cost consultancy practice in the construction market is 'cultural conservatism' or strong resistant to change as uncovered. Organisations with mostly 'dinosaurs' workforce (as uncovered in some of the participating organisations) will find it even more difficult to adapt to the 5D process evolving trend. Either because of the initial up-front investment on relevant software technologies and training of staff or the fear of compromising basic QS required analytical and checking skills to automated BIM competencies (Smith, 2013). Digital technological competencies acquired by younger QSs and cost consultants is perceived as threats by senior QS practice personnel in construction organisations and this is constituting even more stronger barrier towards 5D BIM adaptation and this agrees with Peter Smith's position on the skill threat of the younger cost professionals to the older ones (Smith, 2013).

According to Smith (2014), "the added complication is that the technology is always evolving, lots of time and expense could be spent on software and training with uncertain outcomes. The pioneering path can be high risk as firms become 'test pilots' for certain technology whilst their competitors wait in the wings to see if the 'testing' will result in commercial value and competitive advantage". Secondly, the study also found out that clients and contractors have an existing bespoke cost model, specific cost coding system of design elements/objects and lots of other existing intelligent database that drives their business processes. This in practice is already a strong hitch and impedes collaborative working in 5D digital environment. Construction practitioners insist on familiar approaches, processes and standards making them unamenable to evolving 5D BIM practices.

The industry at the moment is still grappling with the challenges and complication of working with varying existing cost database and standards as effort is made towards collaborative assembling of project party members. Presenting contractors and the supply chain with varying details of existing cost model for cost estimation and cost planning purposes in nearly every project complicates efforts to benchmark digital performance and drive efficiency as interoperability is literally unachievable. Best procurement considerations for successive work stages with potentials to offer myriad BIM benefits towards integrating 5D processes are challenged by these variances. With widespread recognition to improve productivity, reduce waste and achieve 25% cost savings on centrally procured public sector projects (Cabinet Office, 2016), construction industry leadership should embrace developed industry common standards for BIM projects – initiating collaborative performance benchmark for generating 5D cost information. This will advance the understanding of the stages in projects where cost efficiencies and cost benchmarking can be achieved, improve cost estimation and functional capabilities across projects and alliances, deploy collaborative procurement techniques, embed and increase the use of digital technology for BIM Level 2, enhance process implementation while driving whole-life cycle costing (WLCC) approach.

5.4 TECHNOLOGY (TECHNOLOGICAL LEVEL)

Emerging theme also identified good use of BIM technology as an advantage for a seamless enforcement of employers and project requirements, ability to collate, process, manage and share information from a common data environment. According to Eastman et al (2011), digital models with 3D data only without object attributes, models with no support behaviours, models with multiple 2D CAD component files which are to be combined to define a building or models with no capacity to automate design changes on adjacent design elements are not BIM models. Therefore, it becomes imperative to make good use of BIM technological tools for digital automation, component quantification (5D), integration of process information and design process efficiency – causing a paradigm shift from 3D design as graphical entities only (with inability for effective 5D process) to intelligent smart object BIM models. BIM models define objects with respect to building elements, building systems such as spaces, walls, beams, and columns containing both physical and functional associated information and project lifecycle information (Azhar et al, 2012).

5.4.1 Value Engineering

Skilled employees with a good understanding of the entire digital process use appropriate technological tools to automate cost estimate tasks enabling value improvement while optimising results. This function within the BIM process has been discussed elaborately under Process (Operational Level) (see 5.3.1).

5.4.2 Automated Quantification/Integration of Process Information

Quantity measurement and classification has evolved from the traditional processes into the digital age, taking off quantities against multiple measurements digitally. This is requiring early project collaboration across the whole spectrum of construction professionals bringing in expertise in planning, cost estimation, constructability and value engineering - hence the obvious need for early contractor involvement (ECI) in delivering projects. The conventional manual interventions or interpretation of data breeds risks of inconsistency and error in costing activities whereas BIM has capabilities to quantify accurately while reducing error margins. BIM with a multi-dimensional capabilities and the information sharing abilities enables all parties involved in a construction project to visualise the model content from a single dimensional image and provides detailed designed elements and quantification for QS use (Mena *et al*., 2010). To import quantities from a model into a costing software in a BIM enabled data environment, elements are selected either individually or as a group. Correct classification of elements in the model for automated BIM process are considered extremely important and names for different material/object types is to be shared for correct interpretation as appropriate naming convention is currently a challenge. One of the key findings of literature was the inability of the traditional measurement approach to correctly classify elements while undertaken measurement, hence an error prone measurement process. This problem was extensively engaged while conducting interviews to know how the industry practitioners deal with the issue of elemental classifications and naming of objects within virtual or digital environments. A respondent who is a cost consultant explained further with the following:

"Here's the thing, it entirely relies on the information given to us by the designers, so if it's the same designer working on the different projects and he uses always the same naming convention for his objects, then we can set up our template on it. If he changes the name, it's going to change the links, the clever links that we've put inside of our system to put in the rate which is why it's incredibly frustrating for us to work with designers who do not have a naming convention in place because it will screw up our automatic rate up system. It's already named. If you go on Revit and you want to put a table in that room and you've used always the same table, it's got a name, but sometimes because they choose to be annoying, or because they don't know what they're doing, they will change the name; so sometimes it will be called a wooden table and the next project, it's going to be called Table 1 and the next time around, it's going to be called table 001 etc., so we rely on the naming convention of Revit, or whatever system. So whatever comes in, that's the name, that's what we rely on; it might be the same table, or if it's not, if it doesn't have the same name, then we lose the clever link, so we can re-establish it, but that's a waste of time.

The cost consultant continued by stating further that *"…the critical thing for the design of information in models is the naming convention, it's got to be one and it's got to be respected. The BIM library has to be in place and a name convention has to be respected. If you have a naming convention in place, admittedly, you've got to have … if you've got two pieces of information and they've got to be linked somehow, you need to have a common denominator that attaches this to that, A to B, there's got to be a point that says, you're linked into it. That to us, at the moment is the naming convention. So if "A" has a proper name, then "B" is automatically attached to it because it recognises that name, therefore it's that rate. So right now, we rely entirely on the naming convention which BIM addresses, so theoretically, that works. In practice, when the naming convention is butchered by the designers, we lose the link, but BIM should have that link in place"*

Design information that gets to the QS or the cost consultants and the format of that information is critical to the accurate measurement, cost estimating and cost planning process in a digital BIM environment. According to the respondents, designers do not like QSs controlling their design concepts and ideas and there's also lack of QS understanding of different design software and therefore cannot dictate naming conventions for QS functions. Elements are defined by intelligent data-rich objects within the model and these objects contain quantities and specification details enabling automated quantification. BIM based estimating tools vary in their functionality and working processes. It is the responsibility of the QSs at the operational level in collaboration with the management decision to select and engage these tools to be part of BIM based projects and also benefit from the merits of BIM technology. Choice of costing software with abilities to interrogate product models - the responsibility of testing and validating the use of that tool adapted to suit the types of model manufacturers produce is vital in evaluating organisations software need for process automation in 5D BIM quantification. QSs/Cost Consultants have the responsibility to improve their internal business processes by choosing appropriately the estimating tools (liaison with software vendors), looking at the potentials and performance of these tools in handling product data, ability to challenge design programme input, speedy dimensional quantity data extraction and ensuring alignment in their business goal and objectives.

The Figure 5.7 below shows a typical 5D BIM automated process demonstrating an interaction between software products, processes and data required to create 5D on mass in an efficient manner. The diagram demonstrates an automated tested process with a model assembly produced by a costing software 'CostOS' designed to price works according to the RICS NRM 2 method of measurement for capital building works (Craven, 2016). It should be noted that this automated process mirrors what is possible with 'CostOS' and would apparently work differently with other costing software like CostX, Vico, Bentley AECOsim, Solibri Model Viewer/Checker 8, BIM Measure 16.4 etc.

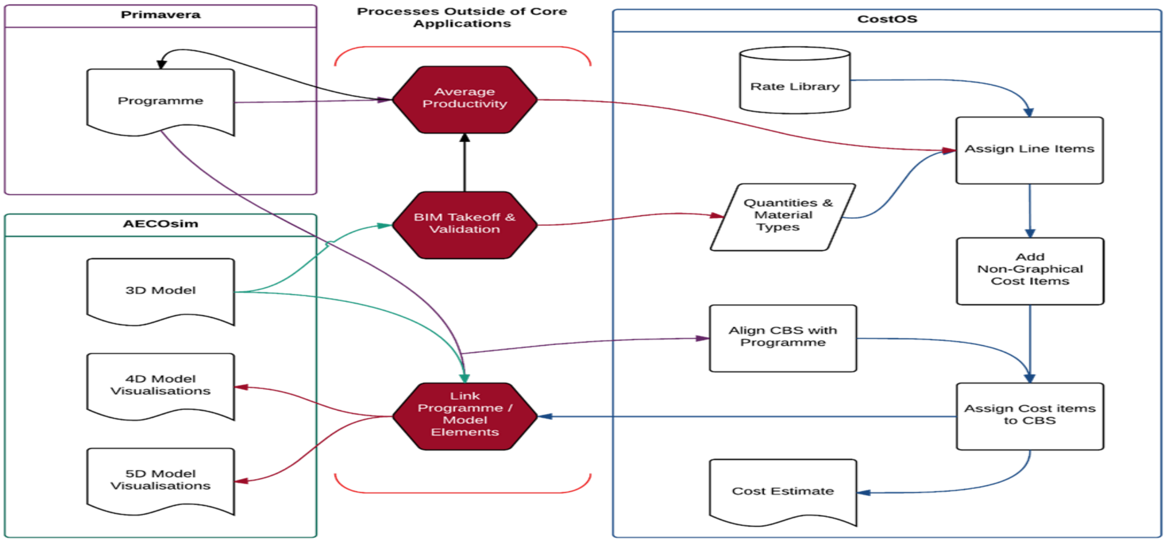


Figure 5.7: 5D BIM Automated Process (Source: LBA/HS2, 2016)

In this ‘CostOS’ process an IFC file is used as input and subsequently elements to price on the basis of their BIM Classification for example “Wall” are selected. From this subset the structural elements are grouped by thickness and a new Bill of Quantities (BoQ) item added for the sum of those elements with matching thickness. The unit rate library provided alongside the IFC has matching Unit Rates for the groupings which the assembly produces and allocates them accordingly. This process is repeated for all the classification types the assembly is programmed to interpret. Parametric factors are set in the assembly run interface to allow estimation of non-graphical items such as rebar content, formwork and soffits for the new line items. Non-graphical items are added automatically to the BoQ and there are pre-programmed cost line items for each of the items the assembly can import to apply prices. If elements in the model are misclassified, the assembly will not function as intended. Data could be passed into the assembly through a coding sequence to define how items are added to the BoQ or what automated non-graphical items would be added' (Craven, 2016). Accurate classification of elements and correct naming of objects in a 5D automated process offers a better data interpretation and mitigates cost estimation risks when used in pricing. A knowledgeable QS is still required though an automated process to guide the software as in the semi-automated process while engaging 'CostOS' procedure for efficient cost 5D output. This is because the QSs will apply professional judgment to determine the suitability of measurement standards (eg NRM 1, NRM 2 and NRM 3) applicable to level of details and level of information (increase in data drops at various stages). An experienced QS with a digital costing exposure will know when model cost estimation is area rate based, object/elemental rate based or a mix between both when design stages overlap and will further determine which formal cost plan applies to changes in data drops. Additions of non-graphical items like site logistics and traffic control logistics not directly relating to the actual physical construction, would need to be added to the cost breakdown manually, or as function of total cost by a QS. Data availability and open relationships in regards to individual product data remains a big challenge facing 5D seamless automation in the built industry (Kirkham, 2015). However, database/data integration supporting applications to draw data from each other's databases (multi-disciplinary database) freely will eliminate the manual import/export of data and will enhance 5D automation processes in the built environment (Craven, 2016).

Manual interventions are still required for an efficient automated process to work well due to few element classification and IFC issues (Pittard and Sell, 2016). Defining the granularity of information produced during design phase supports 5D process to be fully automated and thus the very reason for early contractor involvement as elaborated above. The accuracy range of an estimate is based on the level of project definition in the traditional process using plans and specifications as a primary means to define a correlation between projects definition and the expected accuracy of an estimate. Traditional QS managed, organised, extracted and used cost information in the best means suited however that process shifted in BIM through early contractor involvement (ECI) as more of the functions and cost saving advice begins in the design model phase (Garlick, 2016). This research has found out iterative design outputs (self-imposed design increments, client commentary, external advice on design criteria etc) currently has an overlapping consequence on the early generated 5D cost estimate. However, identifying clearly the key cost drivers, inclusions and exclusions, and ensuring the lead designer and architect understand cost criteria supports design process to 'design to cost' rather than 'costing a design'. Secondly, a well-reviewed procurement strategy and a defined Design Responsibility Matrix (DRM) reduces complexities and making deliverables clear with an early agreement of how cost information will be dealt with as design develops. Thirdly, a robust and informative early cost plan will strengthen clients and contractors understanding of the relationship between design programme and cost and will trigger relevant questions on associated risks with cost plan and programme component if need be.

5.4.3 Common Data Environment (CDE)

This applies to the use of appropriate technology for collaborative approach to processes enabling 5D cost estimation approaches. This was discussed elaborately under

Management (Strategic Level) including the views of the participants on technological application of common standards and naming conventions (5.2.4).

5.4.4 BIM Design Coordination – Process Efficiency

One of the key findings of reviewed literature regarding costing of traditional projects is the much time required to track design changes during the QS measurement processes. If it is a large complex project, manual processes consume much more considerable amount of time to correct all design errors and effectively track design changes (what's new, what's been omitted, or varied specifications from previous design) yet it does not insulate the process from high ineffective and fragmented cost protocols. Consequently, there were oversights of unmeasured quantities initiated by difficulties embedded within the traditional costing procedures - running associated risks of missing items and serious impact on overall project cost. Literature also revealed the limitations of the traditional process in detecting multi-disciplinary design clashes (architectural, structural, MEP, civil, specialist trade designs etc) which only creates massive changes of high cost implication at the construction phase of the project. This limitation inflicts delay on project timescale and causes unnecessary claims and disputes with an impact on the overall project budget. With increase in the amount of design information produced while design develops, traditional approach became much more insufficient to coordinate accurate cost processes without significant cost changes. The more information produced, the greater the amount of information to be amended in the event of change. Significant changes proposed at a higher design development requires the work of all the design team to be altered and further reviews with coordination exercises undertaken – making design changes costly and difficult to implement. Further changes at a more design developed level incurs more design team fees plus additional cost of design work as completed by the specialist sub-contractors. It even ramps up as changes impact on the ordering of materials, off site fabrication costs and in the most onerous of scenarios, the need to alter constructed works on site.

As this research developed, software vendors developed enhanced performance tools with visual capabilities to interrogate multidisciplinary designs and detect inherent design clashes. This was a very prominent development for the entire project team as construction virtual environment revealed clashes and analysed interferences from federated models with high cost implication. There was positive impact with design progression reducing errors and variations integrated with traditional approach. The burden of traditional cost checking and monitoring was reduced and design elements were easily captured for cost processes. With the visual enhanced capability of BIM, QSs could carry out on-screen checking on the model to ensure all design items are accurately captured and measured. This varies from QS to QS as their understanding of different design software and interpretations differ. Overall, visualisation is an effective tool in strengthening QSs and design team understanding of project design especially complex relationships and parameters of complex systems. With BIM design coordination, process efficiency is attainable, CAPEX cost (capital expenditure) and OPEX cost (operational expenditure) are improved and impacts on the TOTEX cost (total expenditure or whole life costing), clients and contractors can demand cost certainty, weekly revisioning to provide up to date change cost information. It enables and influences early cost decisions – targeting cost in a transparent way.

One of the Cost Consultant (SME) respondents said the following on the impact of BIM design coordination on revisioning *"Something I haven't touched on yet is the revisions. If you go traditional as in 2D drawing… During the life of the project, during the design phase, you'll get … again, if you follow the RIBA stages and the way that you've set up your BIM Execution Plan, you will get data drops which means that at stage 2, you'll receive your model and at stage 3 again, at stage 4 again, so we have to conduct our cost exercise three times, in theory which means that if it was a traditional project, we'll have to do the whole thing manually every time, so that means re-doing the exact same exercise on the exact same objects to make sure that they're still there and they're still the same dimension. The level of information increases, but some objects will be exactly the same because the designer chose to put that wall there, it's 15 metres long and that may not change from data drop 1 to 2, to 3. If it's traditional, the guy with the ruler will go in and say that's 15 metres. The second time around, yes, that's still 15 metres"*.

The Cost Consultant (SME) continued by saying *"…..If it's 5D BIM, we don't have to do that because again, if it's the same wall and it's got the naming convention in place and it stays consistent from data drop 1 to the next and the next, the quantities will change automatically, so we don't have to go in manually and say yes, still 15 meters etc. The system will tell us it's still 15m, or the system will tell us no, it's 17. We don't have to waste time re-taking the same information. We will only worry what's new. What's new, we worry about and we take care of it; what's old and hasn't changed, or has changed, but was already treated by the system, that's automated, that's going to take care of it, so* *the revisions in BIM are much more efficient, so in terms of cost for us, that's great 'cos we don't have to spend that much time on it"*

BIM design coordination supports automated processes, creating process efficiency that cannot be generated by a traditional approach. Quantities are generated directly from the model through automation for cost estimation. As such QS job performances are much more enhanced as compared with the traditional procedures, it's far more accurate and quicker. To demonstrate the far reaching positive impact of 5D BIM process against the traditional conventions. One of the respondents cost consultant had this to say:

"It's incredibly quicker. We actually ran a test in the office, we were on a specific project, we were given the usual 2D drawings and the 3D model. Now, the QS that was on the project came to us and said 'guys, I've got the model, I've got the drawings, how about I do the usual exercise that I'm required to do on the drawings, I'll take off whatever I can from the drawings, you do it with your 3D model the way that you do it with your CostX thing and we'll compare the results and how long it took us. So at that point, it was just a steel structure for some shop, but big, steel structure, plenty of different beams and columns to take off. It took him half a day to take off all the steel structure and I can't remember the numbers, but he got to somewhere like 1,000tons of steel, something like that, in half a day. He gave us the BIM model, it took us 15 minutes to take off the information and we arrived at maybe 1,150 tons, so because our system is strictly based on the quantities within the model, as such, we can't be wrong, so we for sure have the right result for the steel structure and he was close, but he was not there, he was wrong by 15 per cent and we did it, again, in 15 minutes instead of half a day, so that gives you good information there"

Another respondent who is a BIM Director from a Tier 1 Main Contractor organisation gave another illustration *"With the right people and the right software, utilising costing in a BIM environment can be substantially more efficient and time saving than a non-BIM process. I tell the story that I was in discussion with quantity surveyors, they did a test - they had an M&E package for a large, commercial building and they gave the BIM model to the young graduate and asked him to go away and provide a cost and they gave the drawings of that same package to the sage old QS - non-BIM literate - asked him to provide the package cost. The sage old QS took three weeks, came back 'here's the price.' The graduate did it in an hour and a half because most of the three weeks was taken up with the QS measuring with a scale rule with his red pen".*

BIM Director continued by stating the obvious *"….Both need grey matter because the drawings don't show you wastage factors, prelims, insurances, site set up costs, so the QS still had to apply the knowledge and the cost of things that are not shown in the BIM model, but the graduate again in the BIM model, he did it all digitally, your accurate representation of what's in there and of course, the costs were almost inseparable. So we would rather have the BIM model to save us time in the process and then if there is a problem with the building cost, you've got time to do something about it"*

The experience of the BIM director as narrated aligns with the position of Smith (2013) that though automated competences facilitates measurement and cost estimation duration producing accurate cost information; the QS analytical and checking skills should not be compromised in a BIM digital environment. The reason is that some of the items of work in a design contributing to the cost estimates and tender sums does not reflect some other non-designed work items like the preliminaries, insurances, wastage factors, initial site set up cost, decommissioning temporary site accommodation, mark-ups, overheads and profits. Research findings has demonstrated and shown that stored graphical and non-graphical information in a model promotes QSs job performances, improves accuracy of cost information due to access to a single model and quicker extraction of relevant information. Easy access to the 5D BIM model facilitates better information exchange and sharing of ideas among project party members – improving communication and reducing design and change orders information errors.

5.5 CHAPTER SUMMARY

This chapter has presented the research findings of the study and has used semi-structured open-ended interview as data collection instrument. During the interview, scope was provided allowing extensive discussions with the industry participants. Issues, challenges, benefits and future directions pertaining to the implementation of 5D BIM costing strategy in a digital environment were identified. As extensively discussed above, following data transcription, analysis and coding, three main themes and sixteen sub-themes were identified and discussed as seen in sections above. Significant statements, key phrases, important details, units of data (coded extracts), relationship of participant's views on how a phenomenon was experienced, categorised data with similar meanings created reoccurring theme across transcribed dataset. These statements are either referring to the impact of strategic management strategy on construction processes, methods and directions to adopt on digital protocols, influence of that decision on operational implementation phase, or the availability, issues and benefits of digital 5D BIM tools to delivering those decisions and processes. Hence – the three themes on Management, Process and Technology (Figure 5.1) and the sixteen sub-themes. Key findings of the research showed how management strategic decisions on construction models, methods, approaches and processes adopted affects the entire project outcome with respect to 5D cost information outputs and outcomes. It showcases how management business decisions on procurement route, early contractor involvement, common data environment, EIR, BIM education or literacy, BEP impacts on the overall project delivery with respect to BIM processes (operational level) and technological delivery tools, structures, procedures and protocols. The next chapter will therefore mirror the research themes to develop and present research framework, evaluate the framework using industry practitioners and develop 5D BIM cost protocols with an intent to guide pre-tender process and the actual tendering in a contractor-led procurement project. It's a protocol that supports the contractors and the supply chain with an improved response in terms of accurate cost information, pre-contract tender and post-contract cost performances.

CHAPTER SIX

PRESENTATION OF FRAMEWORK

6.0 INTRODUCTION

Having presented the research findings with the discussion of three main themes and the sixteen sub-themes in chapter 5 of the study - this chapter develops and presents a 5B-CF and 5B-CP. It also evaluates the framework through key industry practitioners who participated during the conducted semi-structured open-ended interview to determine its suitability on the current and future 5D BIM industry practice.

6.1 FRAMEWORK DEVELOPMENT

Review of relevant literatures identified the gap in implementation of 5D BIM within the field of BIM and its processes. To close the research gap, development of interview questions was guided by identified themes in the literature. As an outcome of the data analysis, findings and discussions 5B-CF framework was developed. Both literatures and interview findings established the need for a 5D BIM approach to mitigate the current traditionally integrated cost estimation process which hitherto continue to undermine client's project objectives and outcome. The framework development is based on a contractor-led procurement as opposed to traditional-led procurement. In a traditional project team, the design is produced and developed to a certain level of detail by a design team appointed by the client and a number of contractor's tender for the project with an emerging successful contractor in the end of the tender process. Typically, the client is the employer here and determines requirements, decisions, objectives that influence design solutions, project budget, outcomes and other associated costs and risks except where the traditional design team is novated to the contractor together with the cost and programme risks of design work already undertaken.

The developed 5B-CF is however focused on a contractor-led project team, where the contractor is the employer (normally in a design and build projects) and influences both technical, commercial and management requirements for inclusion within tender process – providing strategic brief of what is required, when and to what standards. Defining cost estimation process, 5B-CP in conjunction with the BEP and requiring details and approaches to meeting cost ceilings as demanded by the client while engaging all project stakeholders. In a contractor-led procurement, the contractor takes full responsibility of governing both early and full appointment of the project team (Pittard and Sell, 2016). The framework is developed as informed by research particularly with this practice approach in mind where a contractor is in charge of strategic level decisions that influence staff process outputs using appropriate technology to improve workflow while increasing effectiveness, efficiency and productivity in 5D cost processes.

Having conducted a qualitative interview with the industry practitioners who had an experience with BIM projects or Level 2 BIM implementation; data transcription, analysis and interpretation of data followed. At the end of the research study, a framework was developed through primary data with an intent to facilitate the uptake of 5D BIM costing processes in a contractor-led procurement project. The framework comprises three main themes (Figure 6.1) as Strategic Level (Management - People), Operational Level (Process) and Technological Level (Technology) with sub-themes under each of the main themes as seen in Figure 6.2.

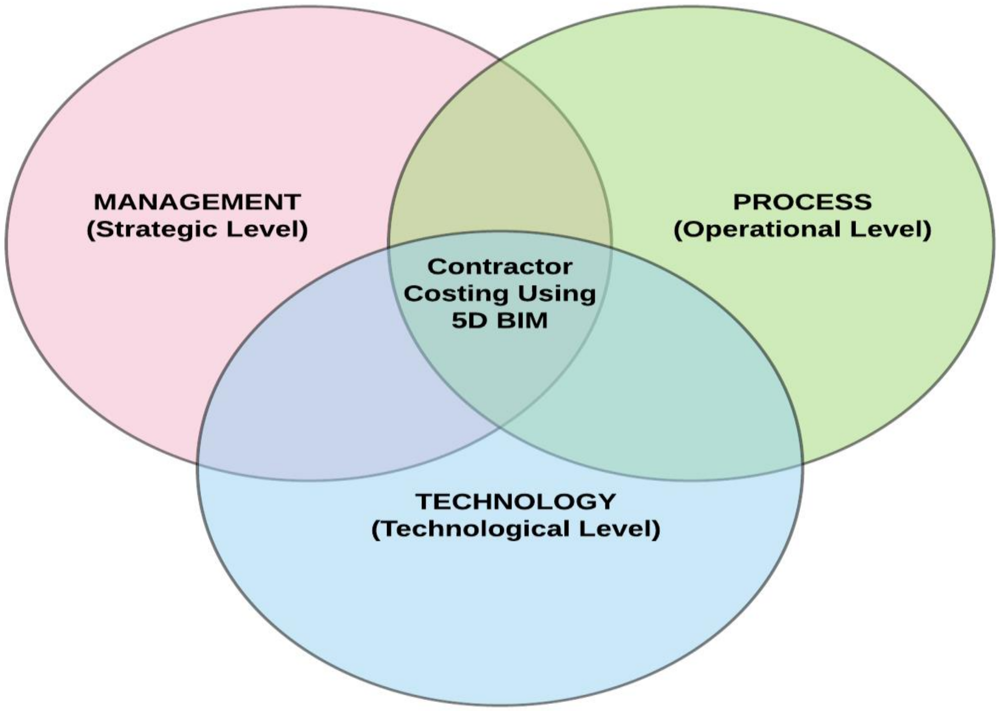


Figure 6.1 Three main research themes – Management, Process and Technology

The framework is proposing a concept that the Strategic Level (Management) of a contractor-led project would make strategic decisions based on the outline strategic brief, assessed needs or project objectives, requirements, defined quality, timeline, 5D cost and performance benchmarks, benefits and value add (Garlick, 2016; Pennanen et al, 2011). The staff with a good understanding of the requirements of those decisions work collaboratively at the operational level (Process) to implement those decisions deploying appropriate technology (Technological Level) to drive solutions (RICS, 2014), since BIM is about Management (people), Process and Technology.

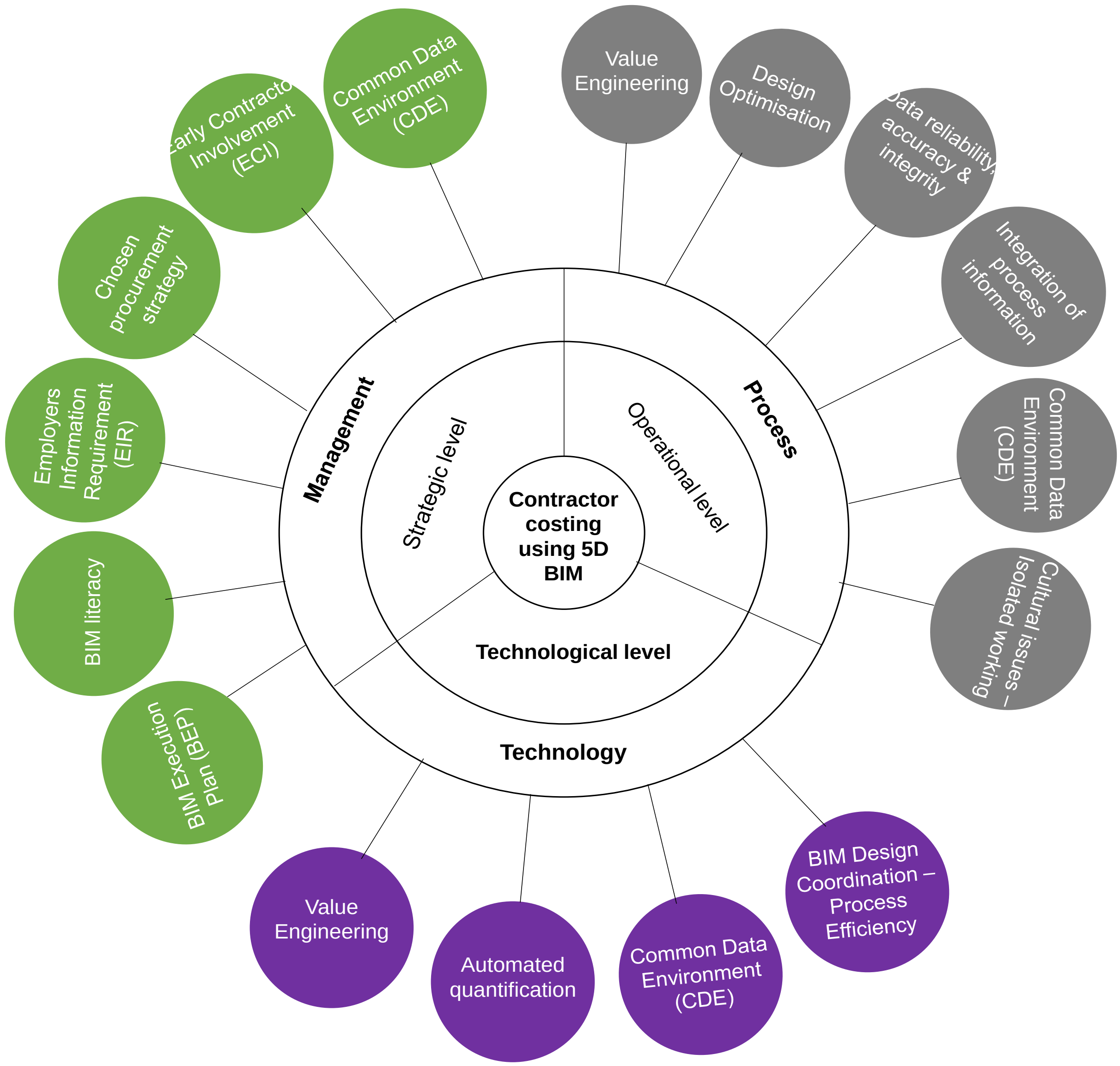


Figure 6.2: 5D BIM Costing Framework (5B-CF) to Facilitate Costing in Contractor-Led Project

6.2 EVALUATION OF RESEARCH FRAMEWORK

Following the development of the 5B-CF (Figures 6.1 and 6.2) above, a set of criteria structured interview questions were developed and sent out to the industry practitioners. The structured interview questions have a quantitative research orientation where the questions and the response categories are predetermined by the researcher (Braun and

Clarke, 2013). The questions were developed as a closed Yes/No questions and each participant was exactly the same questions, in exactly the same way and in exactly the same order. This was not to invent a quantitative approach of data collection but to use set of criteria questions to guide responses from industry practice and limit responses to evaluate the themes within the framework.

To determine how contractor-led procurement management (strategic level) decision of information processes could facilitate the uptake of 5D BIM costing approach and how those top decisions influence the workforce at the operational level for appropriate implementation applying the right technological tools. This was to evaluate and determine the suitability of the framework for both current and future 5D BIM industry practice. Responses from top industry practitioners across UK construction sector who engage in a virtual world are shown below:

6.2.1 First Response from a BIM Director

The respondent affirmed the suitability of the framework to industry practice with a negative response on questions regarding ‘Value Engineering (VE) and Common Data Environment (CDE)’. This could notably suggest the respondent organisation practice probably undertakes a different approach for VE and may engage less CDE methodology in their BIM projects, therefore more experience could improve their perspective. Affirming that strategic level decision for engagement of CDE would support 5D BIM approach (Appendix C) and then declining the effect or the implementation of that decision at the operational level (organisation staff) could be conflicting. The researcher therefore thinks that as 5D expertise improve with more emerging capabilities, the views of the respondent could shift to the positive.

6.2.2 Second Response from a Head of BIM

The respondent affirmed the applicability of the framework to industry practice but declined regarding questions on how 5D process will support design optimisation in a BIM project (Appendix C). Supporting the notion of 5D impact on value engineering which ultimately is optimisation of processes (value improvement) and then declining on the 5D impact on design optimisation underscores an issue of the participant's understanding of the word 'design optimisation'.

6.2.3 Third Response from a BIM Programme and Project Manager

The respondent affirmed that the framework is suitable to industry practice at both the management, operational and technological levels (Appendix C). The views could have been influenced by the level of maturity in executing BIM projects and probably their wider application of BIM processes.

6.2.4 Fourth Response from a Design Manager

The responses (Appendix C) suggest less experience in a direct dealing with the Employer's Information Requirement (EIR) being a specialist trade subcontractor in practice, this could suggest that there is a bit of resistance to change towards collaborative working approach. According to the respondent's views, it is not very clear how 5D processes will resolve cultural issues (isolated working). This response could have been influenced by lack of adequate BIM education. Also responding with 'unsure' on how CDE at the operational level would support 5D cost output and then affirming interoperability of file formats in a Common Data Environment and how that supports 5D BIM uptake shows possibly less engagement of CDE in industry practice. More experience working in a CDE with emerging 5D capabilities and expertise may improve on the respondent's perspective.

6.3 5D BIM COST PROTOCOL (5B-CP)

5B-CP is developed based on the outcome of evaluation of the above 5B-CF (Figure 6.2) developed through semi-structured interviews with industry practitioners and emerging literature in the field of 5D BIM. Its function is to support the contractors and the supply chain in the generation of reliable and accurate cost information during design, construction and operational phase in a contractor-led procurement project. It constitutes questions with potential to inform strategic management decisions, influence functions at the operational level while engaging the right technological tools. It is presented to guide 5D process specifications for tender process and inclusions.

The novel 5B-CP presented here is developed as a document that should be read in conjunction with the Pre-Contract BEP and the EIR. It is designed to follow a similar vein to these established documents within the UK BIM process, whilst drawing on primary knowledge derived from this research. It could also be adapted for a Post-Contract BEP as deemed suitable. The purpose of the document is to provide stakeholders in the design and construction process detailed information on the 5D requirements for a contractor led BIM project to ensure. The questions/bullet points presented in each section support the stakeholders in providing a specific definition of 5D cost information requirements in successive project stages. It is flexible in application and structured to accommodate bespoke project developments across a spectrum of construction suppliers and practitioners who engage in business processes within virtual environment. The details of the document are hereby presented as follows:

6.3.1 Management (Strategic Level)

S/N	Category	Questions
1.	Early Contractor Involvement (ECI)	▪ How will the contractor ensure that 5D data is available throughout the process through collaborative working? ▪ What specifications of 5D data in successive design stages would inform BIM model design inputs ▪ What input/output is required from the contractors QS from the outset of a design phase to ensure 5D cost estimating processes are in place ▪ How would the value of a QS or cost managers contribution be measured for early engagement in a BIM project?
2.	Chosen Procurement Strategy	▪ What would constitute early evaluation of cost outputs during the design

		programme considering a chosen procurement route ▪ What flexibilities within the procurement options will facilitate 5D cost processes ▪ What would be the cost benefit criteria for a chosen procurement option? How is this to be measured?
3.	Employers Information Requirement (EIR)	▪ How would pre-contract BEP be evaluated against the EIR to ensure it meets the cost ceiling criteria of work stages as defined by the client? ▪ How would 5D requirements within EIR streamline processes and improve collaborative workflow? ▪ What plain language questions (PLQs) relate to ensuring a fully integrated 5D processes?
4.	Common Data Environment (CDE)	▪ How would the contractor ensure a naming protocol that would support 5D automated processes?

		▪ What data exchange file format would be engaged during design phase to support cost information exchange ▪ What would be the take-off agreement in a BIM model, digital measurement or automation of quantities or hybrid?
5.	BIM Literacy	▪ Is any specific training required to enhance QS or Cost managers function on the BIM project? ▪ What are the key training components to engage to ensure a full 5D skill acquisition?
6.	BIM Execution Plan (BEP)	▪ What are the key 5D requirements to be included within a BEP to ensure verifiable capabilities, capacity and competences ▪ How would tender submissions be evaluated using a 5D validation framework or template? ▪ How is consistency of data reliability and

		integrity ensured within the 5D process ▪ How would the inclusion of a 5D requirement ensure design process efficiency?

6.3.2 Process (Operational Level)

S/N	Category	Questions
1.	Value Engineering	▪ What input data is required to the 5D process to ensure optimisation of design outputs ▪ What measures are in place to ensure the 5D requirement within the BIM process ensures the price of construction estimate is not in excess ▪ How would the contractor engage a 5D BIM QS to ensure product improvement without sacrificing functionality
2.	Design Optimisation	▪ How would 5D requirements ensure option appraisal for different design options ▪ How would 5D process requirements influence design model (data) to enable QS to interpret, automate quantities and price design

		outputs. ▪ How would 5D requirements for RIBA work stages (0-7) ensure best design solutions
3.	Data Reliability, Accuracy and Integrity	▪ How would 5D input data specification ensure reliability and accurate graphical and non-graphical data input ▪ How would design information input be restricted to expected client's cost ceiling engaging 5D in successive stages as design evolves ▪ What processes are to be adopted to ensure 5D model supports automated cost information update – revisioning
4.	Integration of Process Information	▪ How would 5D data requirement improve construction workflow ▪ How would 5D processes resolve costs and risks impact at project interfaces ▪ What integrated system development is required to support 5D requirements improve process and cost efficiency

5.	Common Data Environment (CDE)	▪ How would 5D requirements ensure application of common standards during design, construction and maintenance phase ▪ How would 5D specifications increase the extent of reliability of project stakeholders on model information while using BIM model ▪ How would 5D establish costs and risks impact link to model design changes ▪ What 5D procedures are to be integrated in design information modelling to facilitate model mapping for costing
6.	Cultural Issues	▪ How 5D information requirement resolve isolated or independent way of working ▪ What 5D specific information requirements will be submitted alongside a post-contract BEP to certify seamless integration of Tasks Information Delivery Plan into Master Information Delivery Plan (MIDP) ▪ How would 5D requirements retain agreed standards in an evolving post-contract BEP

		where additional supplier appointments are made during design, construction and maintenance project phase

6.3.3 Technology (Technological Level)

S/N	Category	Questions
1.	Value Engineering	▪ How would 5D process tools improve visual communication of cost information supporting product design optimisation ▪ How would 5D requirements circumvent excessive design additions to BIM model supporting value improvement
2.	Automated Quantification	▪ How would 5D information requirement determine information exchange format ▪ What software tool included as a 5D requirement will support accurate quantity extraction automation and pricing of estimates
3.	Common Data Environment (CDE)	▪ What software tools included in 5D

		requirements will have uniformity for naming convention ▪ What 5D cost software tools will create database of elemental rates and establish a link between BIM model and cost database. ▪ What will be the minimum 5D requirement for interoperability of file formats ▪ What system of cost coding would be a 5D requirement to benchmark standard layout model cost for each aspect of the project work stages
4.	BIM Design Coordination	▪ What 5D requirement is needed to measure cost savings from clash detections ▪ How would process efficiency using appropriate software tools be actualised in a 5D virtual world

6.4 CHAPTER SUMMARY

A 5B-CF was developed and presented in this chapter using the research findings from interviews and relevant literatures. Evaluation feedback from the construction industry practitioners established 5D BIM process as a panacea to the challenges and issues embedded in the traditional measurement, cost estimating and cost planning process. It's a framework that is focused on contractor-led procurement project where all project requirements (management, commercial and technical) are controlled and influenced by the contractor who acts an employer – providing initial briefs, determining timelines of cost activities with full responsibilities of contractual appointments.

Based on the evaluation feedback from the industry experts, this chapter develops a novel 5B-CP functioning as a guide towards pre-tender process and the actual tendering. It's a protocol that supports the contractors and the supply chain with an improved cost response to be read in conjunction with the EIR, Pre-Contract BEP and Post-Contract BEP as considered suitable. The protocol is designed to provide structure on cost functions and development within a virtual environment eliminating or at least reducing variation issues due to numerous request for information (RFIs) and change orders at final account project stage. Its intended to provide design, construction, operation and maintenance project stakeholders a detailed information requirement on 5D BIM cost estimating process and could be tailored to satisfy varying project objectives, aspirations, requirements and outcomes. Next chapter will therefore look at how the research aim and objectives as set out from the outset of the study was achieved, stating contribution to knowledge and making relevant recommendation for further research.

CHAPTER SEVEN

CONCLUSION AND FURTHER RECOMMENDATION

7.0 INTRODUCTION

The previous chapter developed and presented research framework, evaluated the framework and developed 5B-CP as a guide for costing virtual BIM models in successive project stages improving accuracy of generated cost information for tender process. The suitability and applicability of the developed 5B-CF is evaluated and confirmed by key construction industry practitioners to be a contributory finding with impact on the best industry practice. Having therefore developed and evaluated a framework for this study, this chapter will look at how the research aim and objectives were met, highlighting contribution to knowledge and making recommendations for further research.

7.1 RESEARCH AIM

The development of an approach to allow contractors to fully utilise BIM for more effective 5D costing is the aim of this study. Developing BIM process with an embedded 5D approach to support contractors and their supply chain migrate the shores of traditional measurement, costing estimating and cost planning to an automated method supported with relevant technology in a digital environment was a research guide and was considered from the outset of this research study. This was to improve visual communication of cost information, automate quantification, generate accurate cost information, improve productivity by waste reduction and meeting cost targets, reducing risks, measurement errors and uncertainties while realising client's requirements for overall project success. In the end a framework has been developed through main themes and sub-themes to support contractor's approach to effective 5D costing of a BIM model. The framework was evaluated by top UK industry practitioners and as a result a 5B-CP has also been proposed to support contractors and their supply chain meet 5D requirements and consequently generate a more accurate and reliable cost estimate and cost plan during design, construction and operational phase in a contractor-led project team.

7.2 RESEARCH OBJECTIVES

With the above aim in view, the following objectives were developed and met during the investigative studies.

- **To undertake a critical analysis of research in the field of BIM and its current use in costing**. A review of past literature in the area of BIM and its current application in the industry, traditional costing approach, cost estimation and cost planning, new rule of measurement, existing industry standards, procurement and project and cost management was conducted. The research informed of the current industry practice which is majorly traditional costing approach and the need to further establish an effective costing approach with potentials to supporting the contractor and their supply chain to fully utilise 5D BIM processes and tools.

- **To carry out semi-structured open ended interviews informed by research with industry practitioners who are experienced in carrying out BIM projects.** Having established a research gap through the reviewed existing work in the field of BIM and other relevant materials, a pilot and semi-structured open ended interviews were conducted. Interview scope with the industry participants was not limited to drafted interview questions but extensive discussions on the phenomenon under study was allowed to enable the researcher identify issues and challenges beyond that which is perceived by the researcher or the findings of reviewed literatures. Industry practitioners across a spectrum of relevant construction organisations with experience and background in BIM projects were engaged to further investigate literature findings and to establish a solution framework or an approach with capabilities to supporting digital 5D costing in a BIM project.

- **Develop a proposed framework through primary data using interpretative phenomenology and thematic analytical approach alongside to generate themes.** Interview data (primary data) from across categories of the construction industry was transcribed. A phenomenological data analytical process of a qualitative method of inquiry and thematic analysis was used to identify significant statements, strong sentences, important details and relevant quotes and were coded manually to generate three main predominant themes and sub-themes relating to issue of cost and BIM resulting in a development of framework.

- **Evaluate developed framework to determine suitability for industry 5D BIM processes and practice.** Developed 5B-CF from the research findings were sent to top industry practitioners who also participated in the semi-structured open-ended interview with set of criteria questions to evaluate applicability/suitability of the proposed framework in industry practice and how that could facilitate 5D costing in a given BIM project. The respondents affirmed the suitability and impact of the framework to 5D BIM industry practice with fewer concerns on some set criteria questions.

- **Develop a 5B-CP from key research findings of the framework as impact to industry.** Based on the framework's evaluation feedback from industry practitioners, a 5B-CP which is to be read in conjunction with the Pre-Contract BEP/EIR and Post-Contract BEP as deemed fit is proposed. The document will provide stakeholders in the design and construction process detailed information on the 5D requirements for a construction BIM project. It should enhance accuracy and reliability of construction cost information when applied appropriately.

- **Determine future directions of contractor costing using BIM and to identify further challenges and benefits of contractor costing in BIM**. The 5B-CF and the 5B-CP as proposed is the future direction of contractor costing in BIM. Challenges and benefits are also well outlined within the research study

7.3 CONTRIBUTION TO KNOWLEDGE

The 5D BIM Costing Framework (5B-CF) facilitating cost modelling in Contractor-Led Projects and 5D BIM Cost Protocol (5B-CP) – a document informed by costing framework to be read in conjunction with the Pre-Contract BEP and the EIR with possible Post-Contract BEP adaptation, are findings that would enhance collaborative and integrated cost professional functions within BIM project team. As a result, this research study has two major contributions to knowledge:

- A developed 5D BIM costing framework to facilitate costing in contractor-led projects within the UK construction industry practice – an approach that allows contractors and their supply chain to fully utilise BIM for more 5D effective costing.
- A 5B-CP – An impact to UK construction industry practice supporting project stakeholders in the design, construction and operational process with detailed but not exhaustive information on the requirement of 5D implementation in a construction BIM project. This means it could be modified for suitability to fulfil a 5D project requirements in various successive projects. Proper application of 5B-CP to tender process should generate reliable and accurate cost information during design, construction and operational phase in a contractor-led procurement project.

7.4 CONCLUSION

Traditionally, pricing of construction projects allows for high contingencies, prime cost sums, provisional sums (lump sums) at the outset with later expectation for variation estimation claims, delays, compensations, redesign and rework. Conversely, 5D BIM processes and available tools has potentials to reduce or erase the need for contingencies as gap between project initiation and definition, design development, cost estimation modelling and actual construction processes narrows. As a complement to traditional cost estimation and cost planning techniques until BIM education and skillsets gain maturity, 5D BIM processes is developing momentum and setting strategies to prevent further cost overrun that burdens project budget from design preliminary to maintenance and operations as digital cost estimates evolves.

This study examined means to develop an improved approach that supports the contractors and the supply chain to fully utilise BIM for more effective 5D BIM costing processes in a contractor-led projects. After reviewing existing relevant literatures extensively, appropriate research method was used to collect data from relevant and significant construction industry sample population through a semi-structured open-ended interview (research instrument). Generated thematics from data analytical process was used to develop 5D BIM costing framework with framework evaluation from key industry practitioners leading to 5D BIM cost protocols as contribution to knowledge. The research found that with visual cost modelling capabilities linked to geometric 3D data, early cost estimation involving cost professionals early in the design development will target to advise on key cost drivers at successive work stages. This will generate within design workflow both cost accuracy and cost efficiency for project budgets. With abilities to visualise and automate quantities, sharing of cost information data, visual communication and consequent mitigation of risks at project early stages, trust and reliance among multi-disciplinary project team members are created.

The developed approach within the framework that allows the contractor and the supply chain to fully utilise BIM for effective 5D costing and 5D Cost BIM protocol as proposed has provided the needed traction to make 5D processes and requirements an integral part of the evolving design, construction, operation and maintenance work stages. Educating and equipping contractors and the supply chain workforce with adequate skillset especially the QS, estimators, cost managers and cost consultant professionals will see the design inputs drive cost certainty. Leveraging on the management decision to follow processes that will generate the most accurate and reliable cost information for the client and implementing it using the right technological tool is critical to effective 5D costing activities. Going forward for all projects both presently and in the future, the study concludes that it is imperative to work with the workforce at the process level who are in possession of a good understanding of the entire 5D costing process to implement processes and tools from early concept design stages through to post construction using relevant technological tool kits. Application of 5D processes may vary at this early BIM implementation stages from organisation to organisation and project to project as the study revealed. This is due to absence of BIM training, information requirement not explicitly stated from the project outset, leadership on digital functions and scope, design scoping challenges leading to inaccurate information input, and lack of acquisition of adequate skillset; lopsided understanding of CDE commercial and technical requirements including variableness in both organisational and project structure and culture. However, as BIM gains maturity and 5D BIM data requirement legislated and mandated for centrally procured public sector projects, application will become more standardised leveraging on the developed 5B-CP and existing PAS documents for full realisation of 5D increased benefits and stronger collaborative relationships.

7.5 RECOMMENDATION FOR FURTHER RESEARCH

Some further research in the field of 5D BIM to consolidate a seamless implementation of the findings of this research and to make this research complete are suggested below:

- A further research to demonstrate how 5D processes and requirements sits within a traditional-led procurement especially when the design team is novated to the contractor with all design cost and risks transferred given the influence of the client on the initial developed or developing design.
- A further research to show how cost data will be linked within the graphical BIM model (linking up rates with the items in the model) using appropriate software tools for quicker automation of quantities and pricing in BIM modelling environment.
- A further research to show means of measuring construction cost efficiency and cost savings in a construction BIM process
- A further research to show a more industry based 5D BIM integrated strategy with abilities to manage project interphases, change orders, project timeline and cost overrun during design, construction and operational phase.
- A further research resolving existing naming convention conflict between NRM elemental naming standard and NBS object naming convention. This will standardise uniformity in naming convention and sort out some digital automation issues while reducing varying use of construction bespoke cost data among organisations.

7.6 CHAPTER SUMMARY

Both the clients and the contractors can seize cost information modelling opportunities that 5D BIM offers to secure the assets, value for money and final project outcomes they need. The contractor is seen as an expert in construction and could be counter intuitive to exclude such valuable expertise from the pre-construction and successive design phases especially with the BIM intent of 'build it twice', once virtually and once physically. 5D BIM is an upcoming requirement for both private and public sector tender strategies and processes. It is supported by both the industry and the successive Governments as a credible means to early cost estimation and visual cost information generation, avoiding and managing project risks, encouraging innovation and value add, making cost and project time predictable, and improving outcomes. The cost saving opportunities that arise with the linking of the 5D (cost information) to a 3D model is more than just a quantity take-off merit as the study has revealed. It conceptualises a methodology and a framework for 5D BIM application to the design, construction and maintenance of BIM projects with a defined objective of meeting client's cost ceiling.

This chapter therefore detailed how the aim and objectives of the research was achieved, the contributions to knowledge which proposes a 5D BIM costing framework with a view to facilitating costing in contractor-led project allowing contractors to fully utilize BIM for more effective costing. It further proposed a 5B-CP to be read and applied in conjunction with other BIM standard documents like PAS suites.

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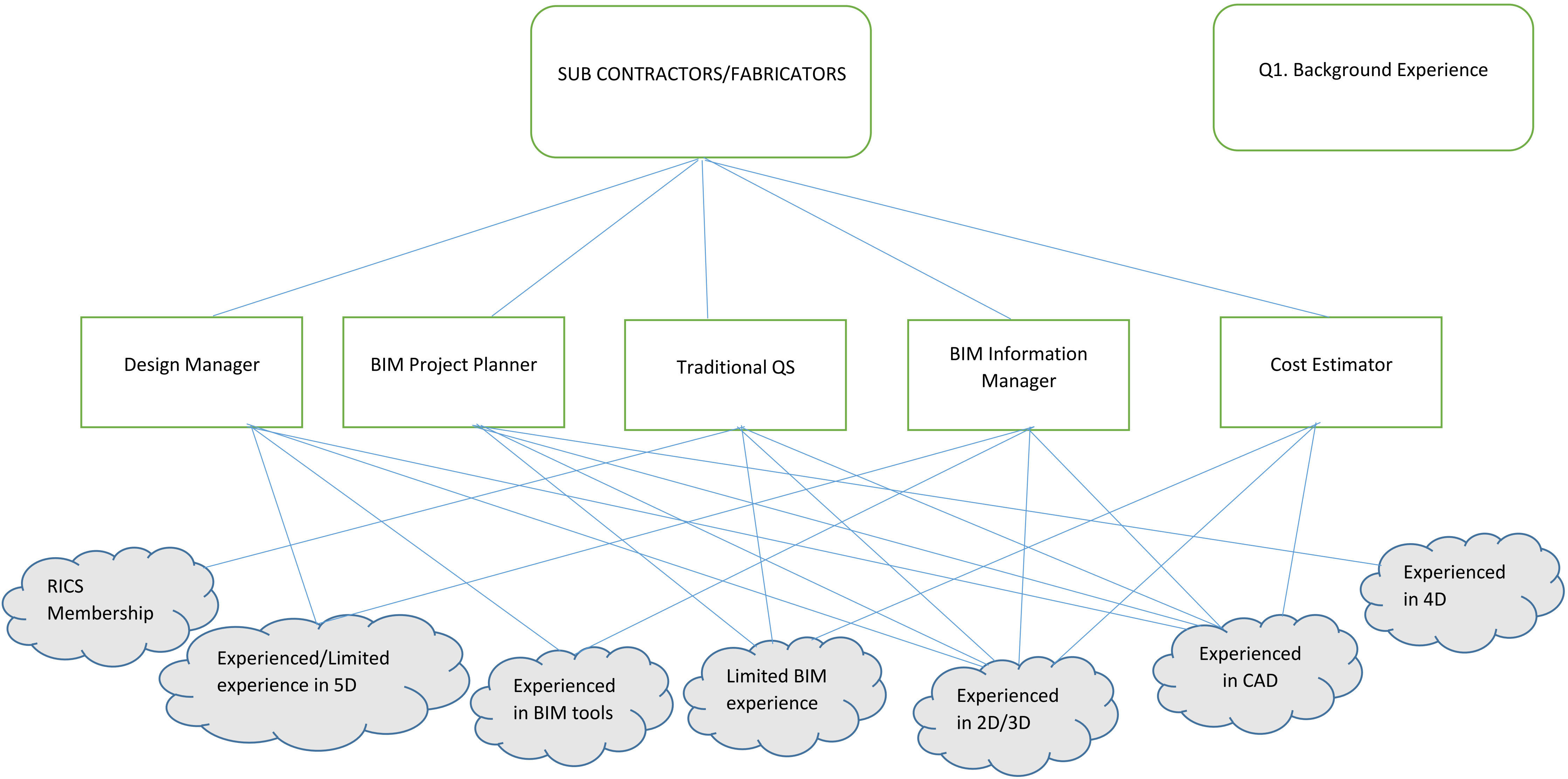
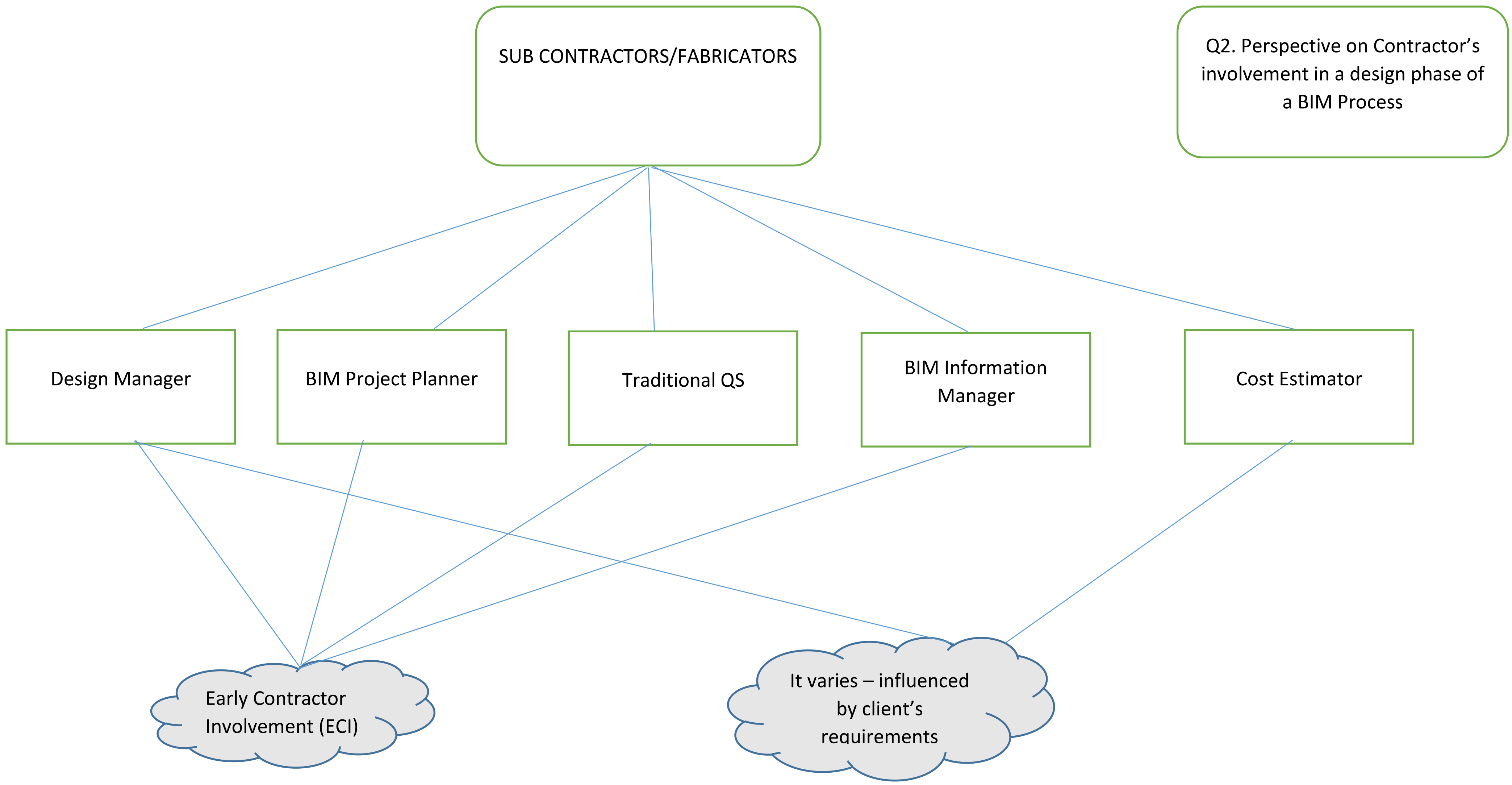
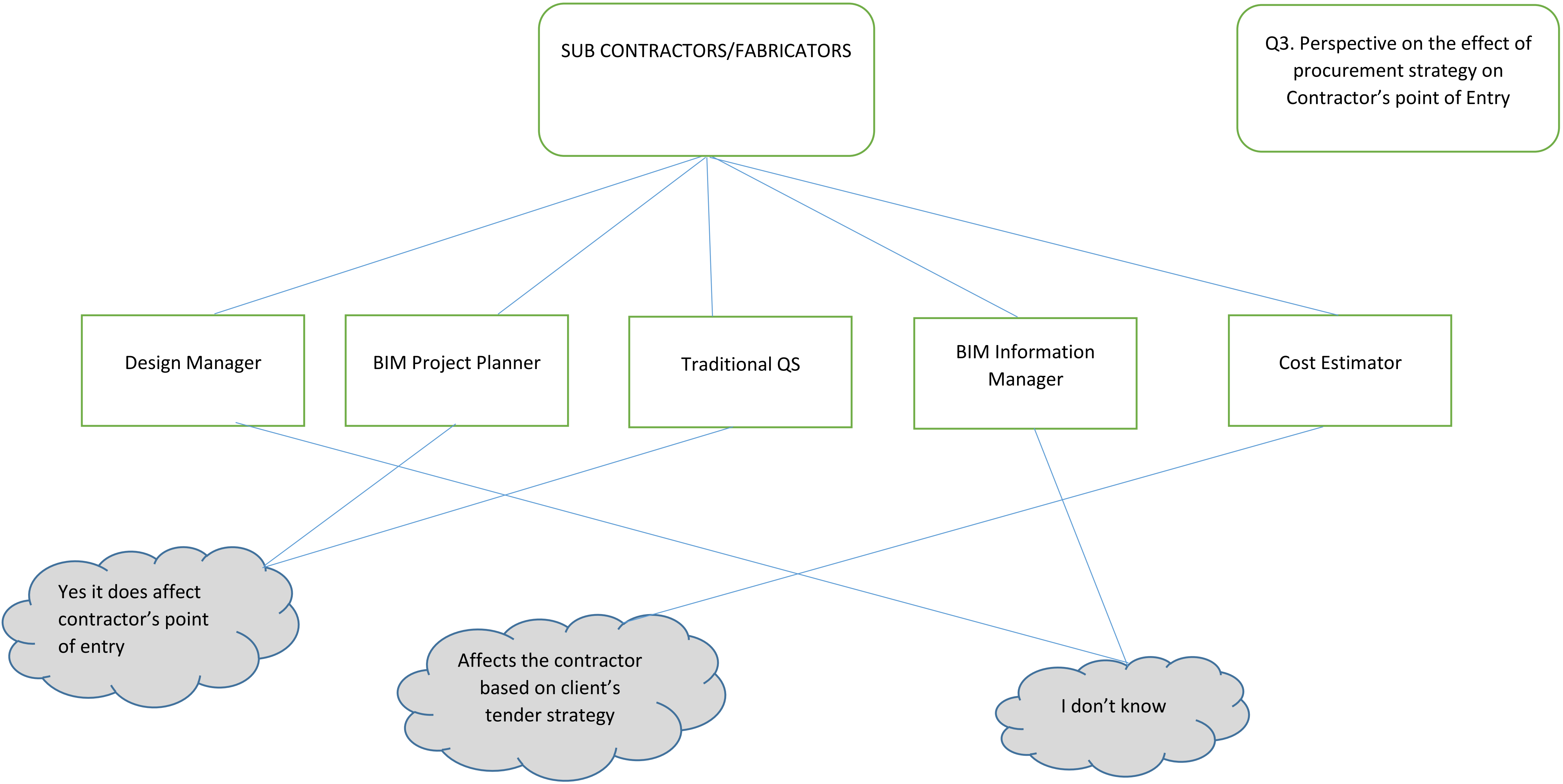
Appendix

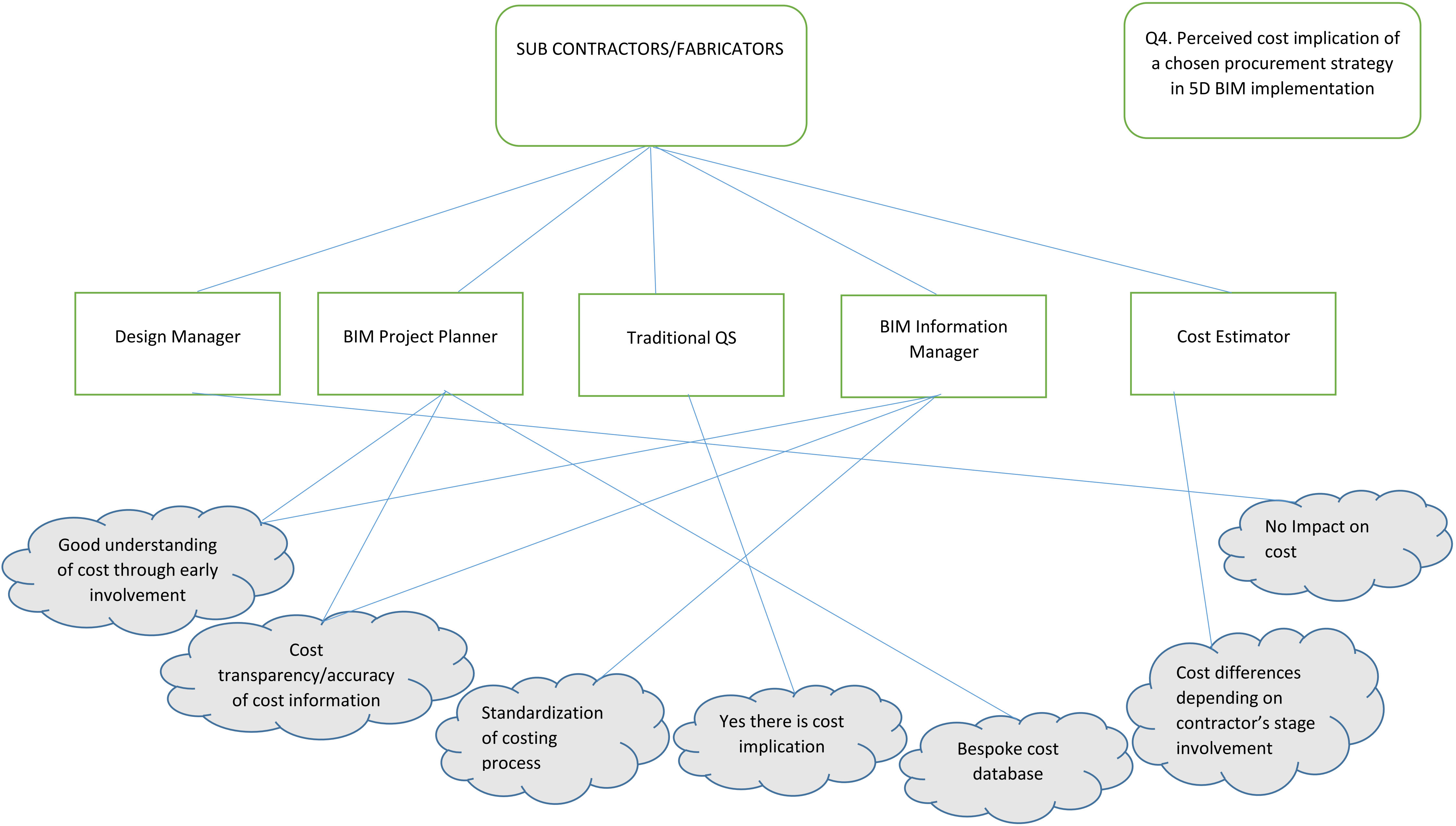
APPENDIX A

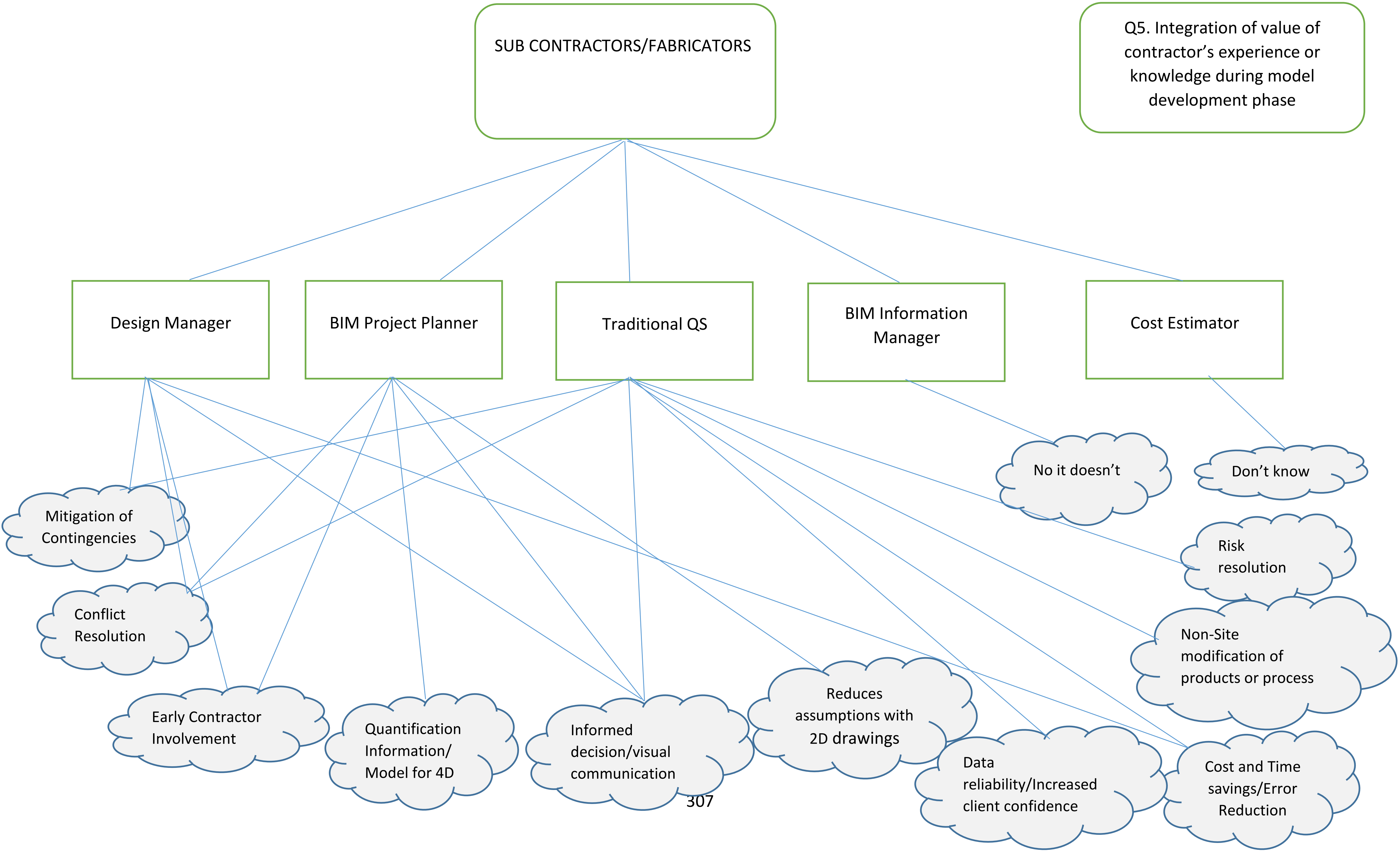
Diagrammatic Representation of Data Analytical Process


SUB CONTRACTORS/FABRICATORS
Q1. Background Experience
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
RICS Membership
Experienced/Limited experience in 5D
Experienced in BIM tools
Limited BIM experience
Experienced in 2D/3D
Experienced in CAD
Experienced in 4D

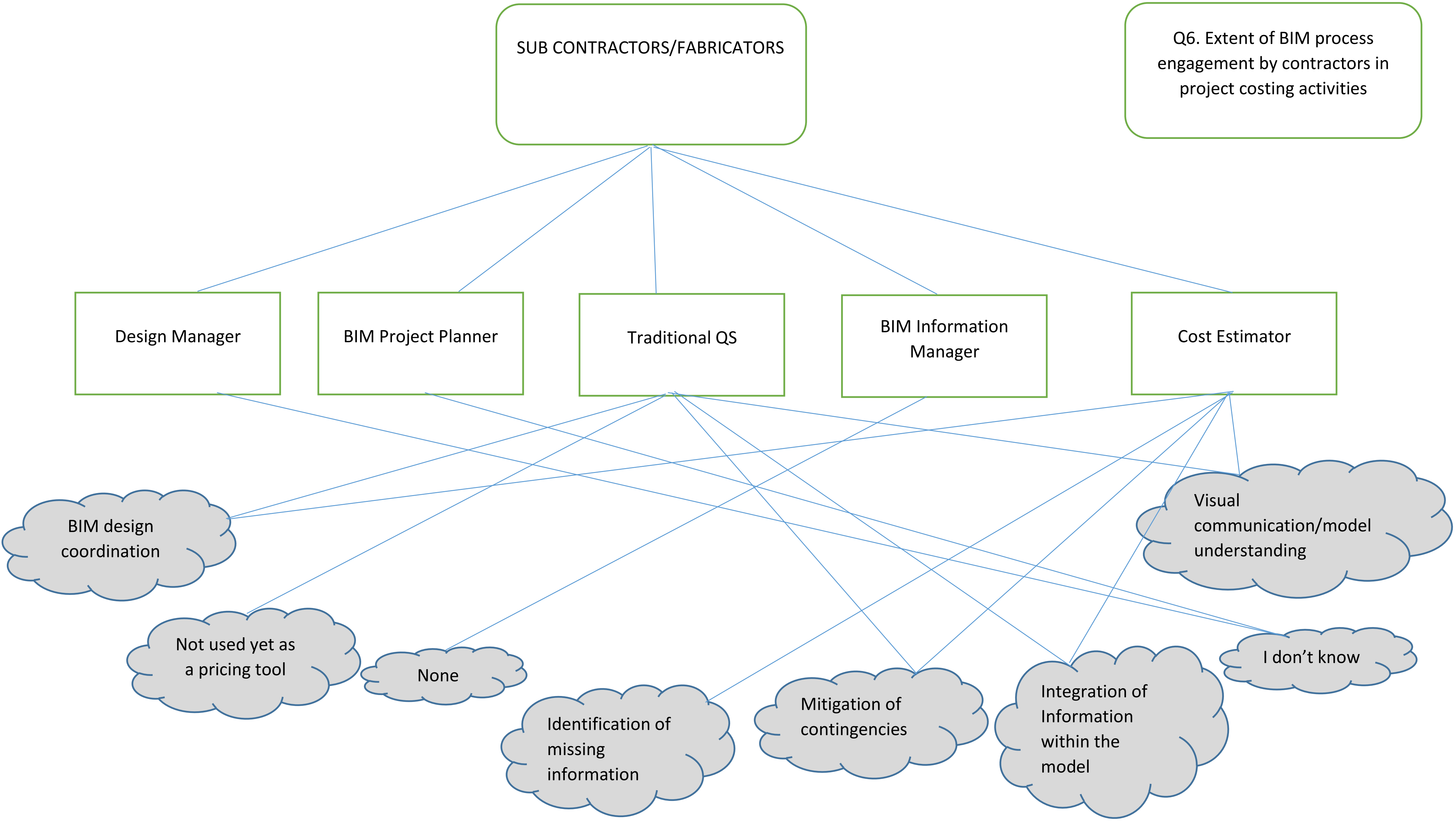

SUB CONTRACTORS/FABRICATORS
Q2. Perspective on Contractor's involvement in a design phase of a BIM Process
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Early Contractor Involvement (ECI)
It varies – influenced by client's requirements

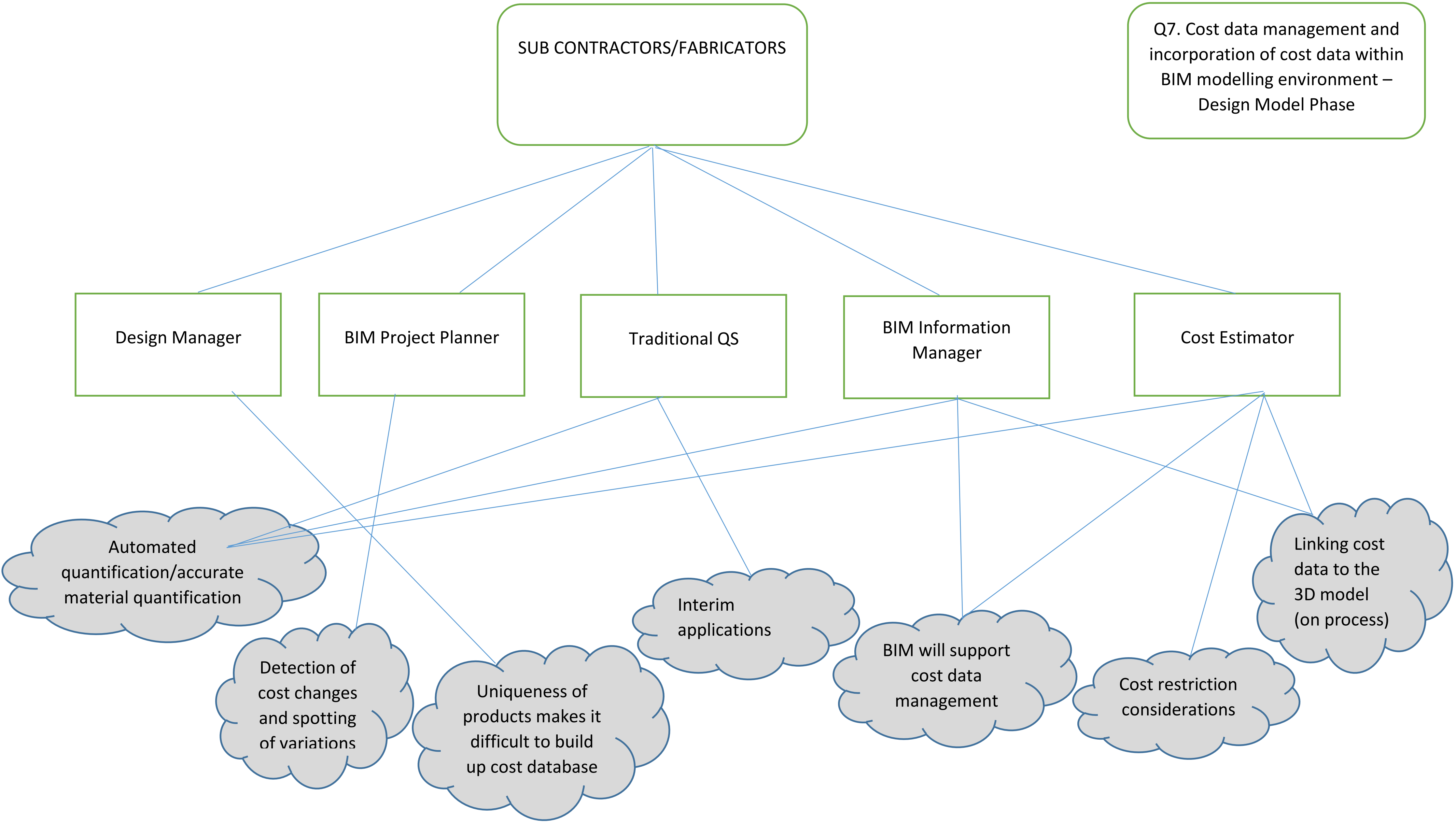

SUB CONTRACTORS/FABRICATORS
Q3. Perspective on the effect of procurement strategy on Contractor's point of Entry
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Yes it does affect contractor's point of entry
Affects the contractor based on client's tender strategy
I don't know

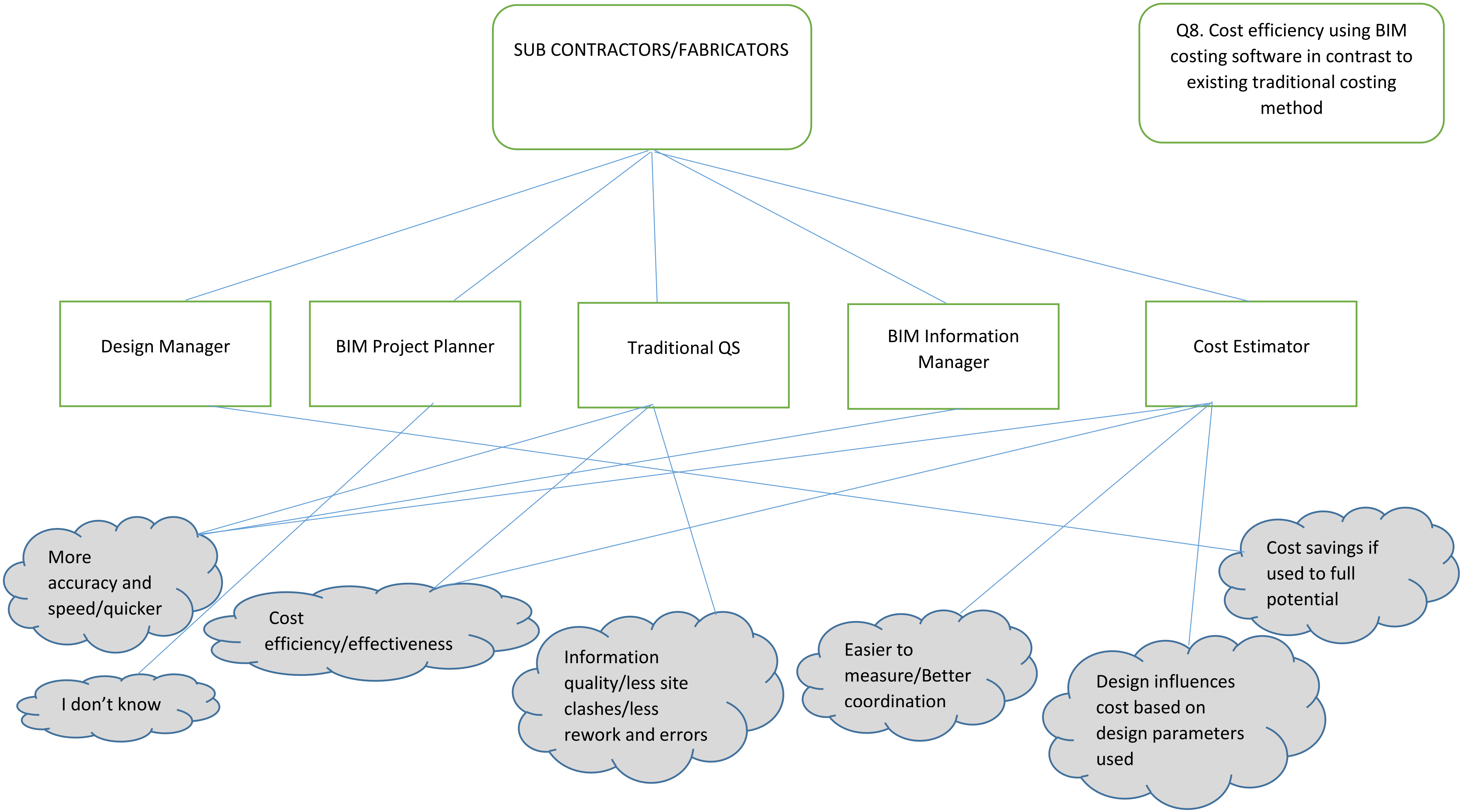

SUB CONTRACTORS/FABRICATORS
Q4. Perceived cost implication of a chosen procurement strategy in 5D BIM implementation
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Good understanding of cost through early involvement
Cost transparency/accuracy of cost information
Standardization of costing process
Yes there is cost implication
Bespoke cost database
Cost differences depending on contractor's stage involvement
No Impact on cost

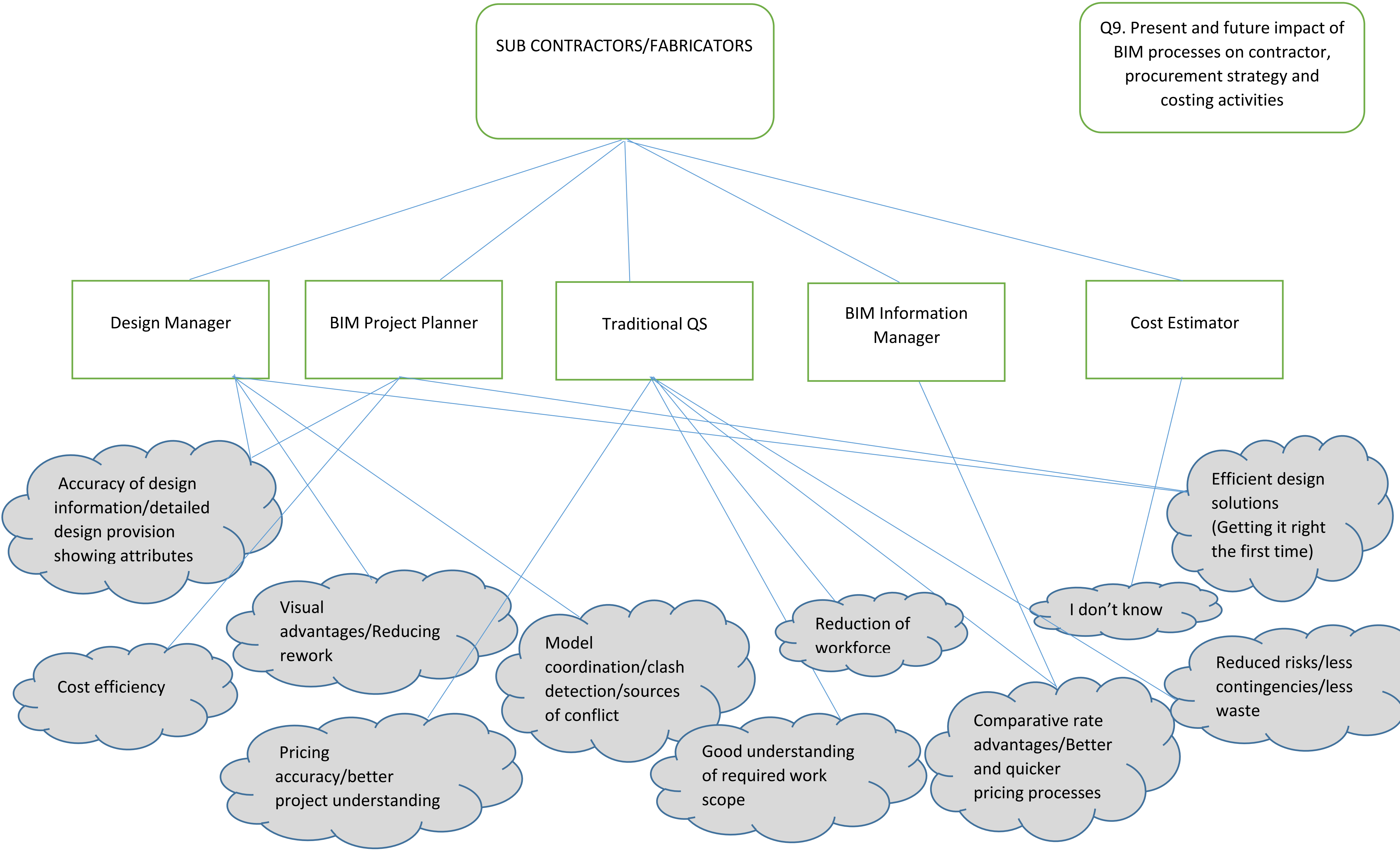


SUB CONTRACTORS/FABRICATORS
Q5. Integration of value of contractor's experience or knowledge during model development phase
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
No it doesn't
Don't know
Mitigation of Contingencies
Risk resolution
Conflict Resolution
Non-Site modification of products or process
Early Contractor Involvement
Quantification Information/ Model for 4D
Informed decision/visual communication
Reduces assumptions with 2D drawings
Data reliability/Increased client confidence
Cost and Time savings/Error Reduction

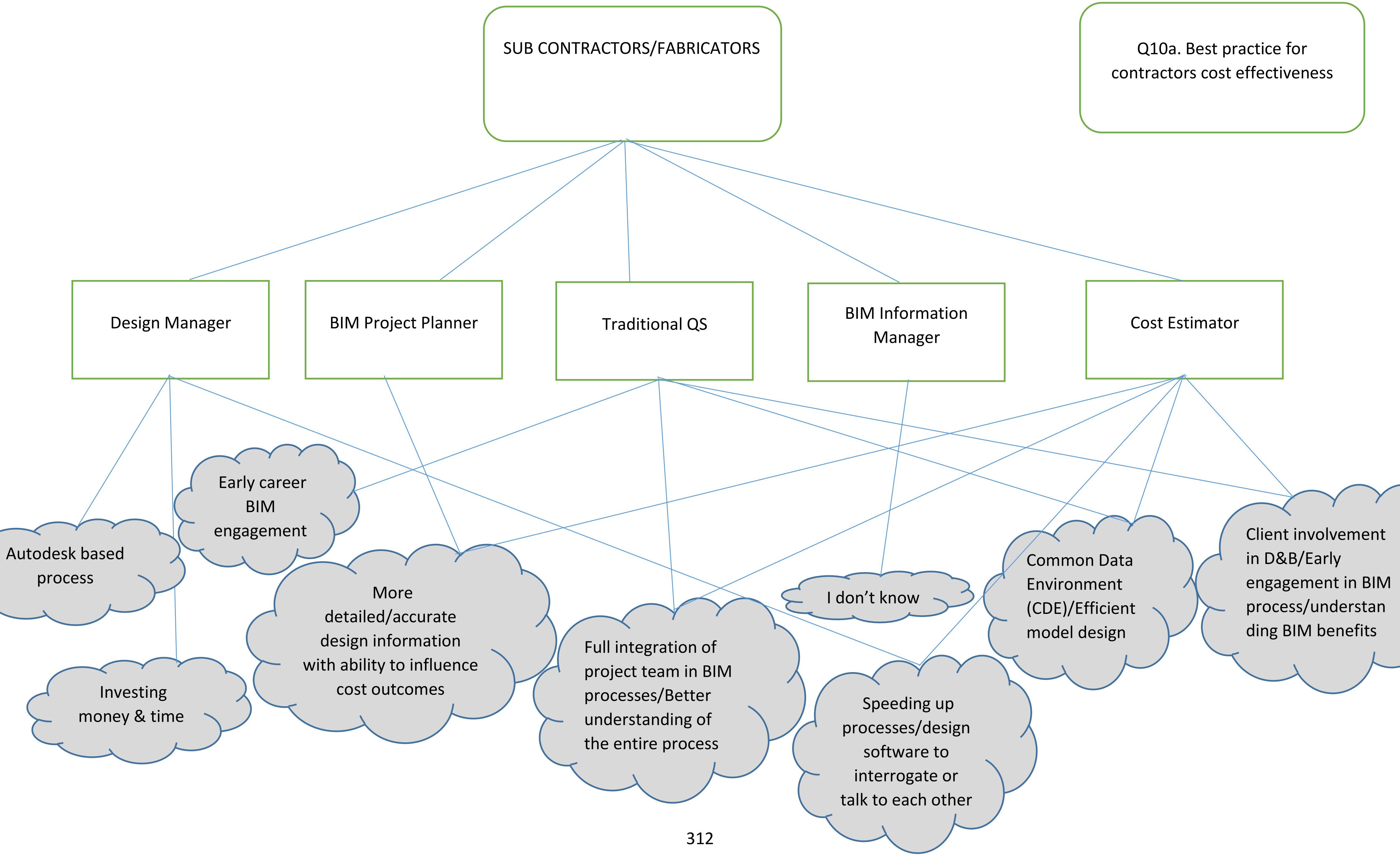

SUB CONTRACTORS/FABRICATORS
Q6. Extent of BIM process engagement by contractors in project costing activities
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
BIM design coordination
Visual communication/model understanding
Not used yet as a pricing tool
None
Identification of missing information
Mitigation of contingencies
Integration of Information within the model
I don't know

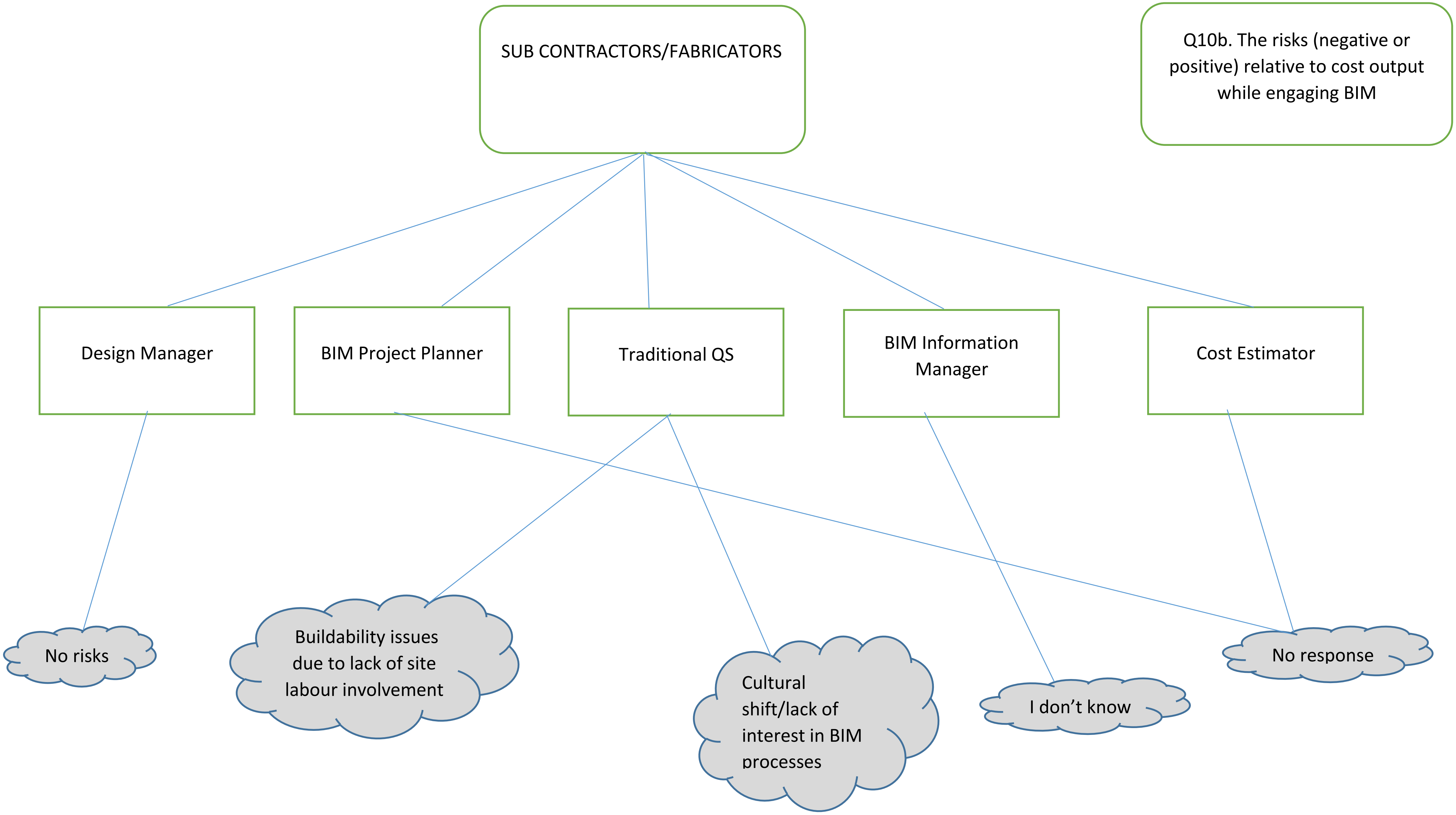

SUB CONTRACTORS/FABRICATORS
Q7. Cost data management and incorporation of cost data within BIM modelling environment – Design Model Phase
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Automated quantification/accurate material quantification
Detection of cost changes and spotting of variations
Uniqueness of products makes it difficult to build up cost database
Interim applications
BIM will support cost data management
Cost restriction considerations
Linking cost data to the 3D model (on process)

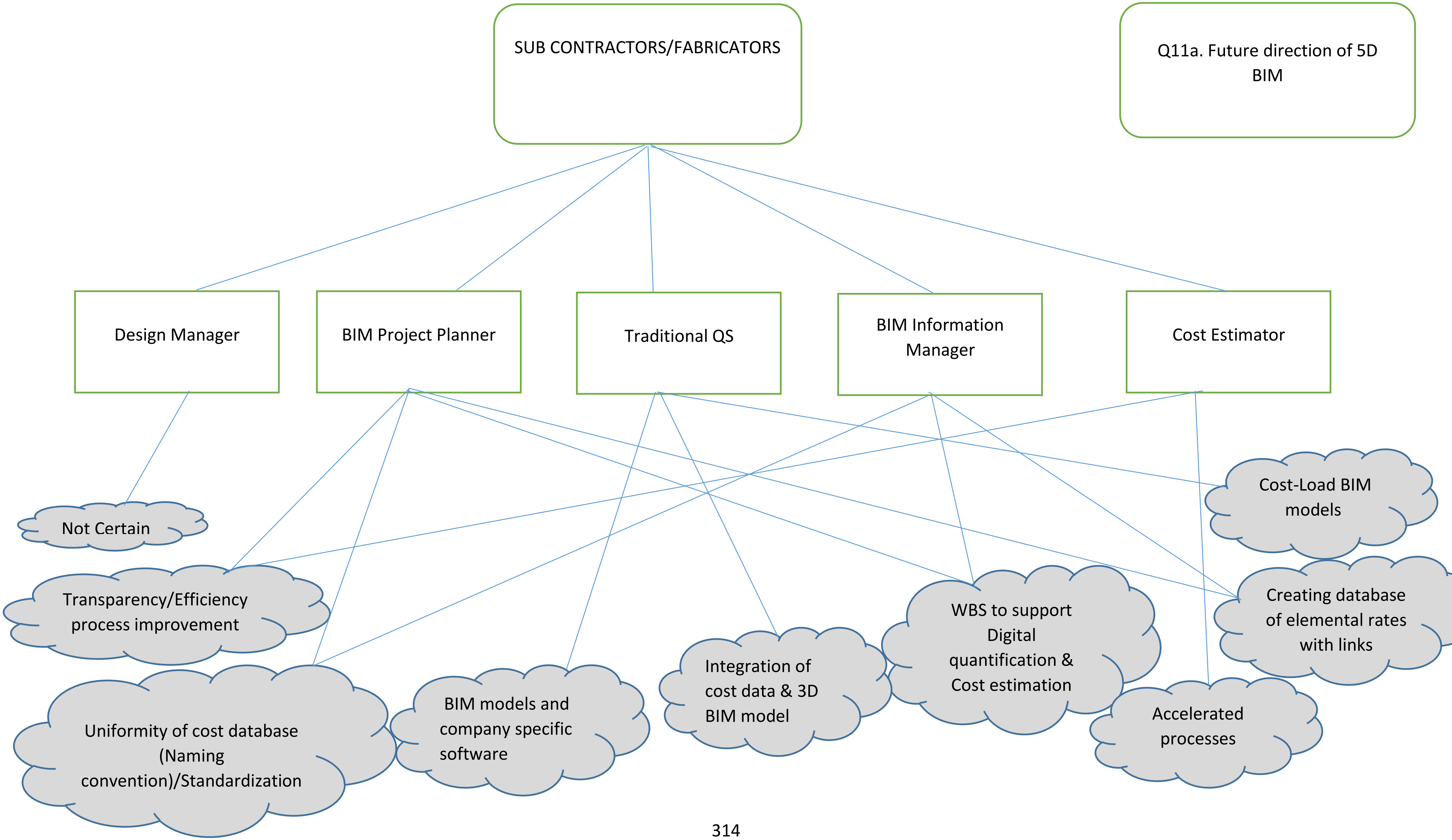

SUB CONTRACTORS/FABRICATORS
Q8. Cost efficiency using BIM costing software in contrast to existing traditional costing method
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
More accuracy and speed/quicker
Cost efficiency/effectiveness
Information quality/less site clashes/less rework and errors
Easier to measure/Better coordination
Design influences cost based on design parameters used
Cost savings if used to full potential
I don't know

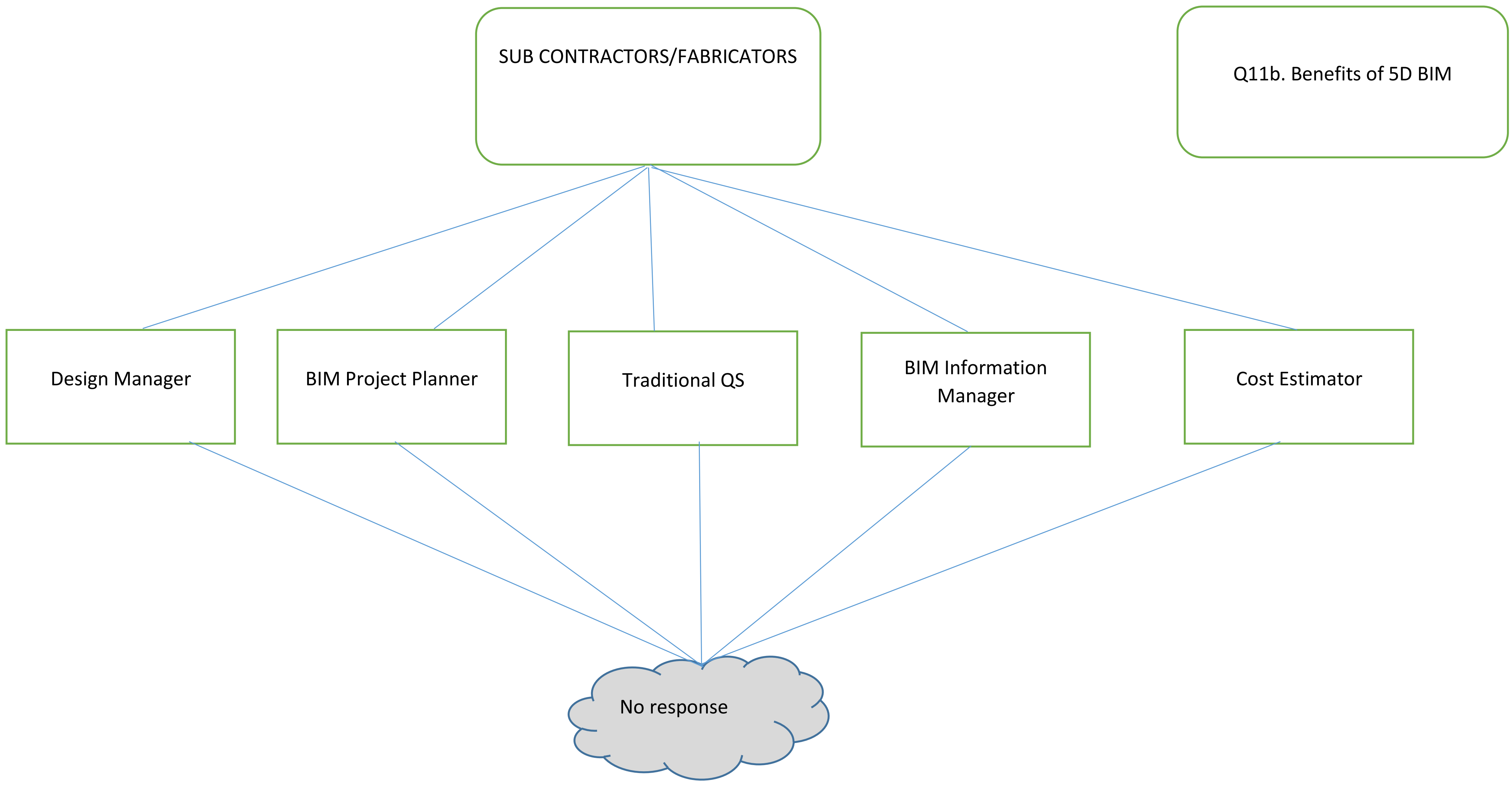


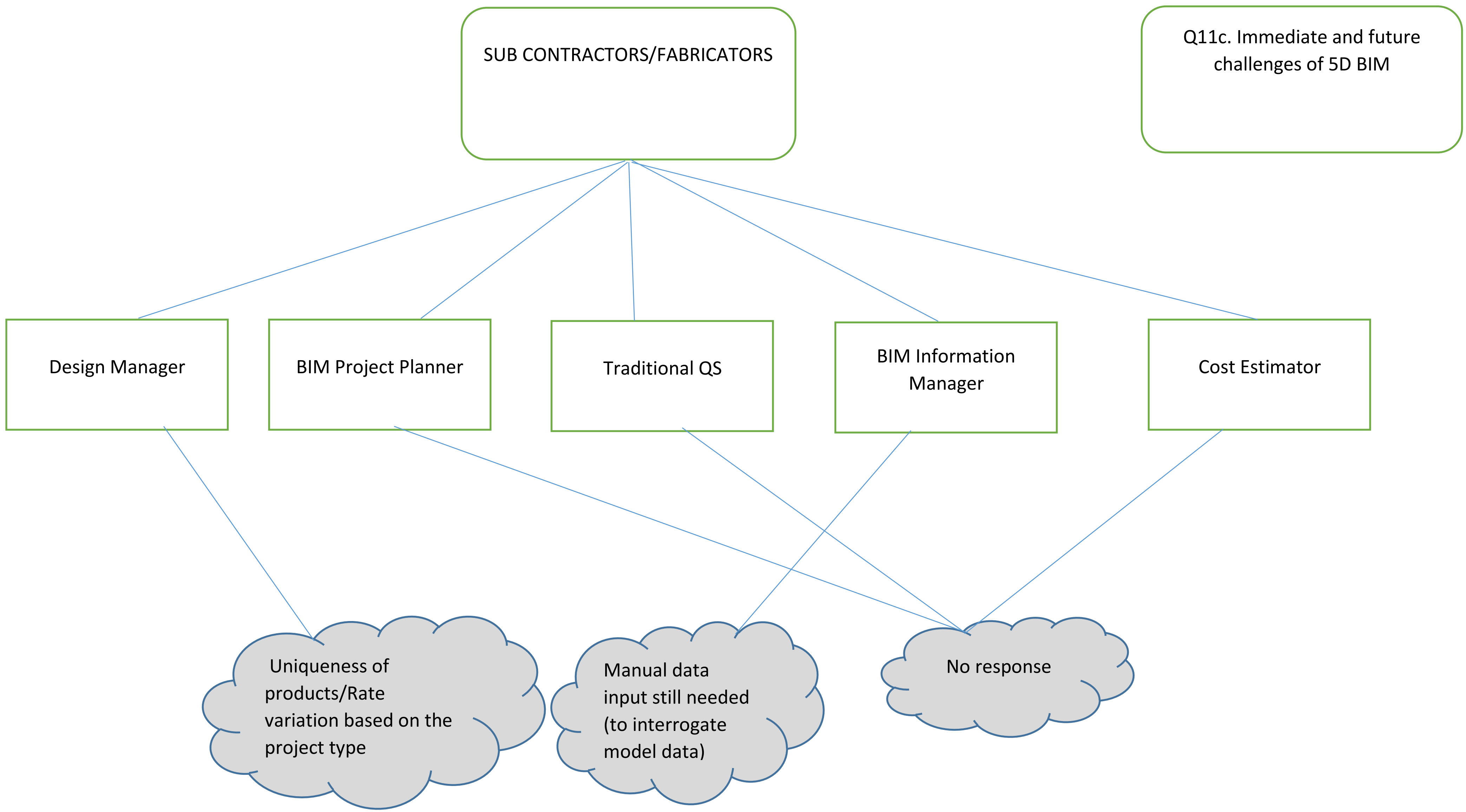
SUB CONTRACTORS/FABRICATORS
Q9. Present and future impact of BIM processes on contractor, procurement strategy and costing activities
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Accuracy of design information/detailed design provision showing attributes
Efficient design solutions (Getting it right the first time)
Visual advantages/Reducing rework
I don't know
Cost efficiency
Model coordination/clash detection/sources of conflict
Reduction of workforce
Reduced risks/less contingencies/less waste
Pricing accuracy/better project understanding
Good understanding of required work scope
Comparative rate advantages/Better and quicker pricing processes

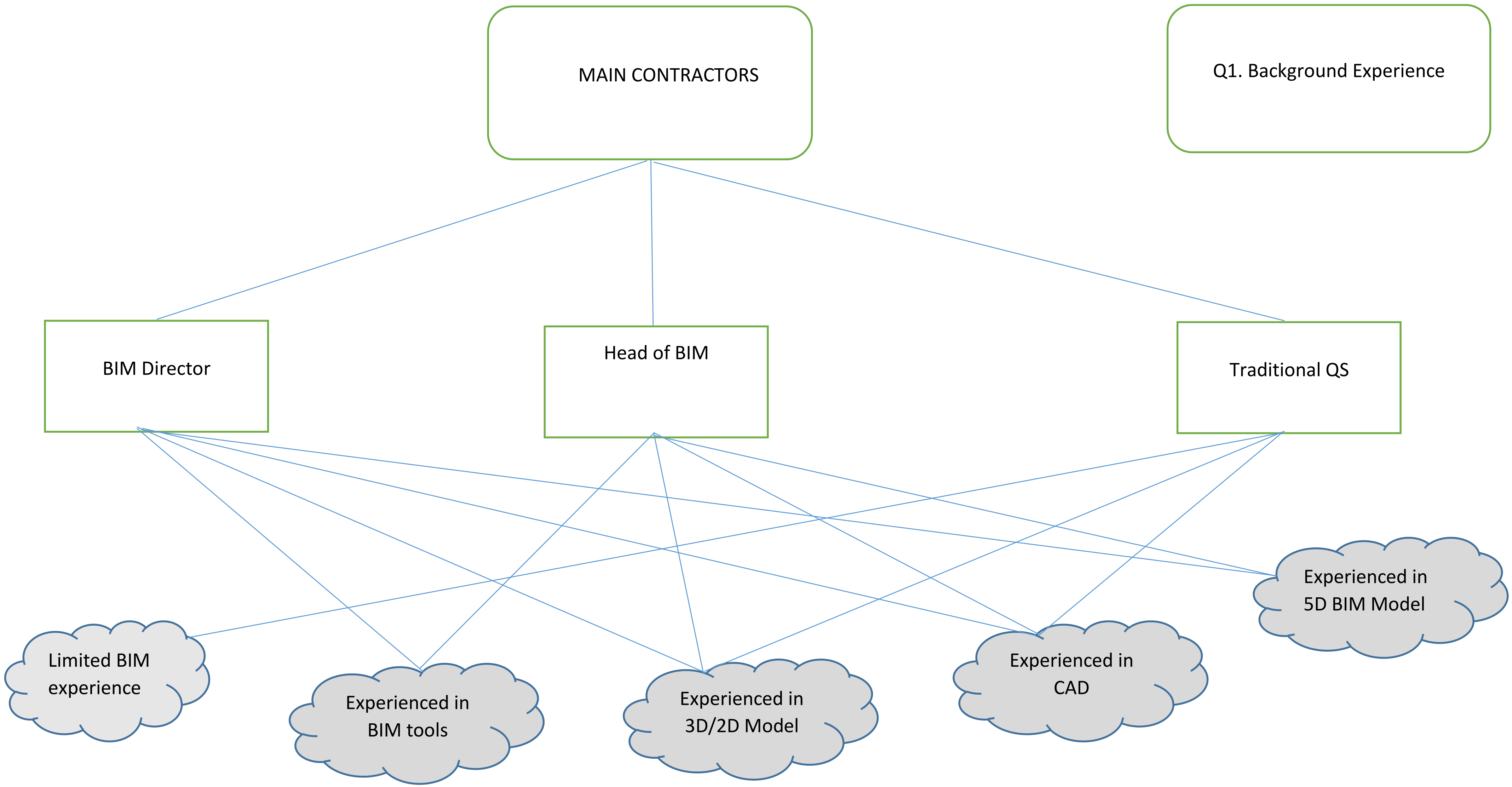

SUB CONTRACTORS/FABRICATORS
Q10a. Best practice for contractors cost effectiveness
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Early career BIM engagement
Autodesk based process
More detailed/accurate design information with ability to influence cost outcomes
Investing money & time
Full integration of project team in BIM processes/Better understanding of the entire process
I don't know
Common Data Environment (CDE)/Efficient model design
Client involvement in D&B/Early engagement in BIM process/understanding BIM benefits
Speeding up processes/design software to interrogate or talk to each other

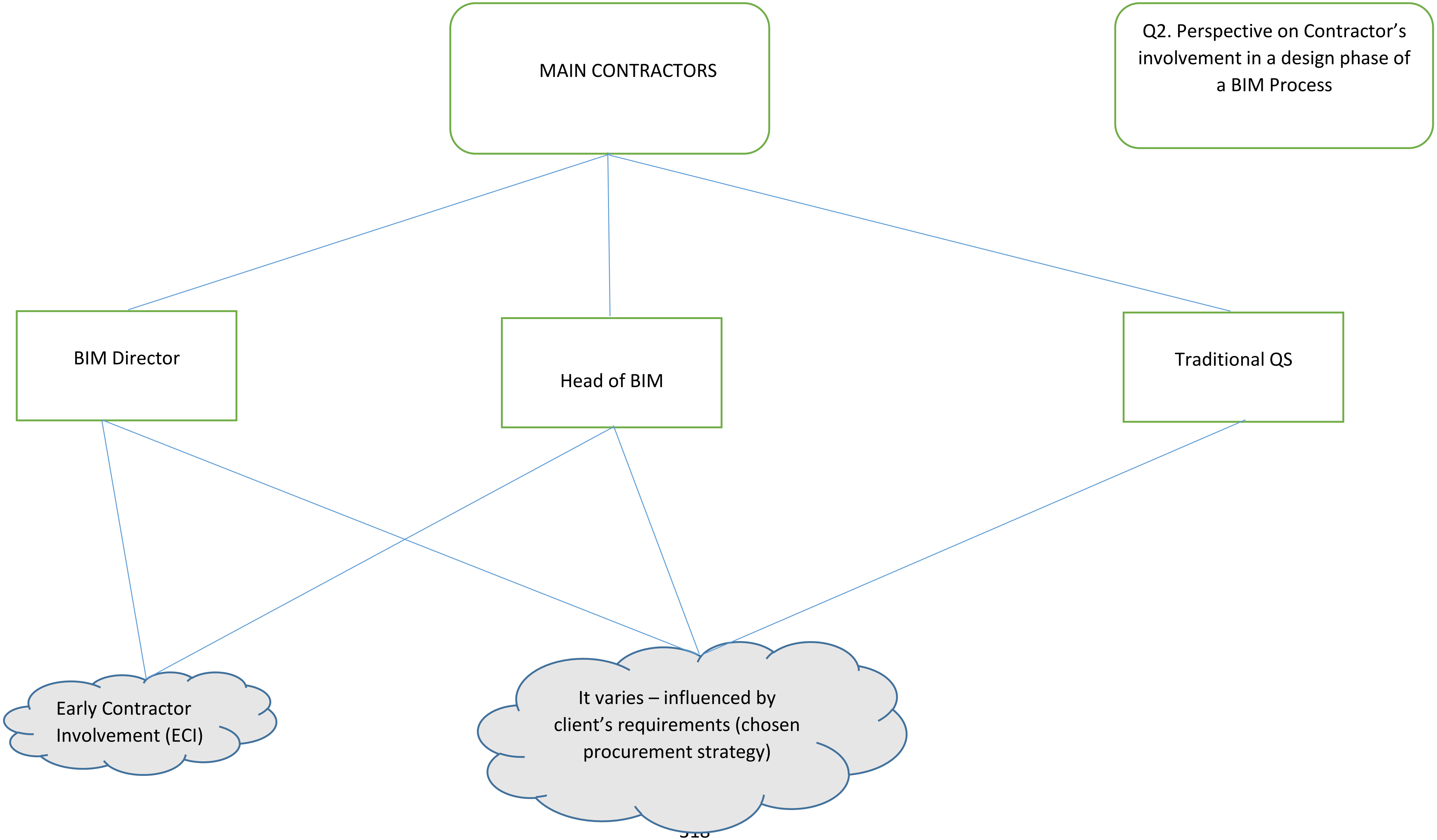

SUB CONTRACTORS/FABRICATORS
Q10b. The risks (negative or positive) relative to cost output while engaging BIM
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
No risks
Buildability issues due to lack of site labour involvement
Cultural shift/lack of interest in BIM processes
I don't know
No response

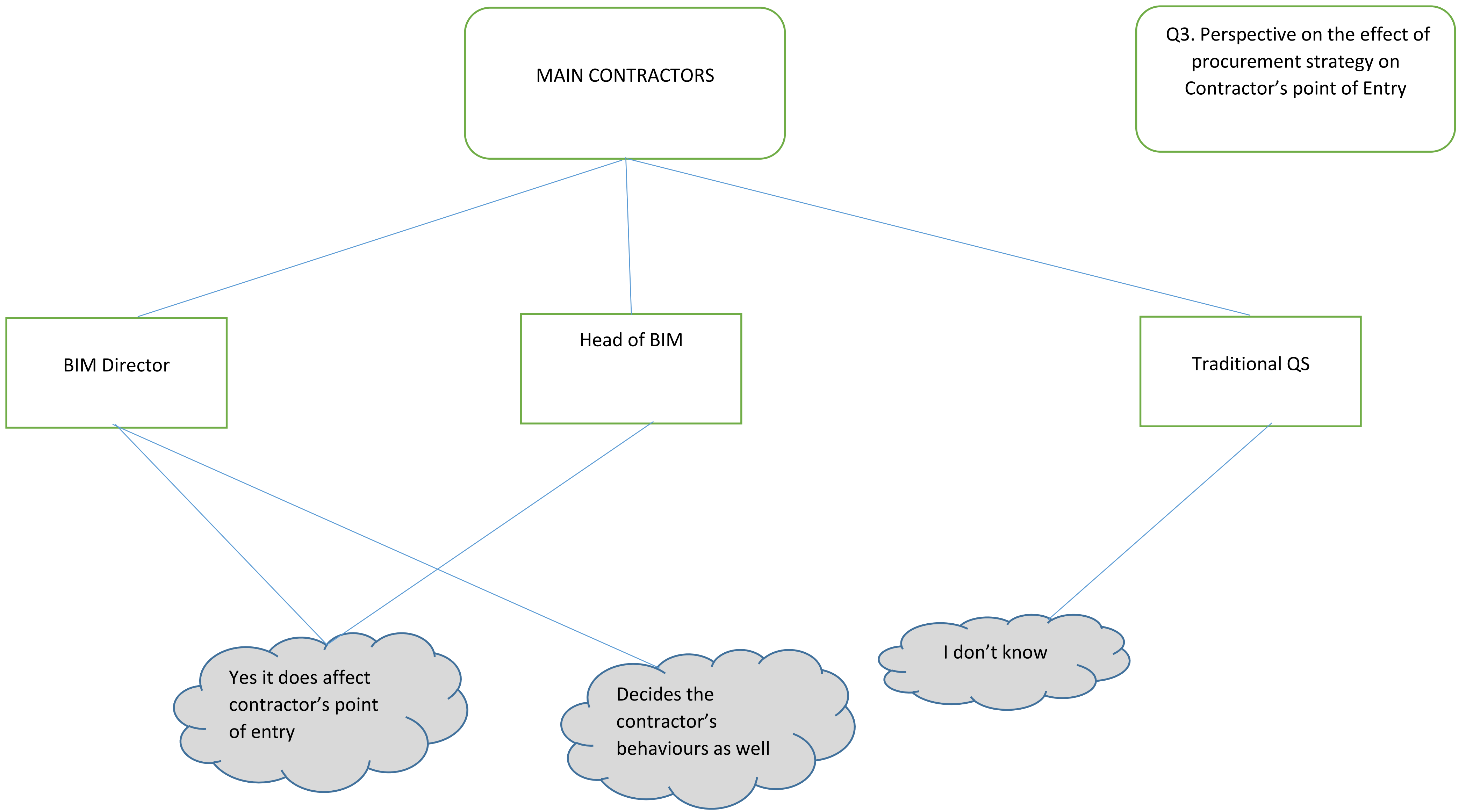

SUB CONTRACTORS/FABRICATORS
Q11a. Future direction of 5D BIM
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Not Certain
Cost-Load BIM models
Transparency/Efficiency process improvement
Creating database of elemental rates with links
WBS to support Digital quantification & Cost estimation
Integration of cost data & 3D BIM model
BIM models and company specific software
Uniformity of cost database (Naming convention)/Standardization
Accelerated processes

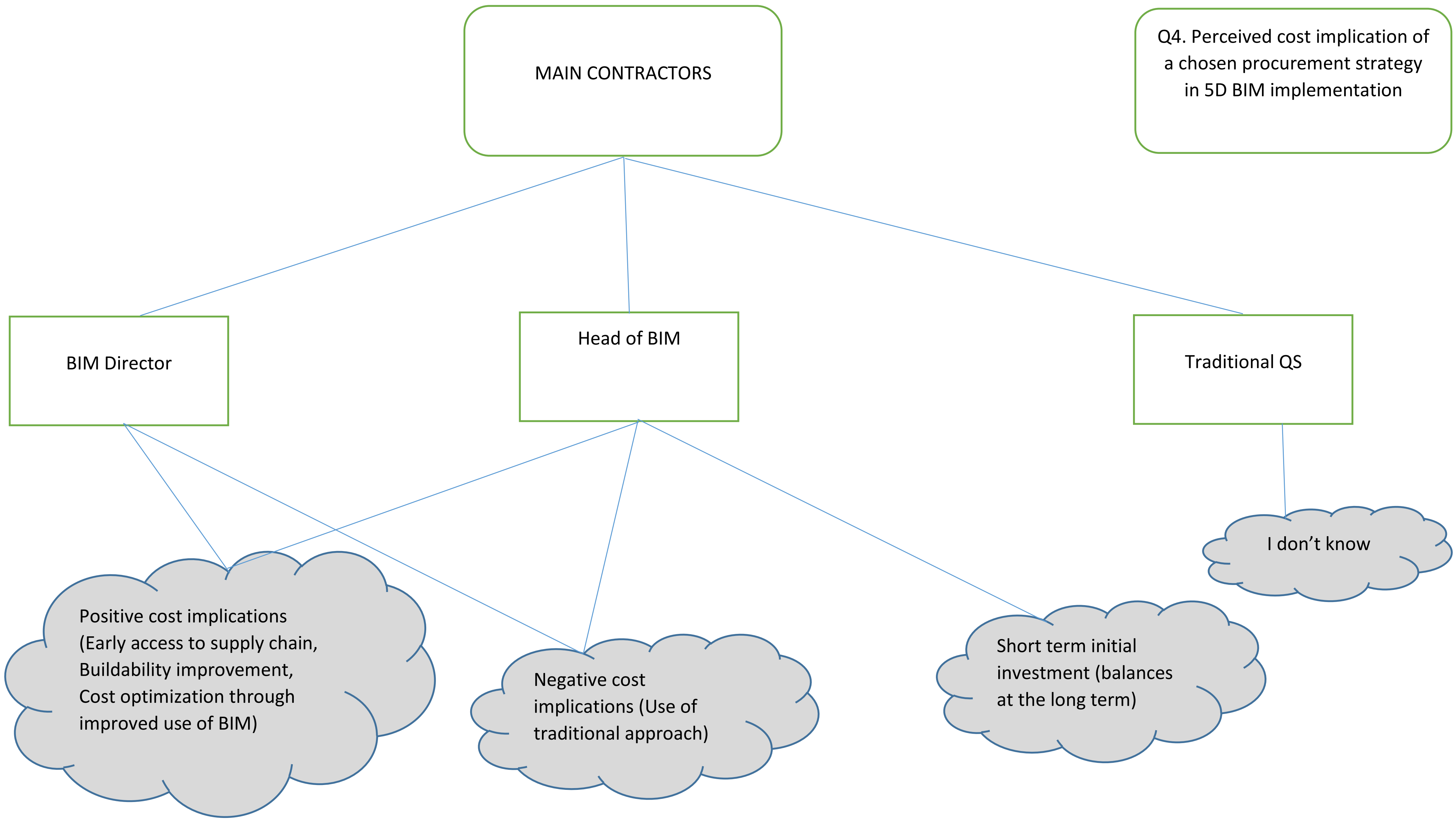

SUB CONTRACTORS/FABRICATORS
Q11b. Benefits of 5D BIM
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
No response

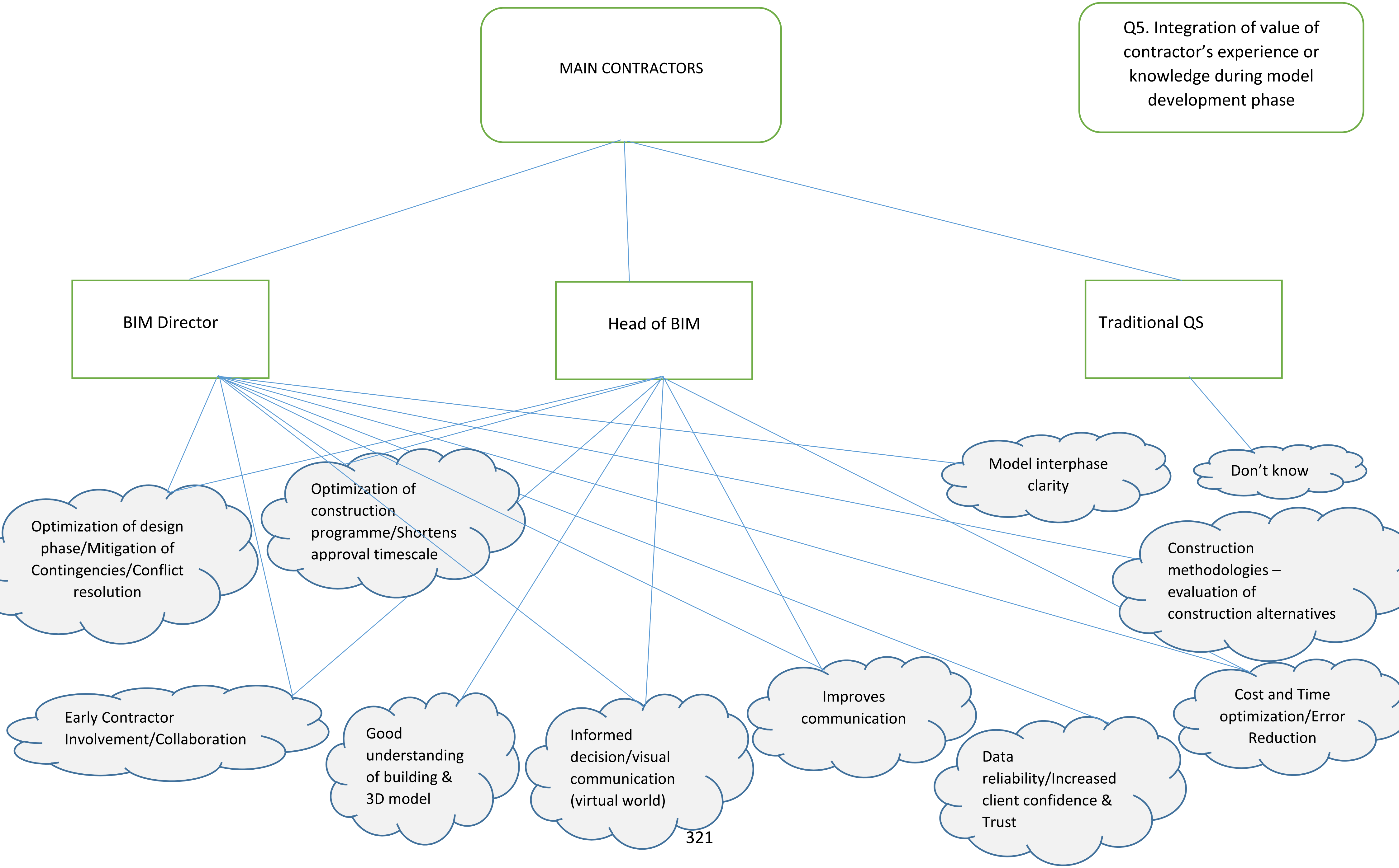

SUB CONTRACTORS/FABRICATORS
Q11c. Immediate and future challenges of 5D BIM
Design Manager
BIM Project Planner
Traditional QS
BIM Information Manager
Cost Estimator
Uniqueness of products/Rate variation based on the project type
Manual data input still needed (to interrogate model data)
No response

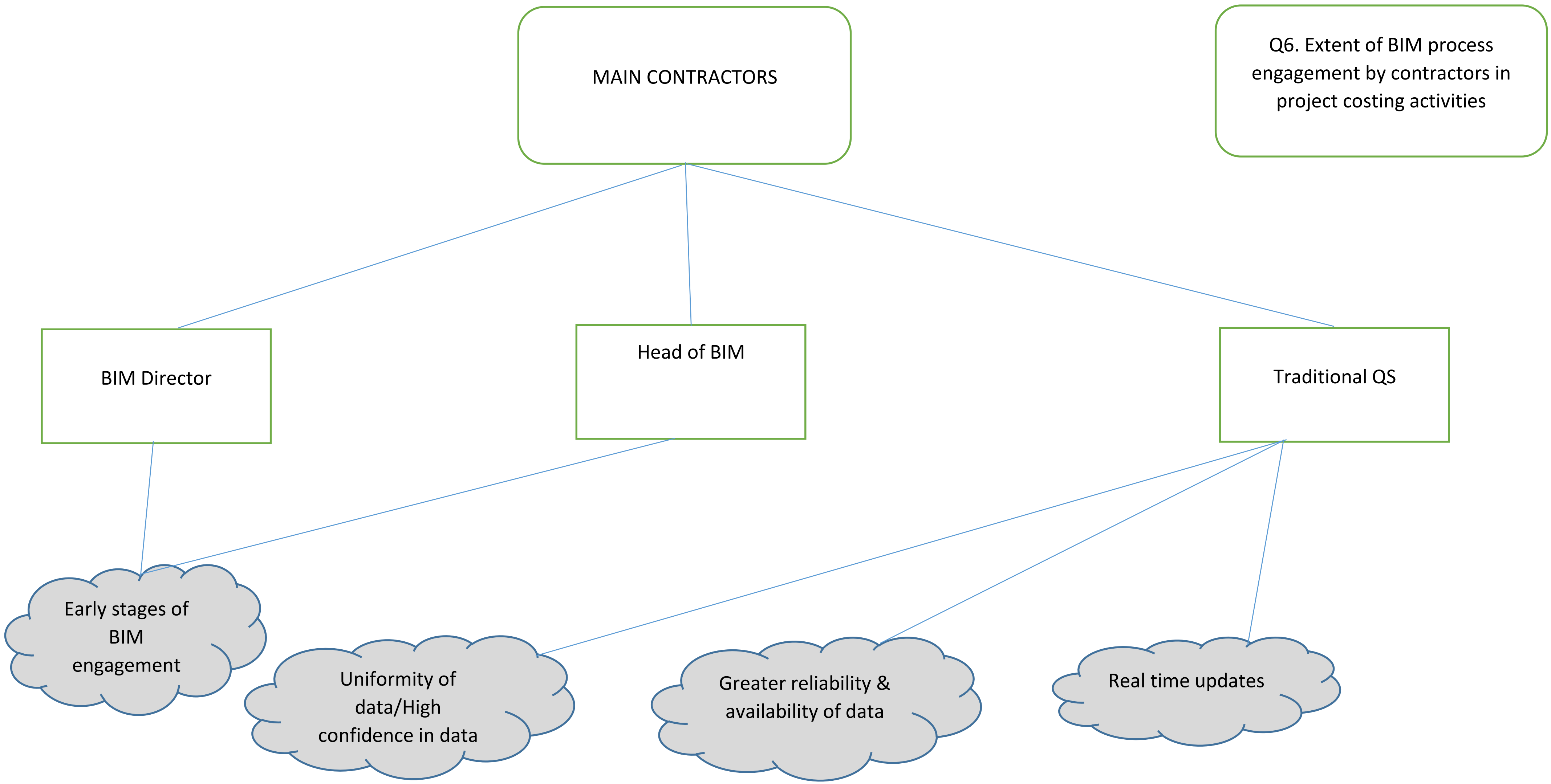

MAIN CONTRACTORS
Q1. Background Experience
BIM Director
Head of BIM
Traditional QS
Limited BIM experience
Experienced in BIM tools
Experienced in 3D/2D Model
Experienced in CAD
Experienced in 5D BIM Model


MAIN CONTRACTORS
Q2. Perspective on Contractor's involvement in a design phase of a BIM Process
BIM Director
Head of BIM
Traditional QS
Early Contractor Involvement (ECI)
It varies – influenced by client's requirements (chosen procurement strategy)

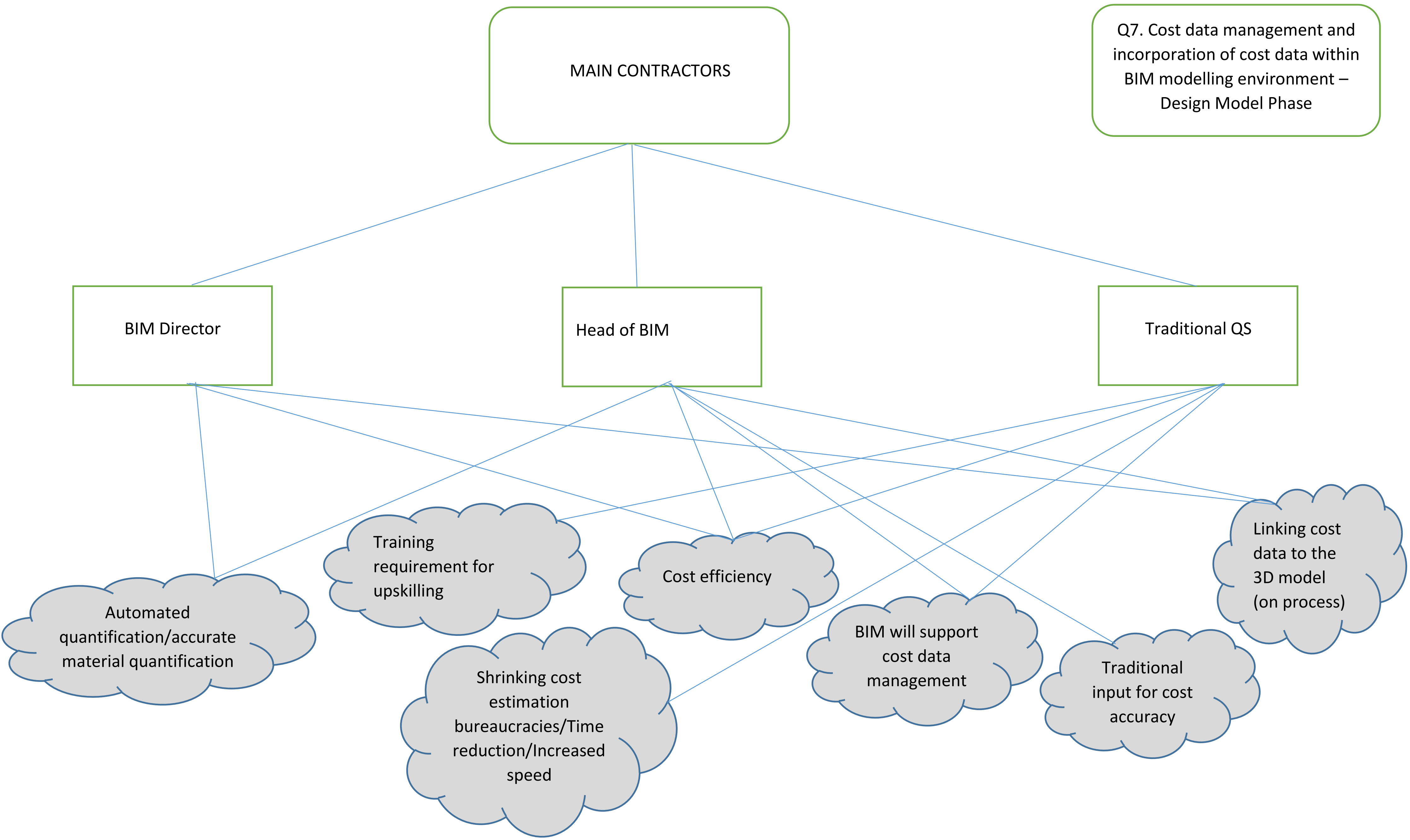

MAIN CONTRACTORS
Q3. Perspective on the effect of procurement strategy on Contractor's point of Entry
BIM Director
Head of BIM
Traditional QS
Yes it does affect contractor's point of entry
Decides the contractor's behaviours as well
I don't know

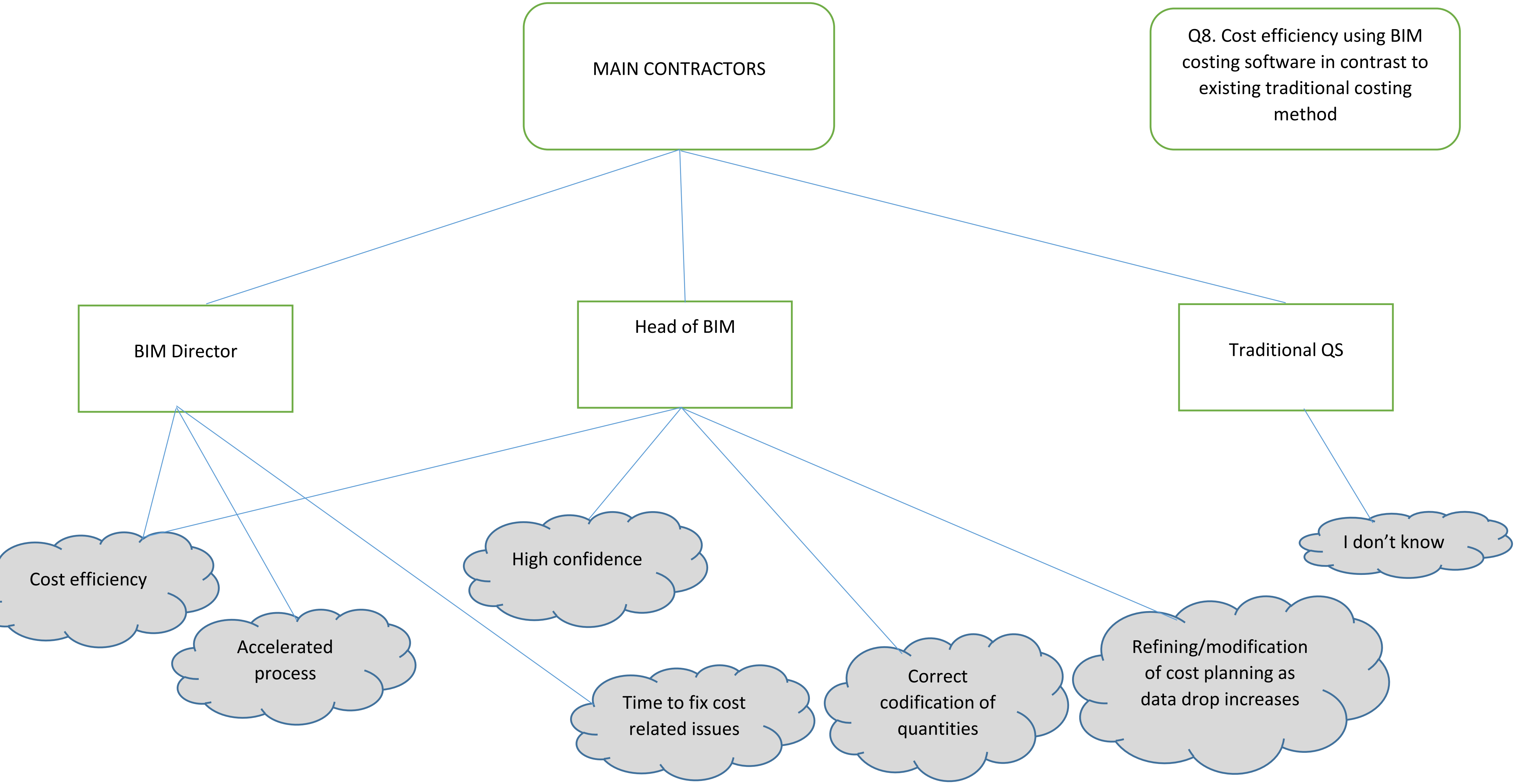

MAIN CONTRACTORS
Q4. Perceived cost implication of a chosen procurement strategy in 5D BIM implementation
BIM Director
Head of BIM
Traditional QS
I don't know
Positive cost implications (Early access to supply chain, Buildability improvement, Cost optimization through improved use of BIM)
Negative cost implications (Use of traditional approach)
Short term initial investment (balances at the long term)


MAIN CONTRACTORS
Q5. Integration of value of contractor's experience or knowledge during model development phase
BIM Director
Head of BIM
Traditional QS
Model interphase clarity
Don't know
Optimization of design phase/Mitigation of Contingencies/Conflict resolution
Optimization of construction programme/Shortens approval timescale
Construction methodologies – evaluation of construction alternatives
Early Contractor Involvement/Collaboration
Good understanding of building & 3D model
Informed decision/visual communication (virtual world)
Improves communication
Data reliability/Increased client confidence & Trust
Cost and Time optimization/Error Reduction

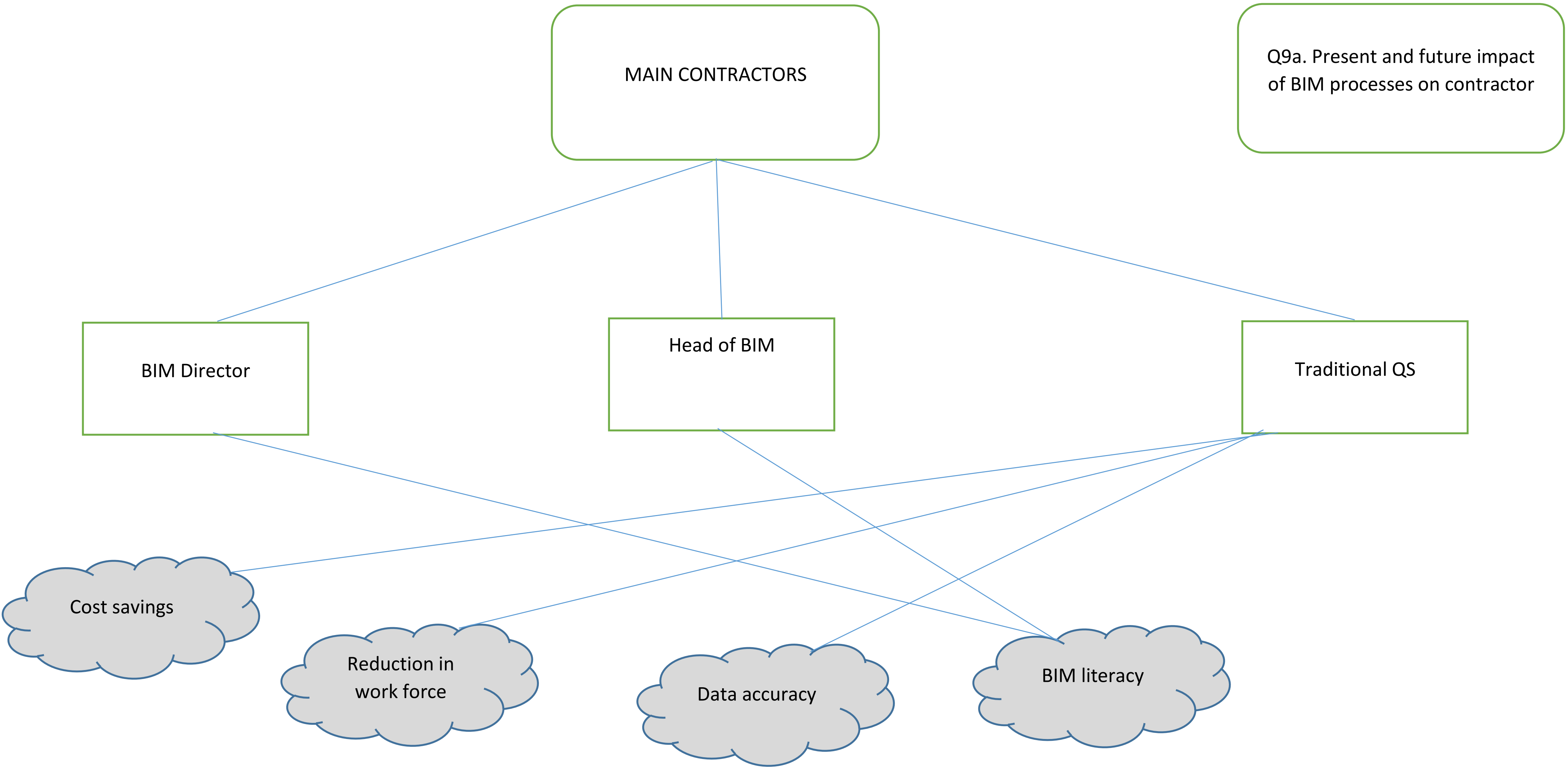


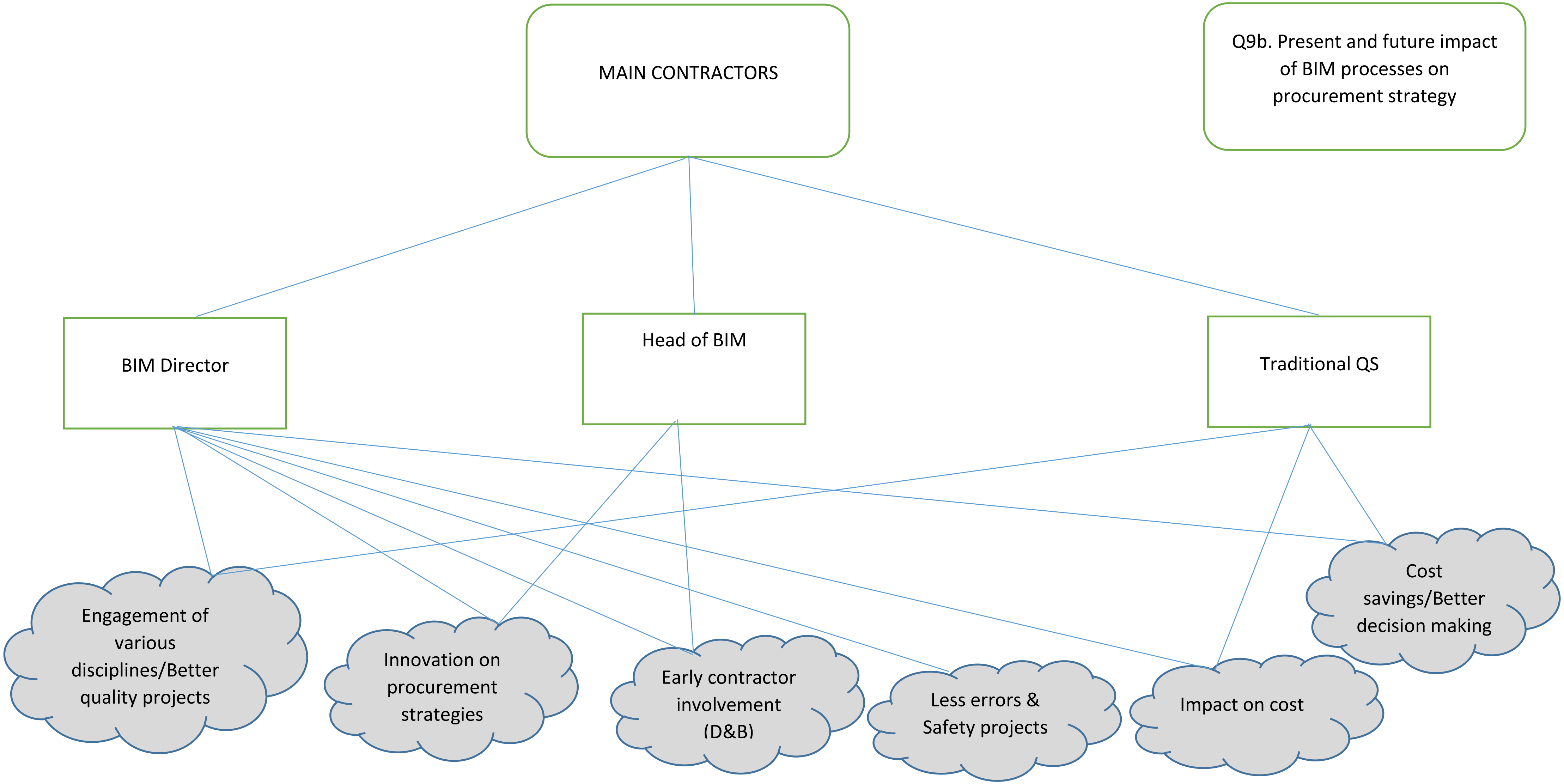
MAIN CONTRACTORS
Q6. Extent of BIM process engagement by contractors in project costing activities
BIM Director
Head of BIM
Traditional QS
Early stages of BIM engagement
Uniformity of data/High confidence in data
Greater reliability & availability of data
Real time updates

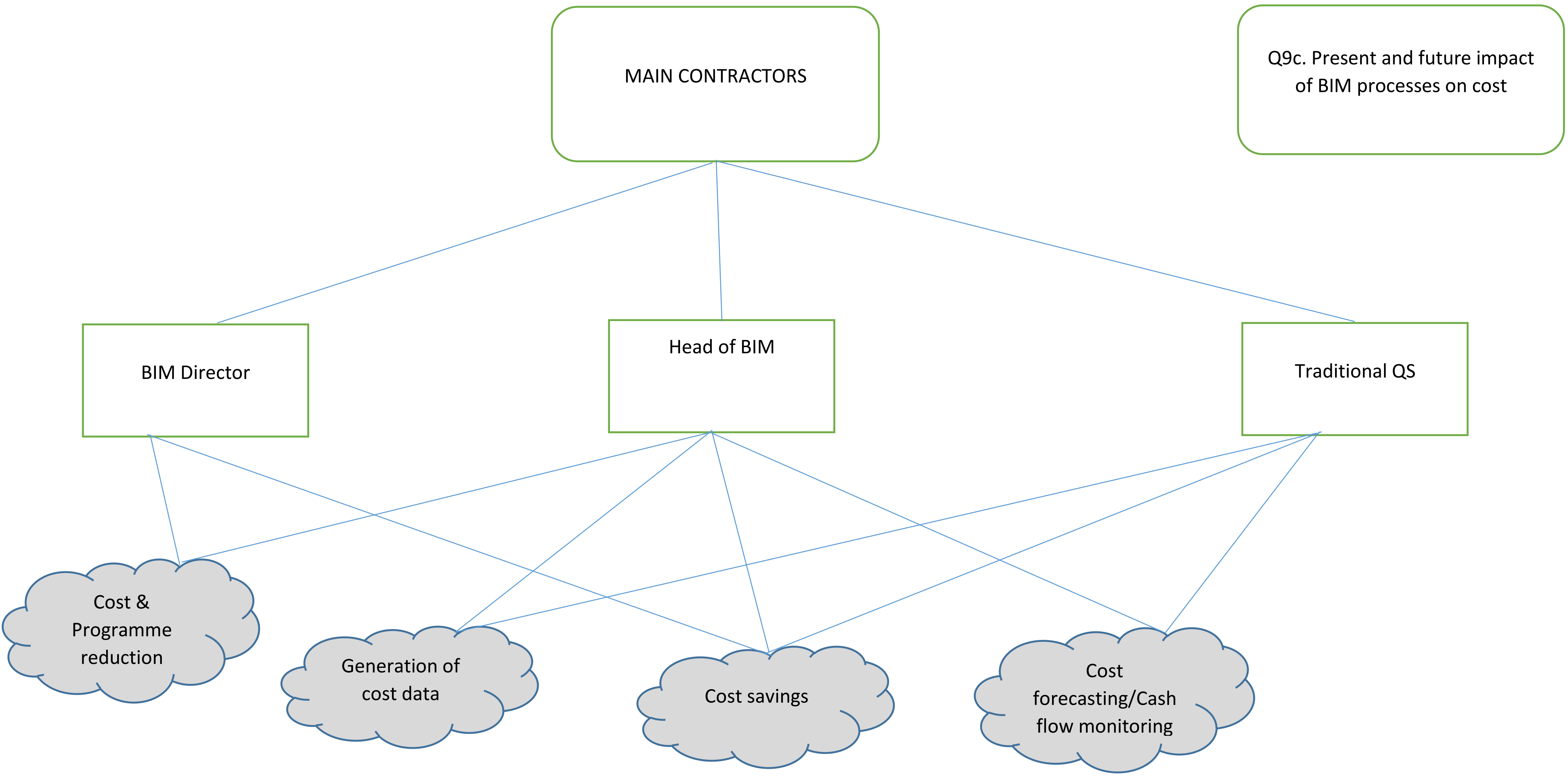

MAIN CONTRACTORS
Q7. Cost data management and incorporation of cost data within BIM modelling environment – Design Model Phase
BIM Director
Head of BIM
Traditional QS
Automated quantification/accurate material quantification
Training requirement for upskilling
Cost efficiency
Linking cost data to the 3D model (on process)
Shrinking cost estimation bureaucracies/Time reduction/Increased speed
BIM will support cost data management
Traditional input for cost accuracy

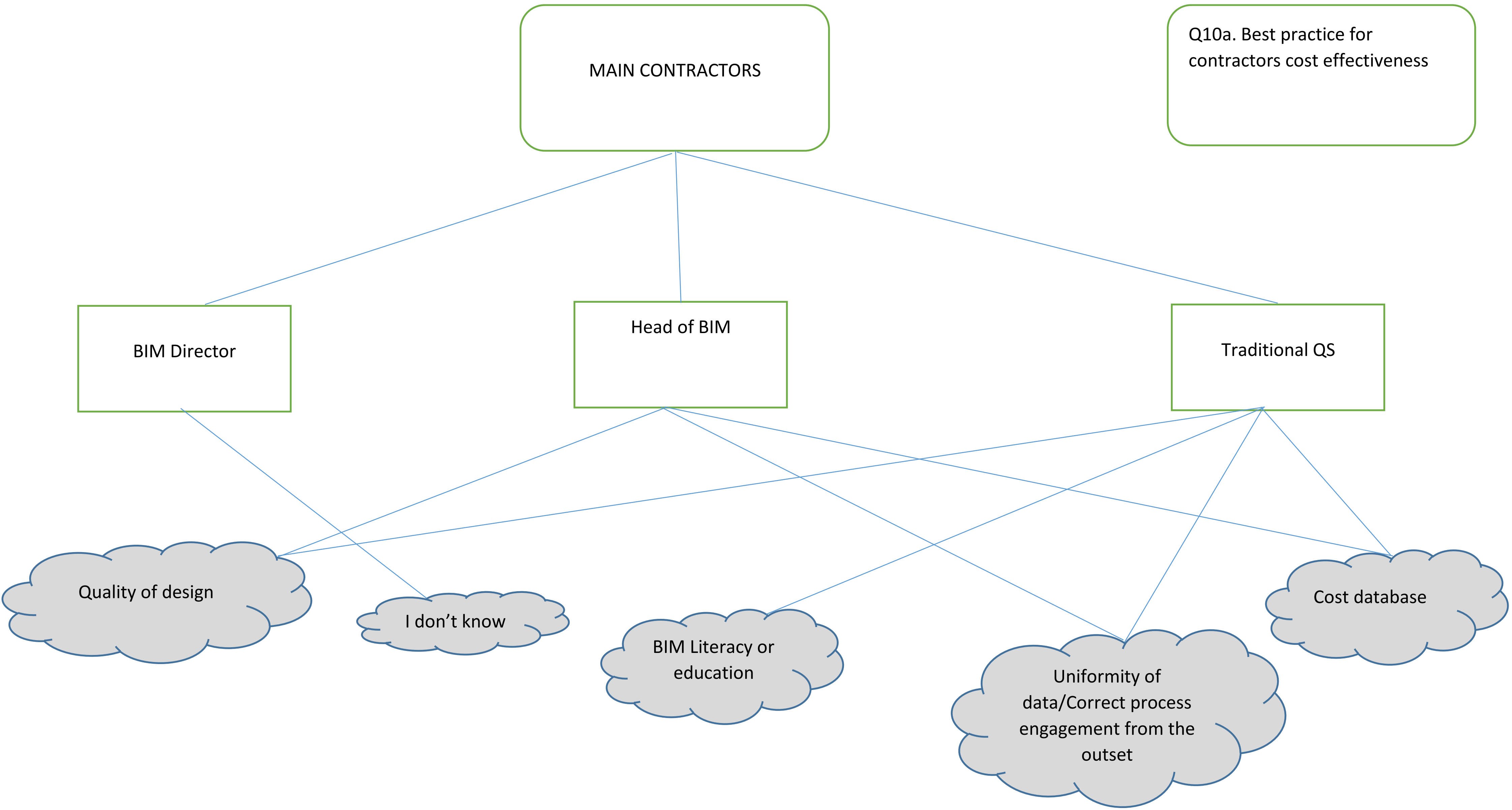


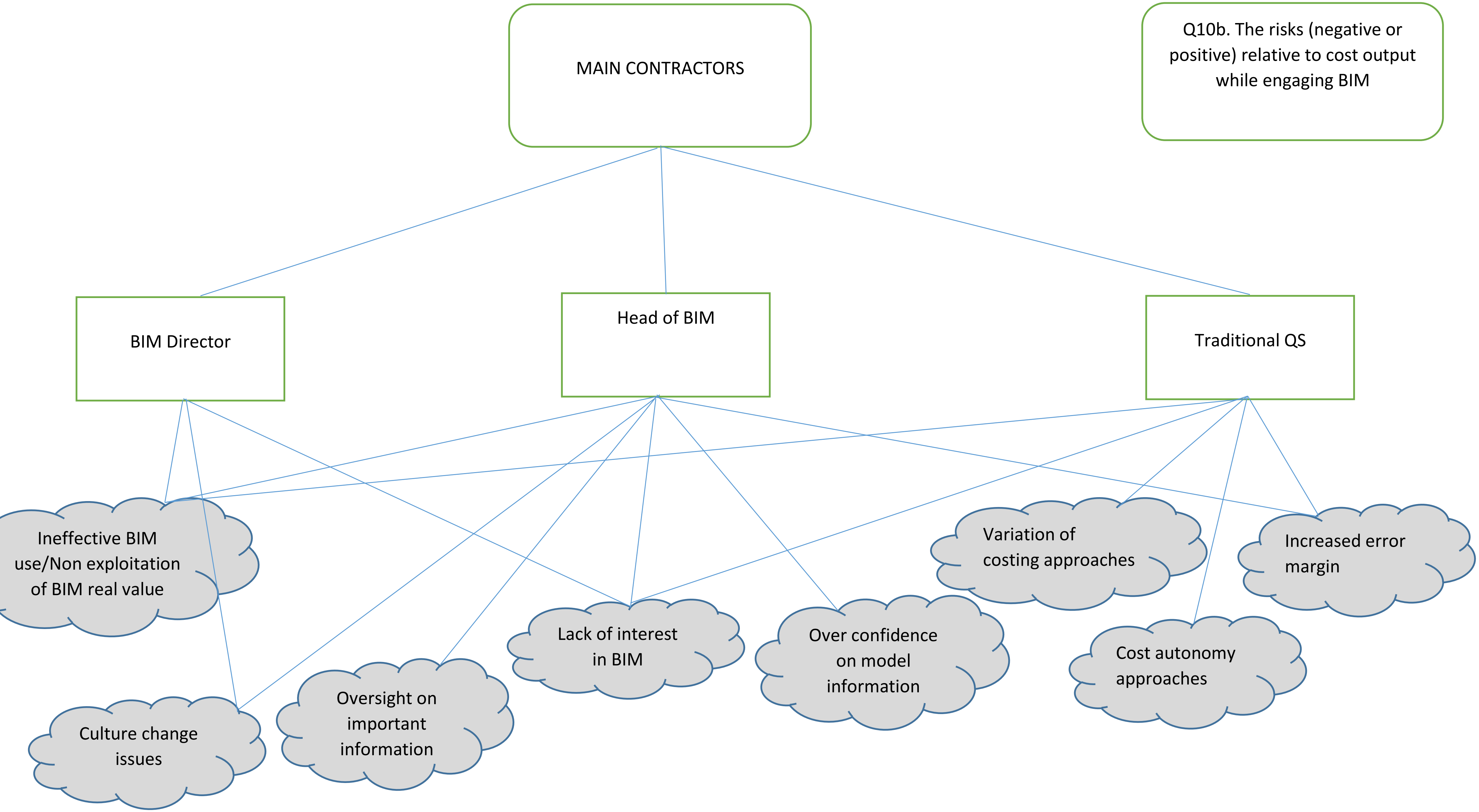
MAIN CONTRACTORS
Q8. Cost efficiency using BIM costing software in contrast to existing traditional costing method
BIM Director
Head of BIM
Traditional QS
Cost efficiency
Accelerated process
Time to fix cost related issues
High confidence
Correct codification of quantities
Refining/modification of cost planning as data drop increases
I don't know

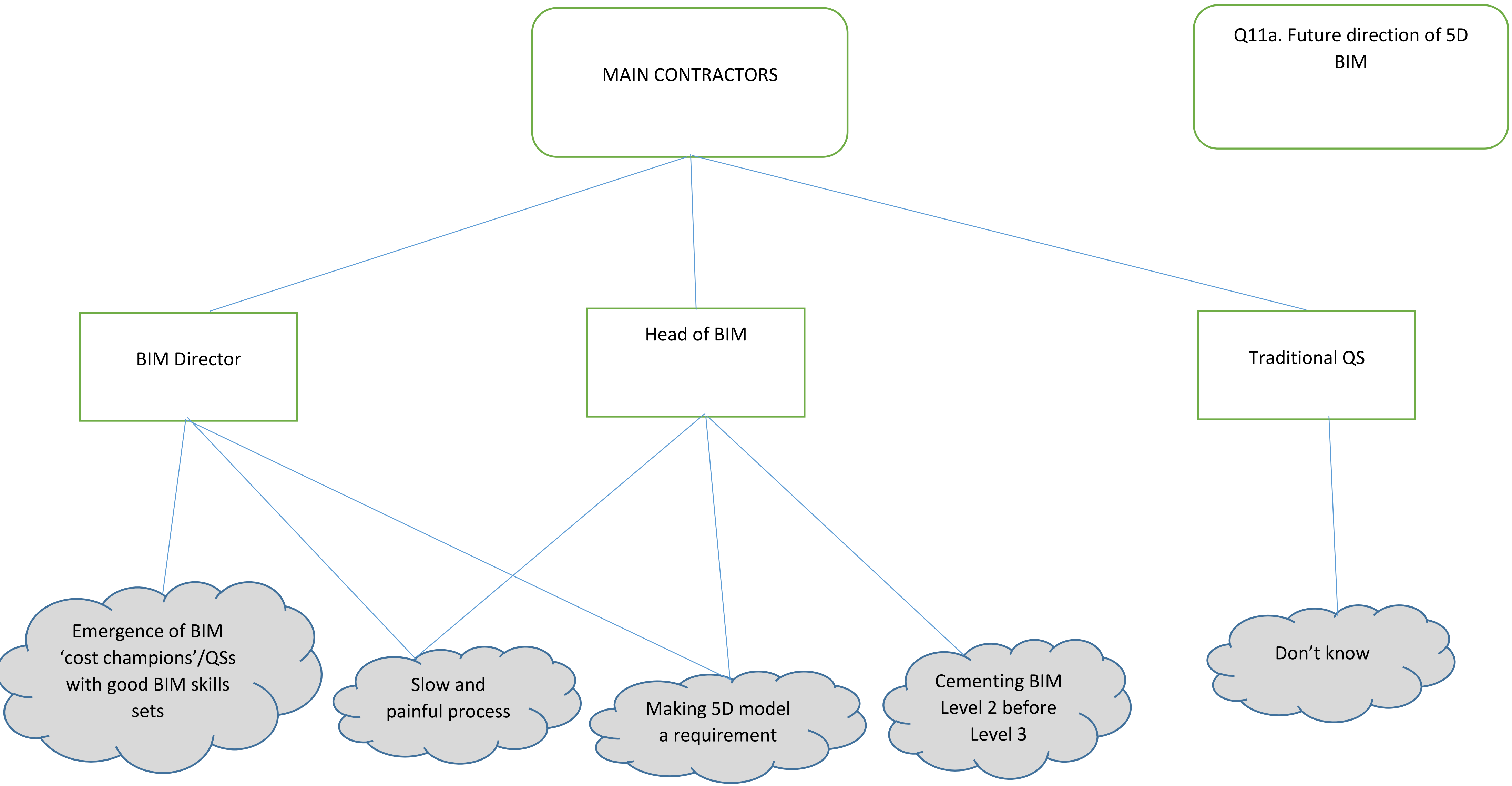

MAIN CONTRACTORS
Q9a. Present and future impact of BIM processes on contractor
BIM Director
Head of BIM
Traditional QS
Cost savings
Reduction in work force
Data accuracy
BIM literacy

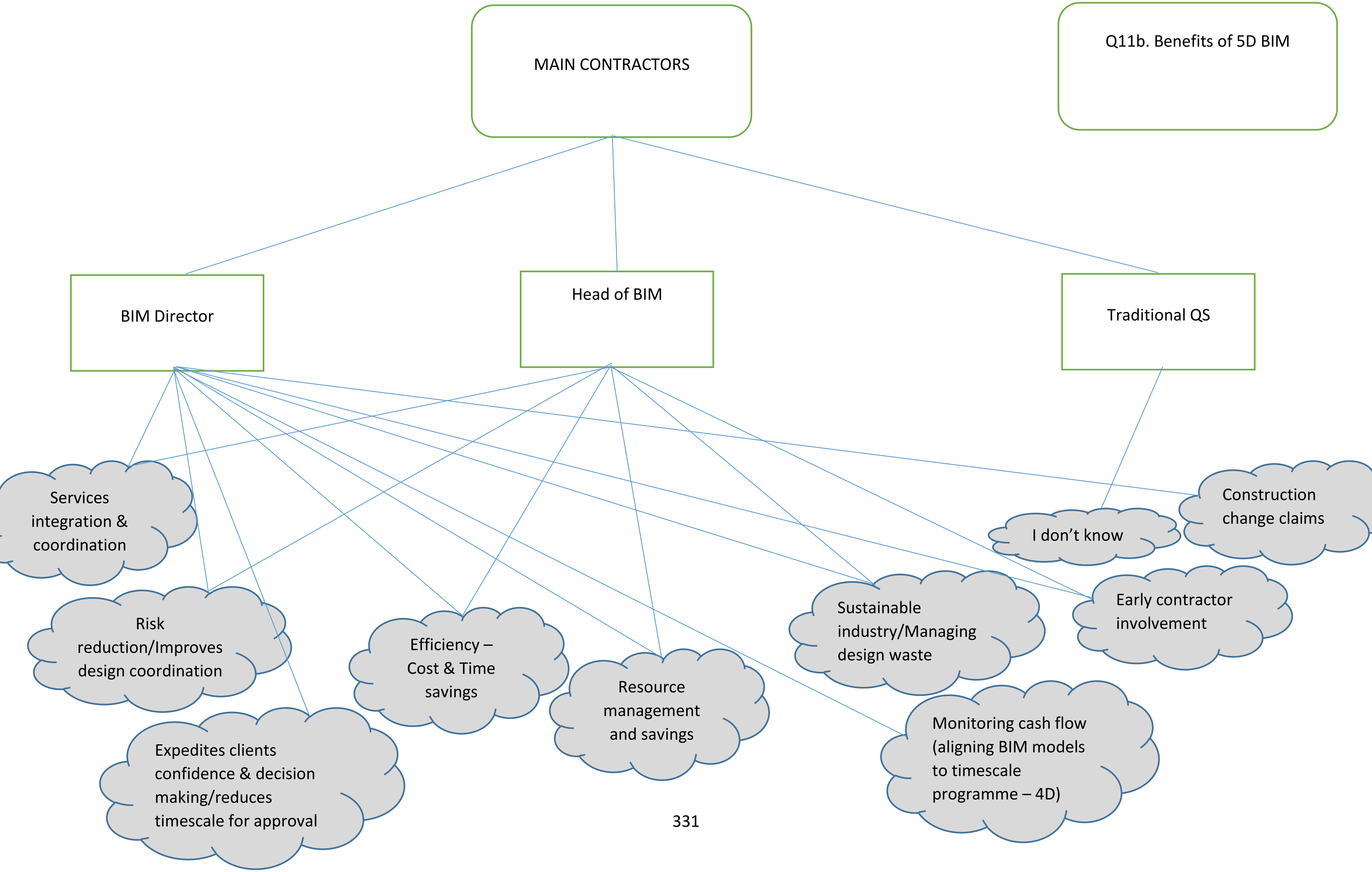

MAIN CONTRACTORS
Q9b. Present and future impact of BIM processes on procurement strategy
BIM Director
Head of BIM
Traditional QS
Engagement of various disciplines/Better quality projects
Innovation on procurement strategies
Early contractor involvement (D&B)
Less errors & Safety projects
Impact on cost
Cost savings/Better decision making

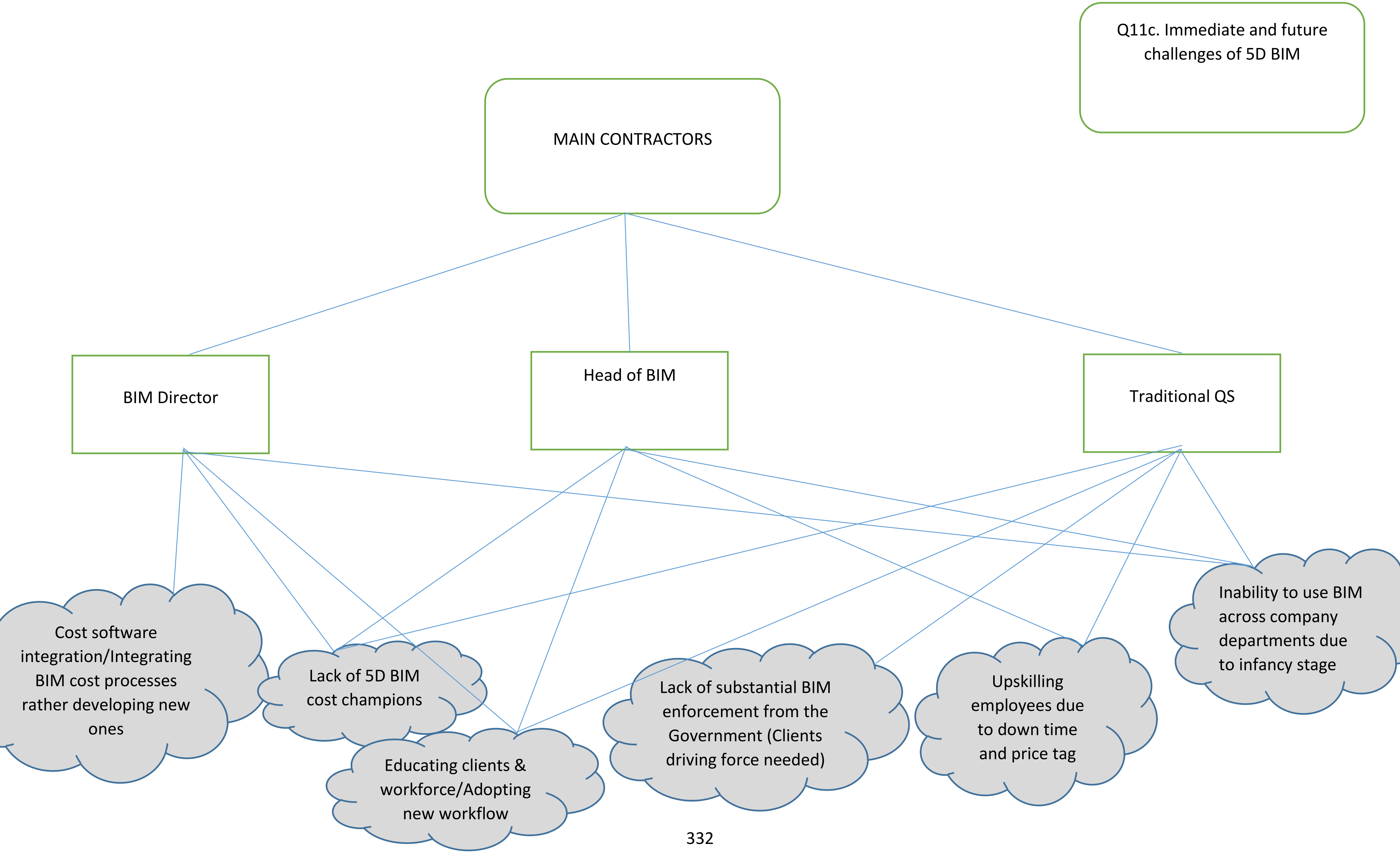

MAIN CONTRACTORS
Q9c. Present and future impact of BIM processes on cost
BIM Director
Head of BIM
Traditional QS
Cost & Programme reduction
Generation of cost data
Cost savings
Cost forecasting/Cash flow monitoring

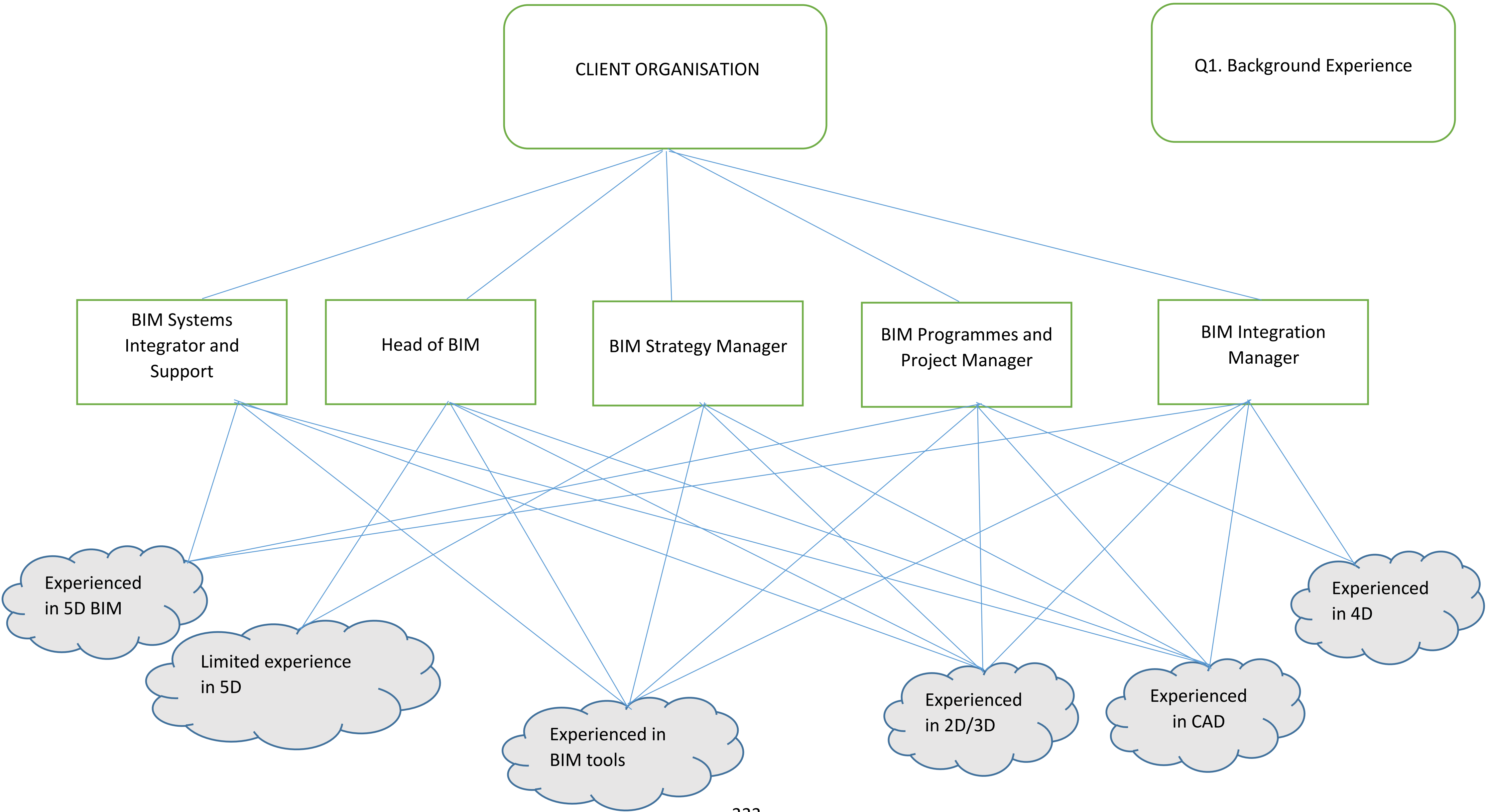

MAIN CONTRACTORS
Q10a. Best practice for contractors cost effectiveness
BIM Director
Head of BIM
Traditional QS
Quality of design
I don't know
BIM Literacy or education
Uniformity of data/Correct process engagement from the outset
Cost database

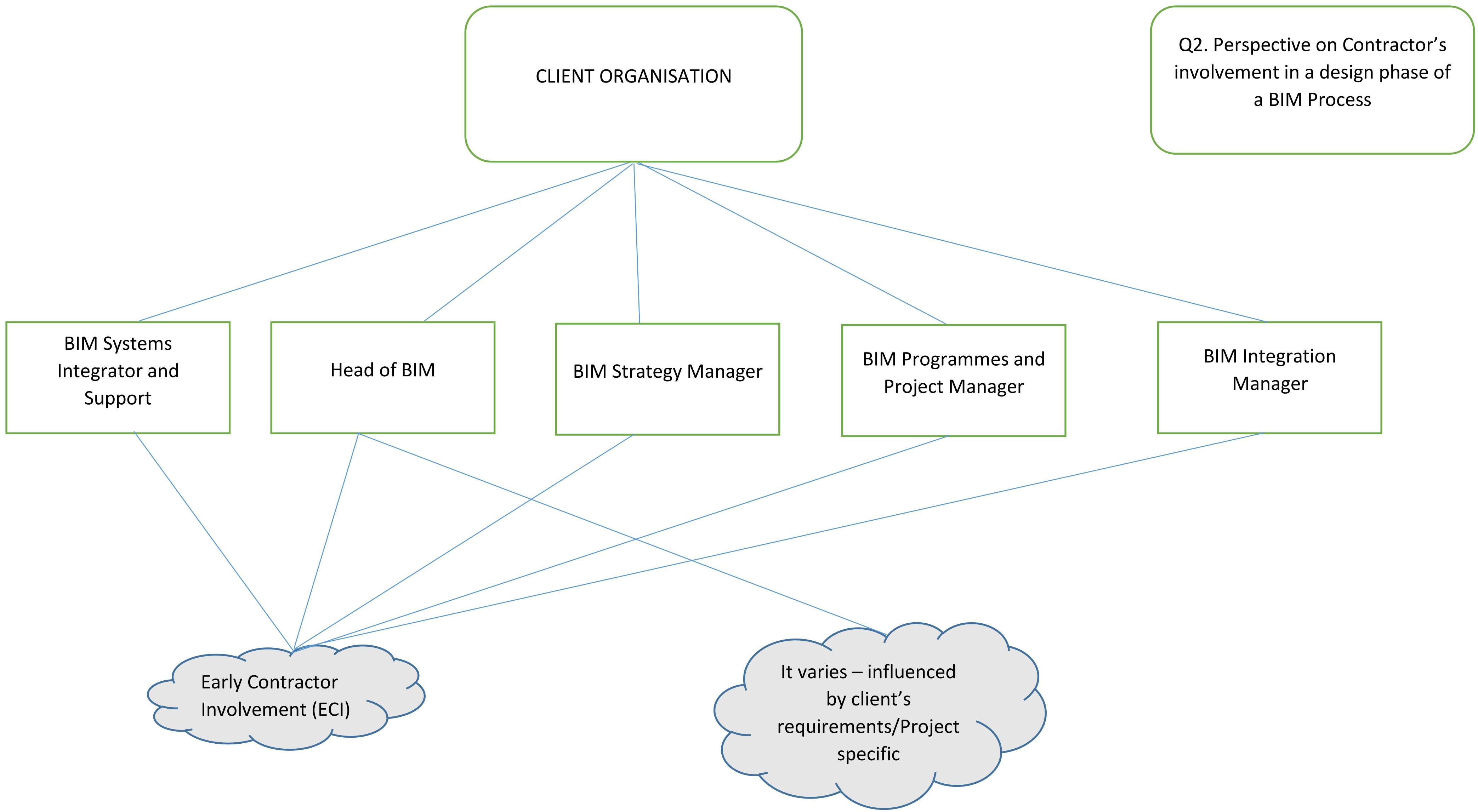

MAIN CONTRACTORS
Q10b. The risks (negative or positive) relative to cost output while engaging BIM
BIM Director
Head of BIM
Traditional QS
Ineffective BIM use/Non exploitation of BIM real value
Variation of costing approaches
Increased error margin
Lack of interest in BIM
Over confidence on model information
Cost autonomy approaches
Culture change issues
Oversight on important information

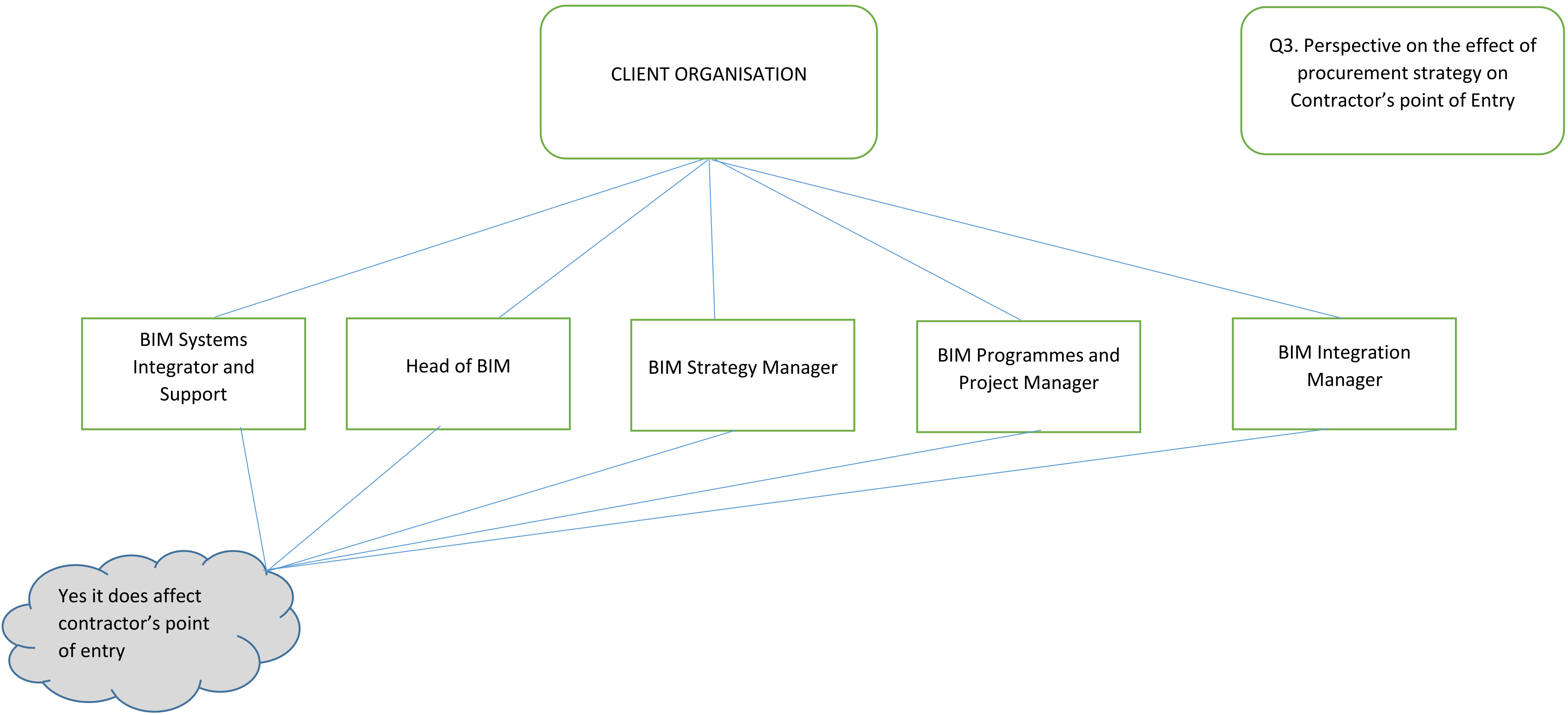

MAIN CONTRACTORS
Q11a. Future direction of 5D BIM
BIM Director
Head of BIM
Traditional QS
Emergence of BIM 'cost champions'/QSs with good BIM skills sets
Slow and painful process
Making 5D model a requirement
Cementing BIM Level 2 before Level 3
Don't know

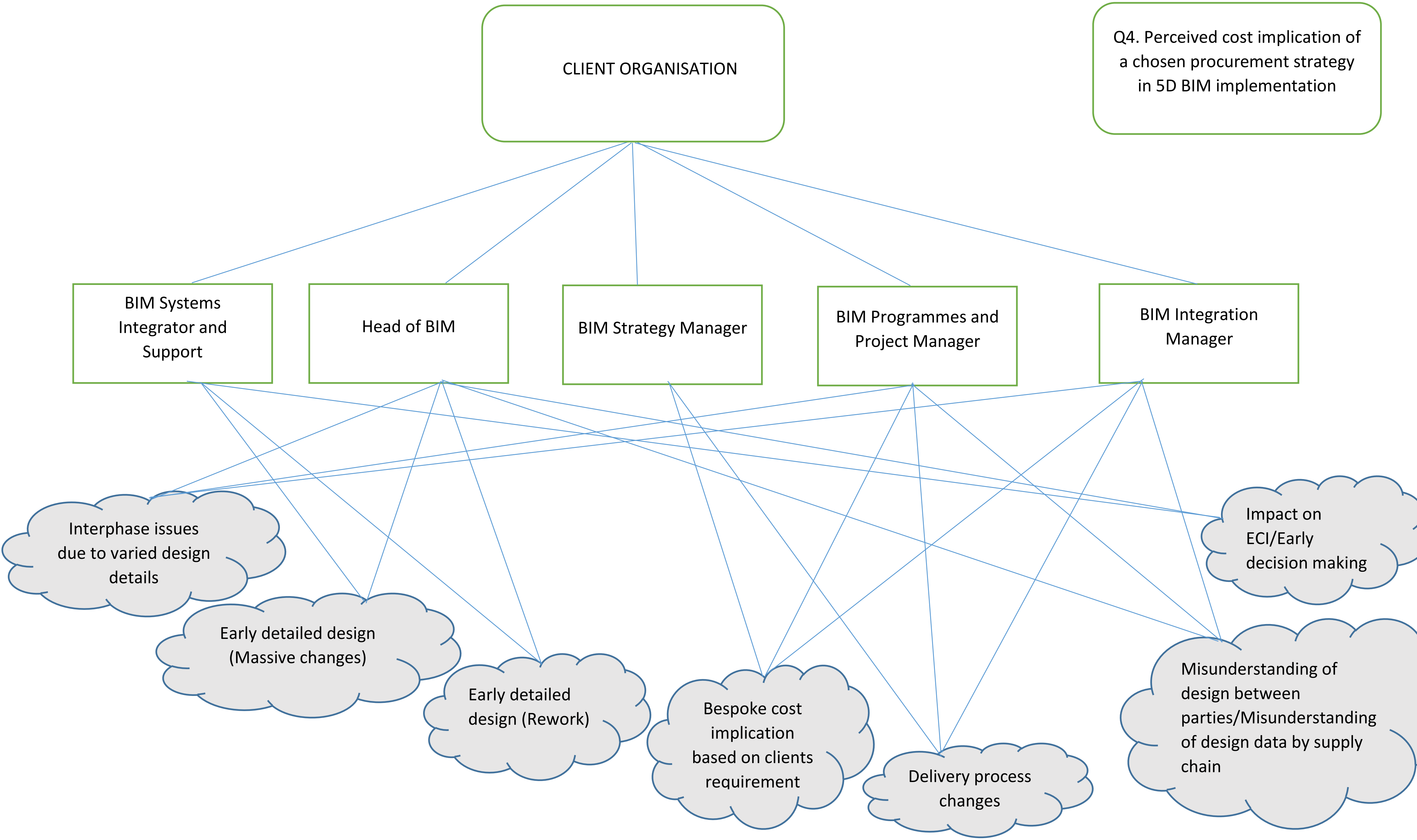

MAIN CONTRACTORS
Q11b. Benefits of 5D BIM
BIM Director
Head of BIM
Traditional QS
Services integration & coordination
I don't know
Construction change claims
Risk reduction/Improves design coordination
Efficiency – Cost & Time savings
Resource management and savings
Sustainable industry/Managing design waste
Early contractor involvement
Expedites clients confidence & decision making/reduces timescale for approval
Monitoring cash flow (aligning BIM models to timescale programme – 4D)


Q11c. Immediate and future challenges of 5D BIM
MAIN CONTRACTORS
BIM Director
Head of BIM
Traditional QS
Cost software integration/Integrating BIM cost processes rather developing new ones
Lack of 5D BIM cost champions
Educating clients & workforce/Adopting new workflow
Lack of substantial BIM enforcement from the Government (Clients driving force needed)
Upskilling employees due to down time and price tag
Inability to use BIM across company departments due to infancy stage

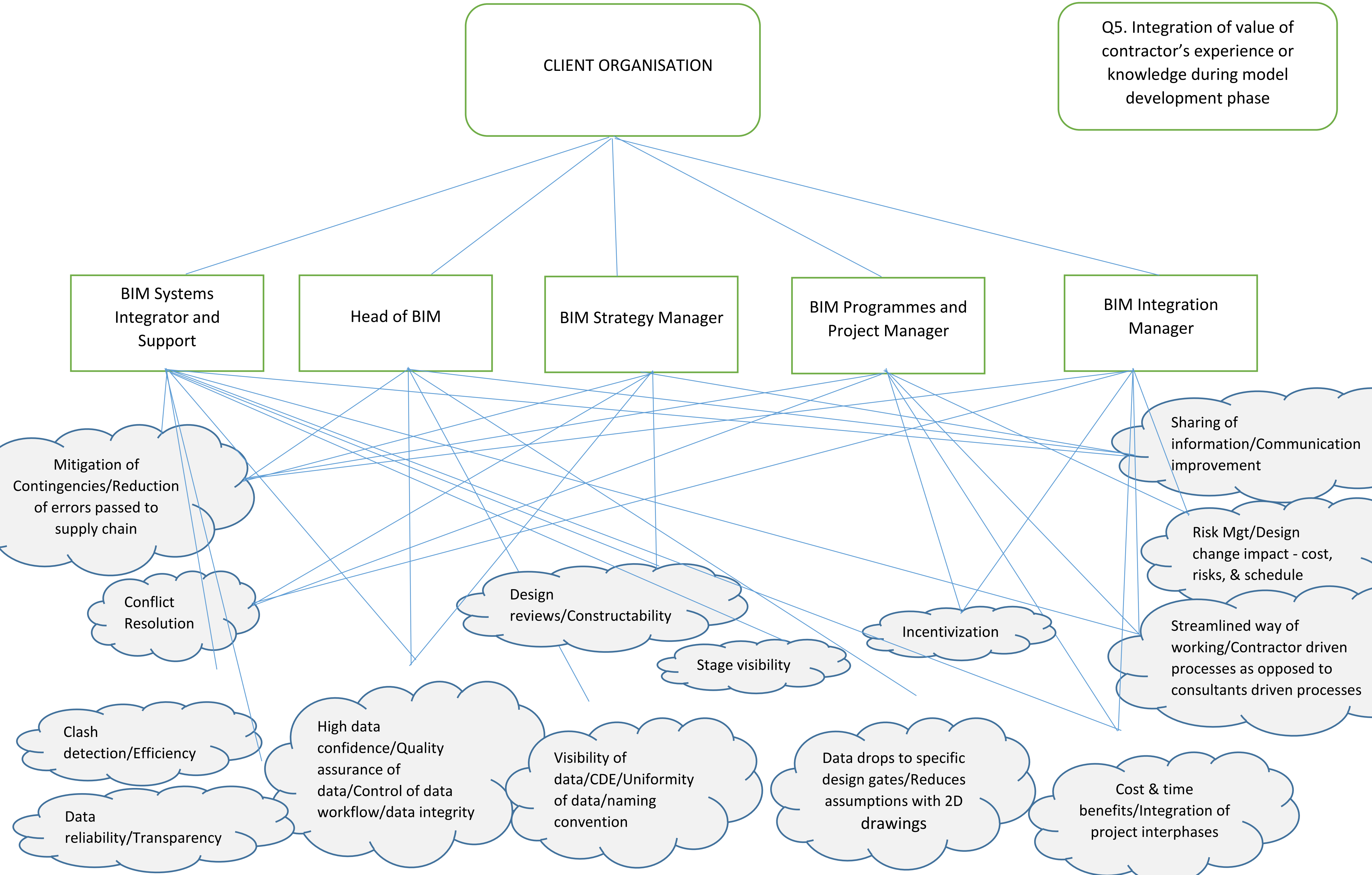

CLIENT ORGANISATION
Q1. Background Experience
BIM Systems Integrator and Support
Head of BIM
BIM Strategy Manager
BIM Programmes and Project Manager
BIM Integration Manager
Experienced in 5D BIM
Limited experience in 5D
Experienced in BIM tools
Experienced in 2D/3D
Experienced in CAD
Experienced in 4D

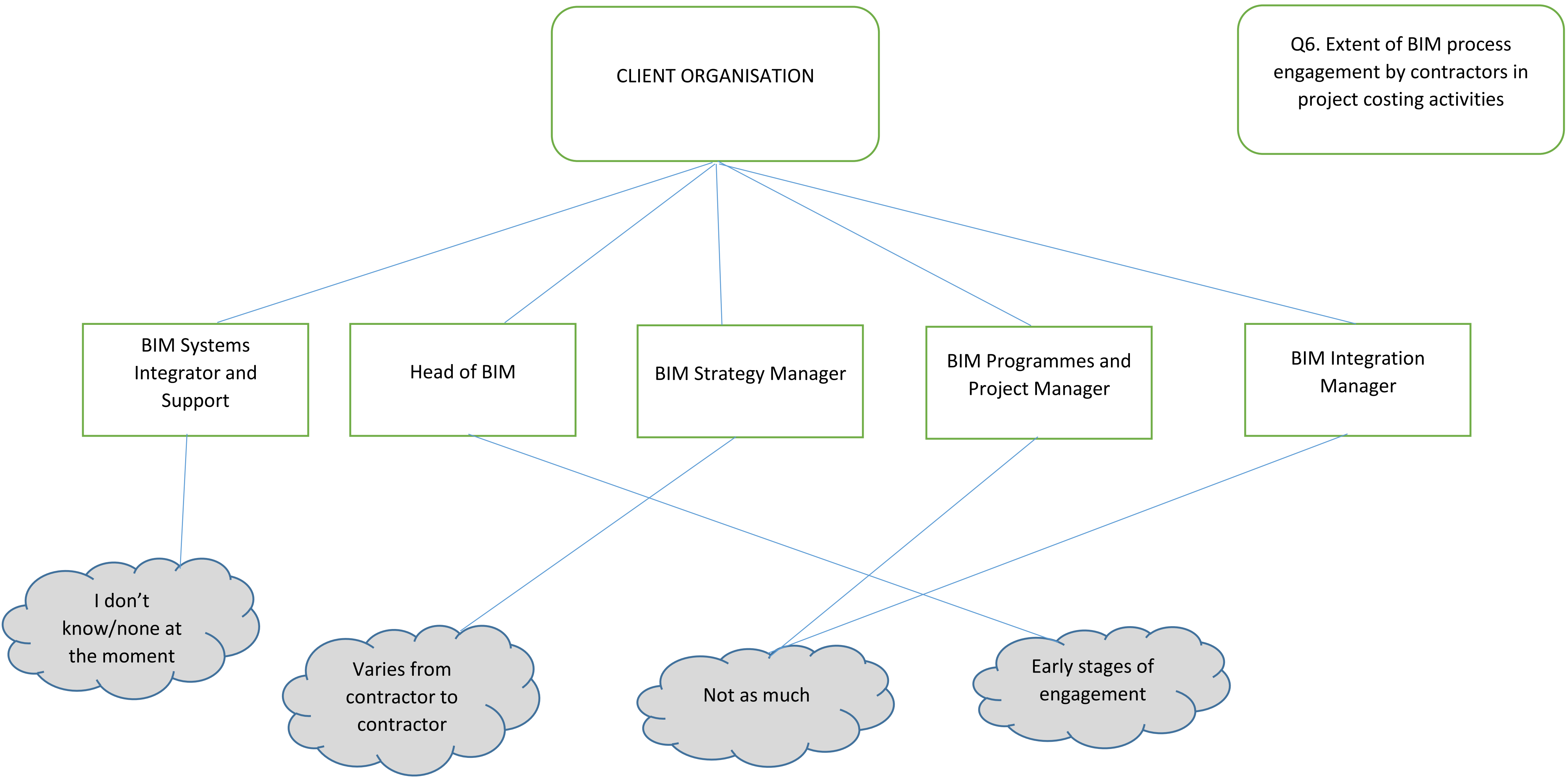

CLIENT ORGANISATION
Q2. Perspective on Contractor's involvement in a design phase of a BIM Process
BIM Systems Integrator and Support
Head of BIM
BIM Strategy Manager
BIM Programmes and Project Manager
BIM Integration Manager
Early Contractor Involvement (ECI)
It varies – influenced by client's requirements/Project specific

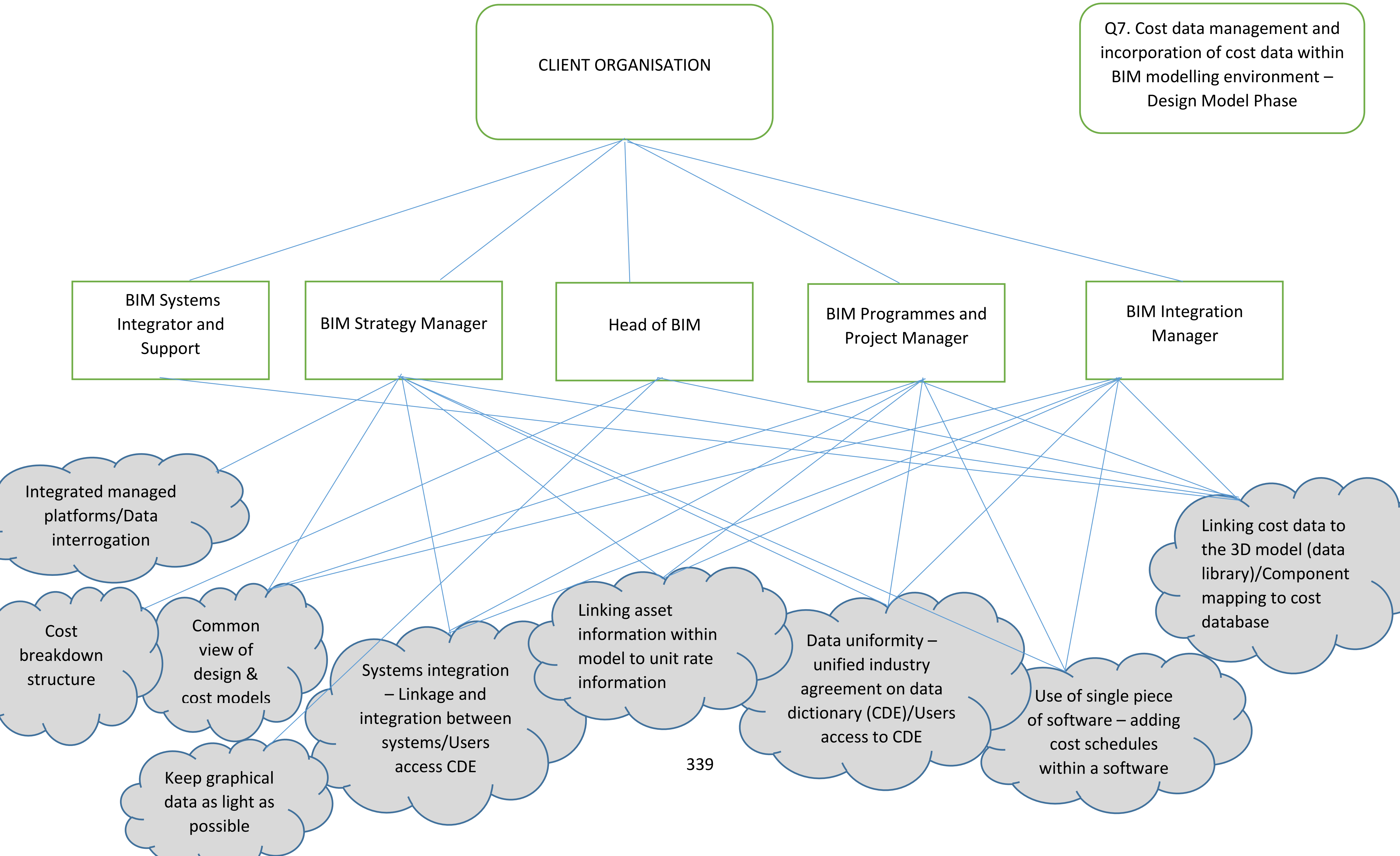

CLIENT ORGANISATION
Q3. Perspective on the effect of procurement strategy on Contractor’s point of Entry
BIM Systems Integrator and Support
Head of BIM
BIM Strategy Manager
BIM Programmes and Project Manager
BIM Integration Manager
Yes it does affect contractor’s point of entry

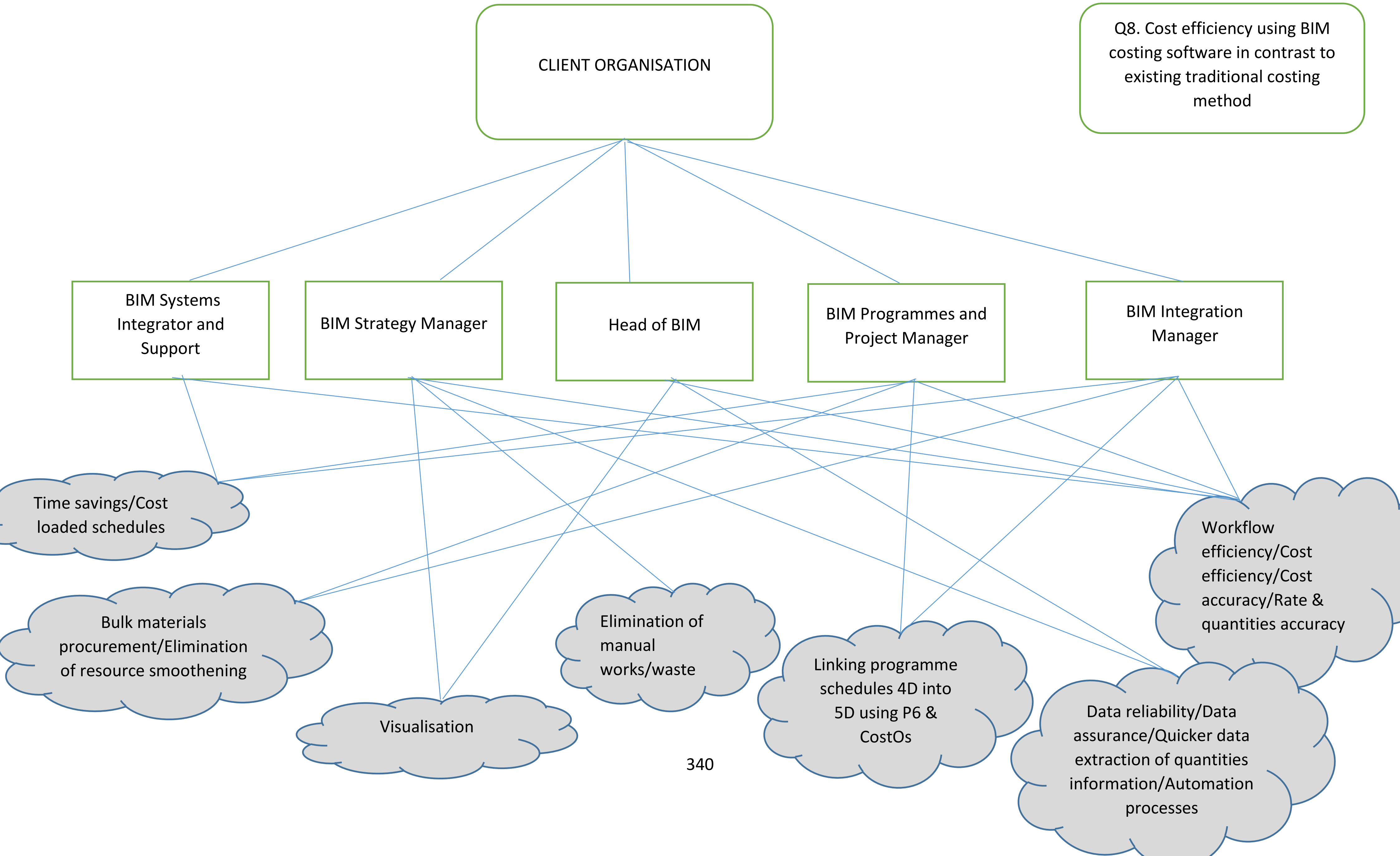


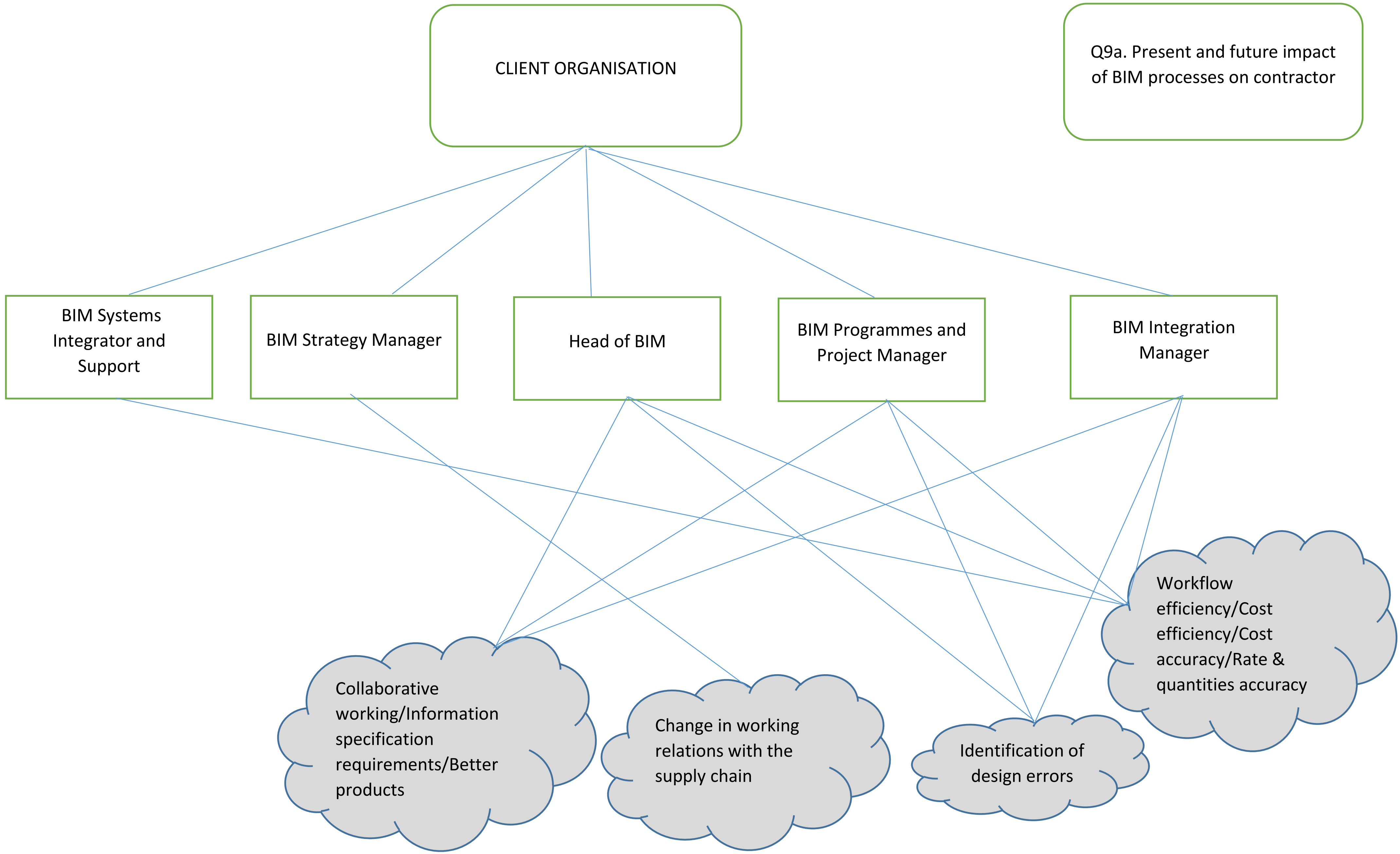
CLIENT ORGANISATION
Q4. Perceived cost implication of a chosen procurement strategy in 5D BIM implementation
BIM Systems Integrator and Support
Head of BIM
BIM Strategy Manager
BIM Programmes and Project Manager
BIM Integration Manager
Interphase issues due to varied design details
Early detailed design (Massive changes)
Early detailed design (Rework)
Bespoke cost implication based on clients requirement
Delivery process changes
Impact on ECI/Early decision making
Misunderstanding of design between parties/Misunderstanding of design data by supply chain


CLIENT ORGANISATION
Q5. Integration of value of contractor's experience or knowledge during model development phase
BIM Systems Integrator and Support
Head of BIM
BIM Strategy Manager
BIM Programmes and Project Manager
BIM Integration Manager
Mitigation of Contingencies/Reduction of errors passed to supply chain
Sharing of information/Communication improvement
Risk Mgt/Design change impact - cost, risks, & schedule
Conflict Resolution
Design reviews/Constructability
Incentivization
Stage visibility
Streamlined way of working/Contractor driven processes as opposed to consultants driven processes
Clash detection/Efficiency
High data confidence/Quality assurance of data/Control of data workflow/data integrity
Visibility of data/CDE/Uniformity of data/naming convention
Data drops to specific design gates/Reduces assumptions with 2D drawings
Cost & time benefits/Integration of project interphases
Data reliability/Transparency

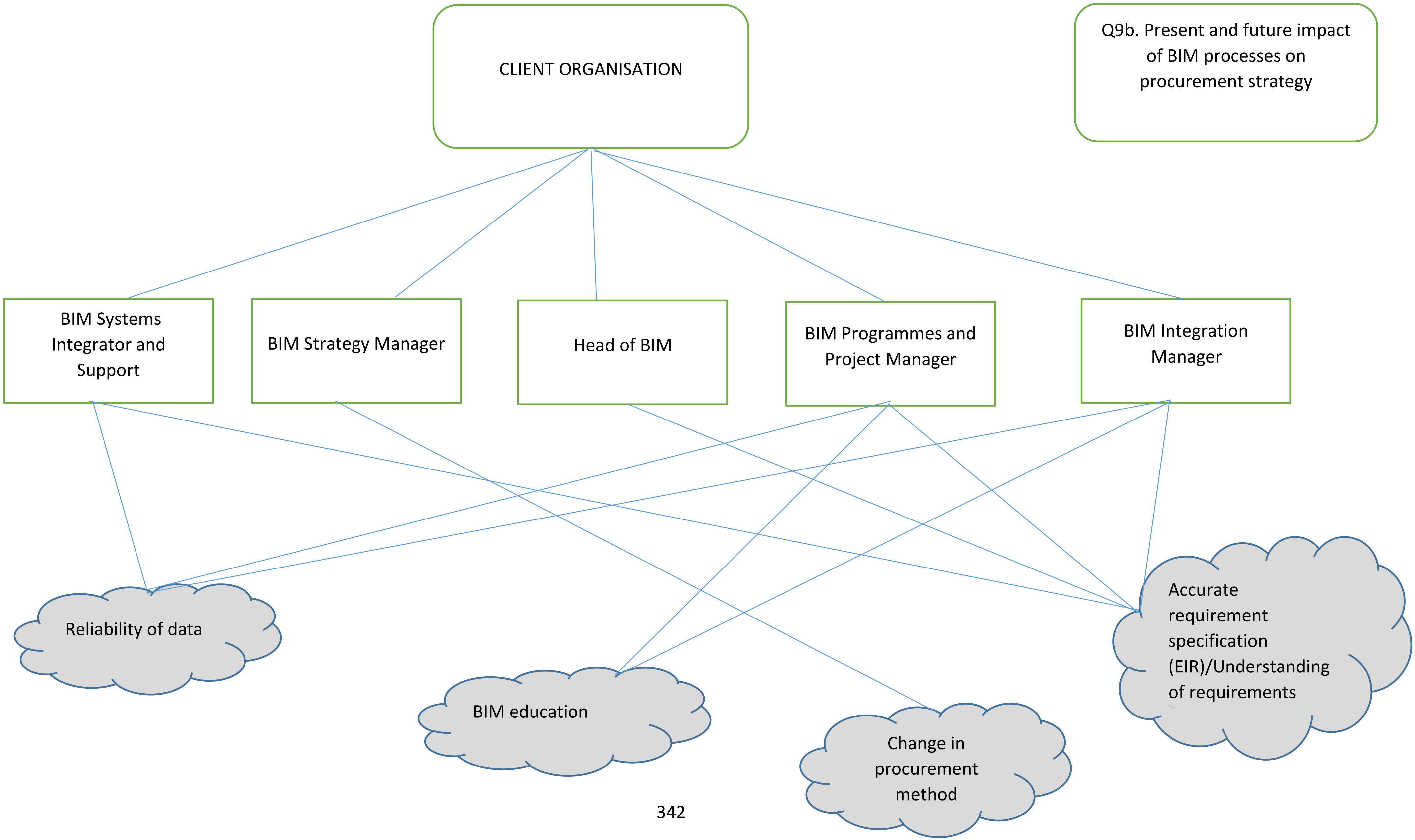

CLIENT ORGANISATION
Q6. Extent of BIM process engagement by contractors in project costing activities
BIM Systems Integrator and Support
Head of BIM
BIM Strategy Manager
BIM Programmes and Project Manager
BIM Integration Manager
I don't know/none at the moment
Varies from contractor to contractor
Not as much
Early stages of engagement

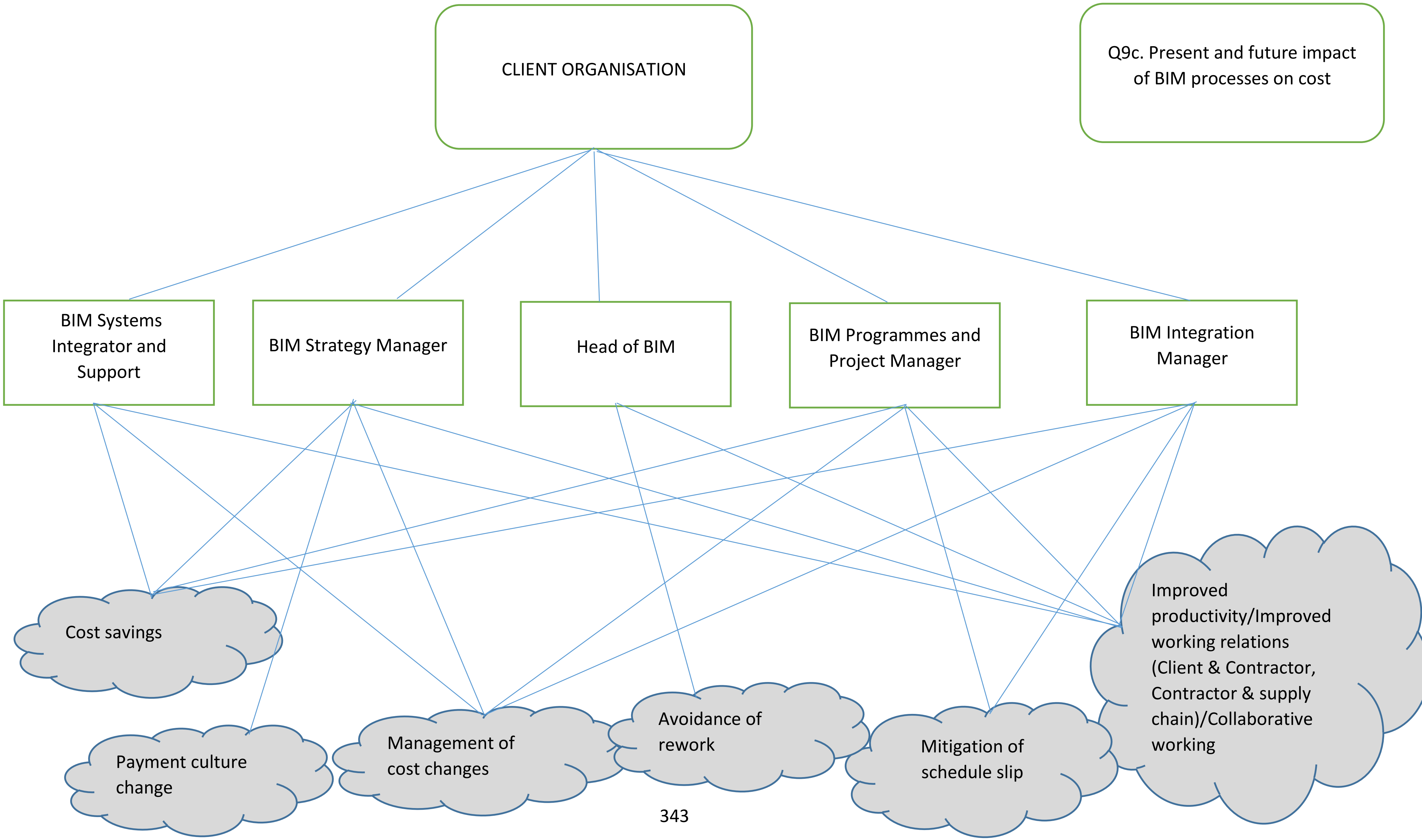

CLIENT ORGANISATION
Q7. Cost data management and incorporation of cost data within BIM modelling environment – Design Model Phase
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Integrated managed platforms/Data interrogation
Linking cost data to the 3D model (data library)/Component mapping to cost database
Cost breakdown structure
Common view of design & cost models
Linking asset information within model to unit rate information
Data uniformity – unified industry agreement on data dictionary (CDE)/Users access to CDE
Systems integration – Linkage and integration between systems/Users access CDE
Use of single piece of software – adding cost schedules within a software
Keep graphical data as light as possible

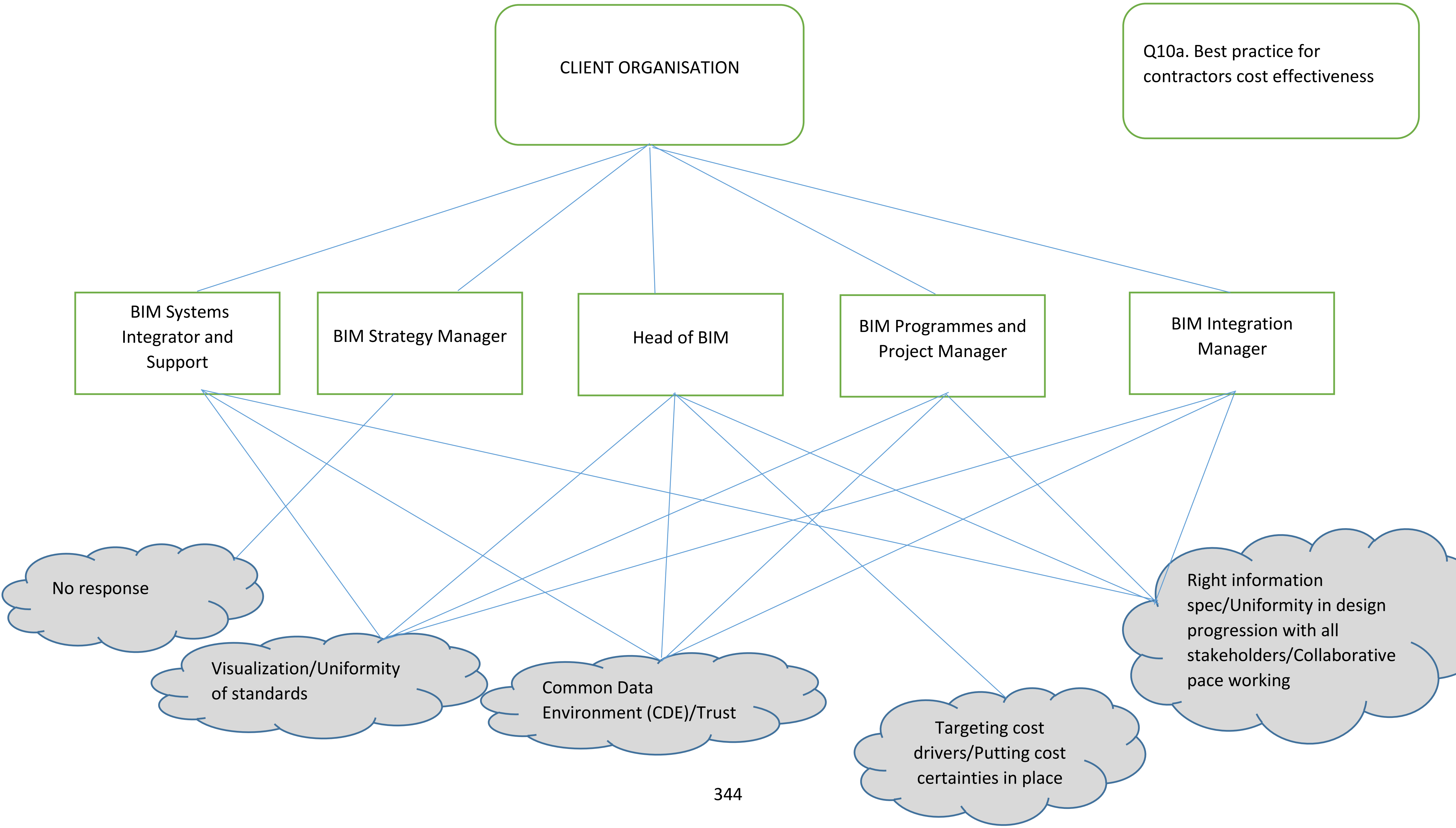

CLIENT ORGANISATION
Q8. Cost efficiency using BIM costing software in contrast to existing traditional costing method
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Time savings/Cost loaded schedules
Workflow efficiency/Cost efficiency/Cost accuracy/Rate & quantities accuracy
Bulk materials procurement/Elimination of resource smoothening
Elimination of manual works/waste
Linking programme schedules 4D into 5D using P6 & CostOs
Visualisation
Data reliability/Data assurance/Quicker data extraction of quantities information/Automation processes



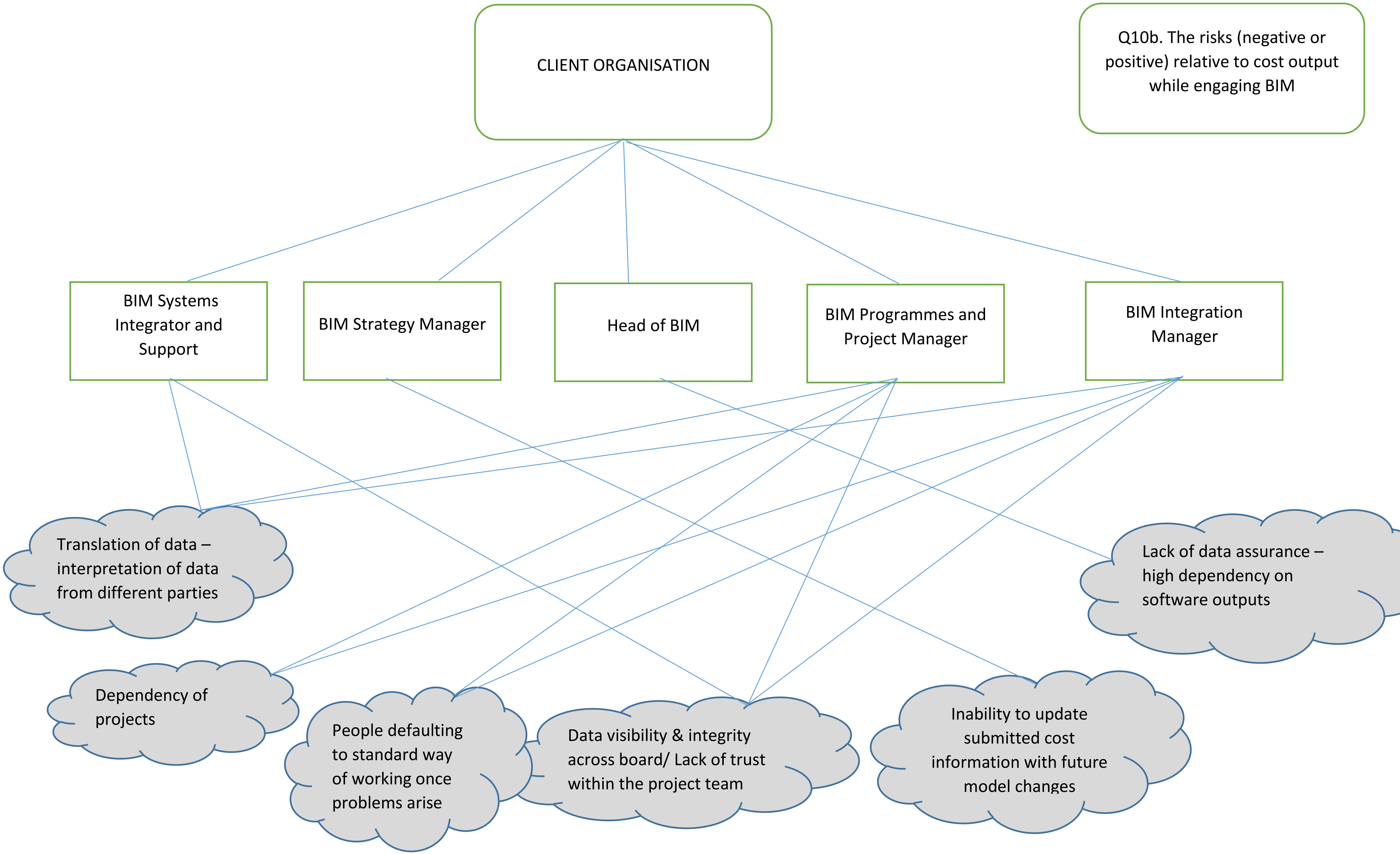
CLIENT ORGANISATION
Q9a. Present and future impact of BIM processes on contractor
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Collaborative working/Information specification requirements/Better products
Change in working relations with the supply chain
Identification of design errors
Workflow efficiency/Cost efficiency/Cost accuracy/Rate & quantities accuracy


CLIENT ORGANISATION
Q9b. Present and future impact of BIM processes on procurement strategy
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Reliability of data
BIM education
Change in procurement method
Accurate requirement specification (EIR)/Understanding of requirements

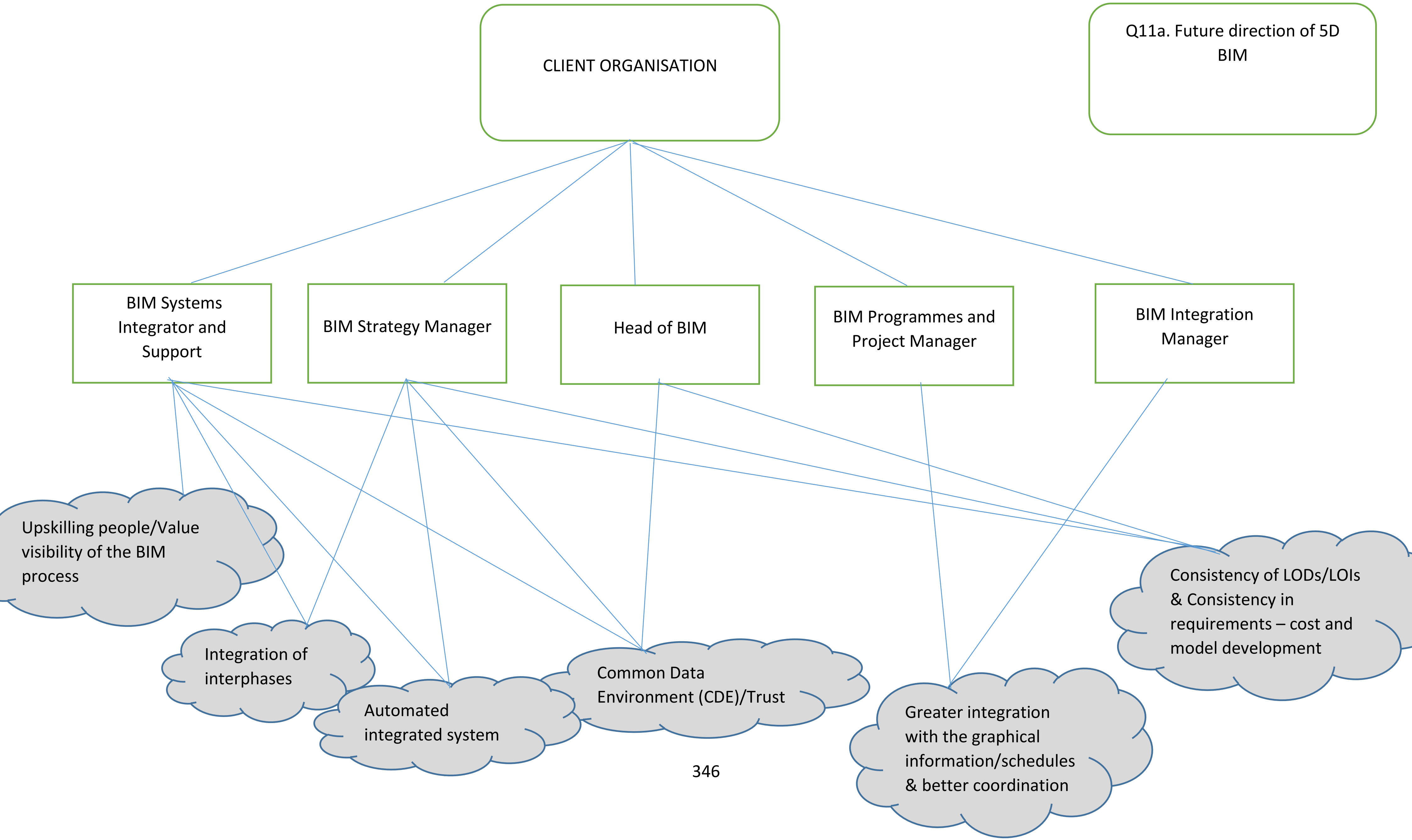

CLIENT ORGANISATION
Q9c. Present and future impact of BIM processes on cost
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Cost savings
Payment culture change
Management of cost changes
Avoidance of rework
Mitigation of schedule slip
Improved productivity/Improved working relations (Client & Contractor, Contractor & supply chain)/Collaborative working

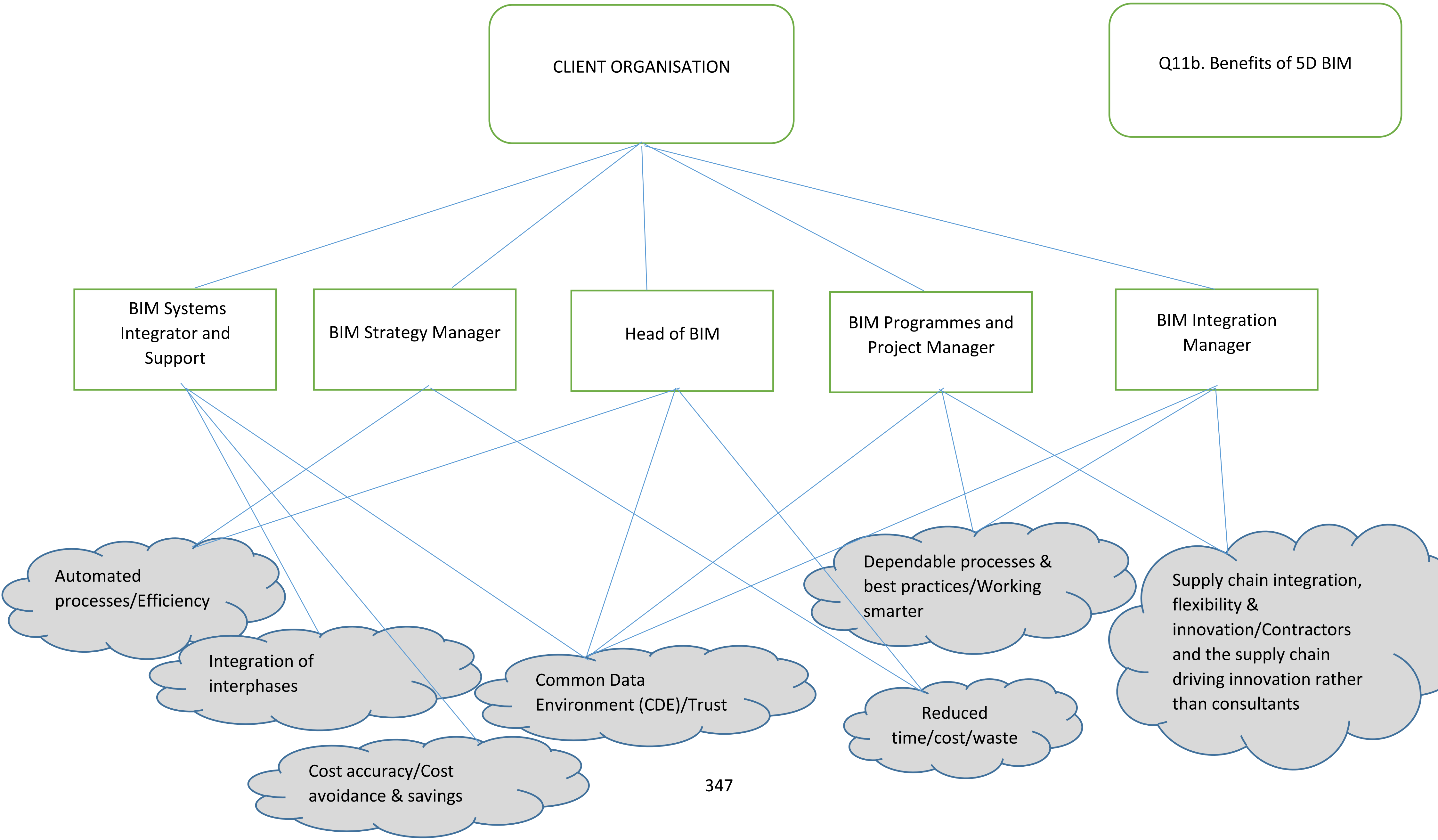


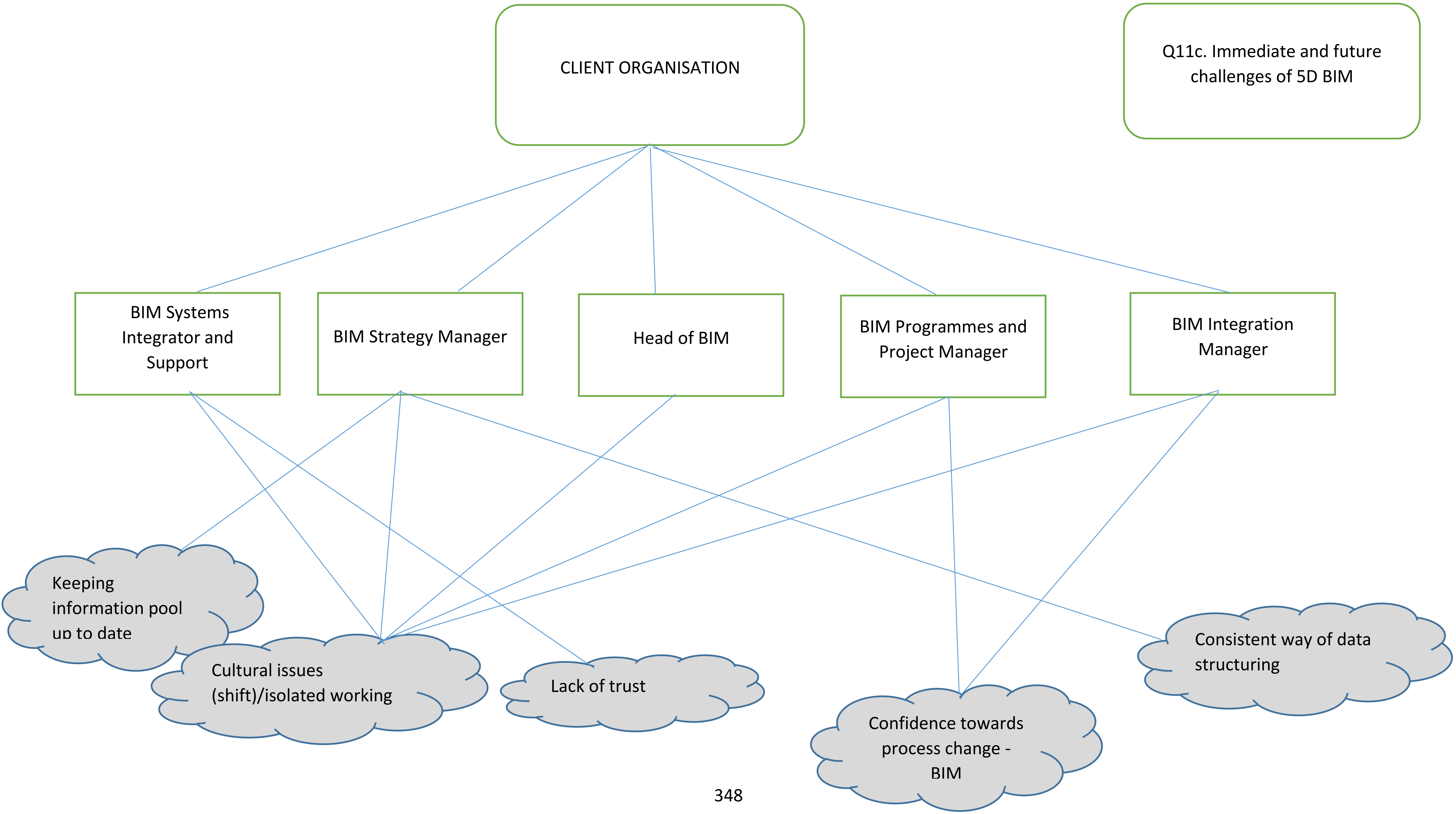
CLIENT ORGANISATION
Q10a. Best practice for contractors cost effectiveness
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
No response
Visualization/Uniformity of standards
Common Data Environment (CDE)/Trust
Targeting cost drivers/Putting cost certainties in place
Right information spec/Uniformity in design progression with all stakeholders/Collaborative pace working

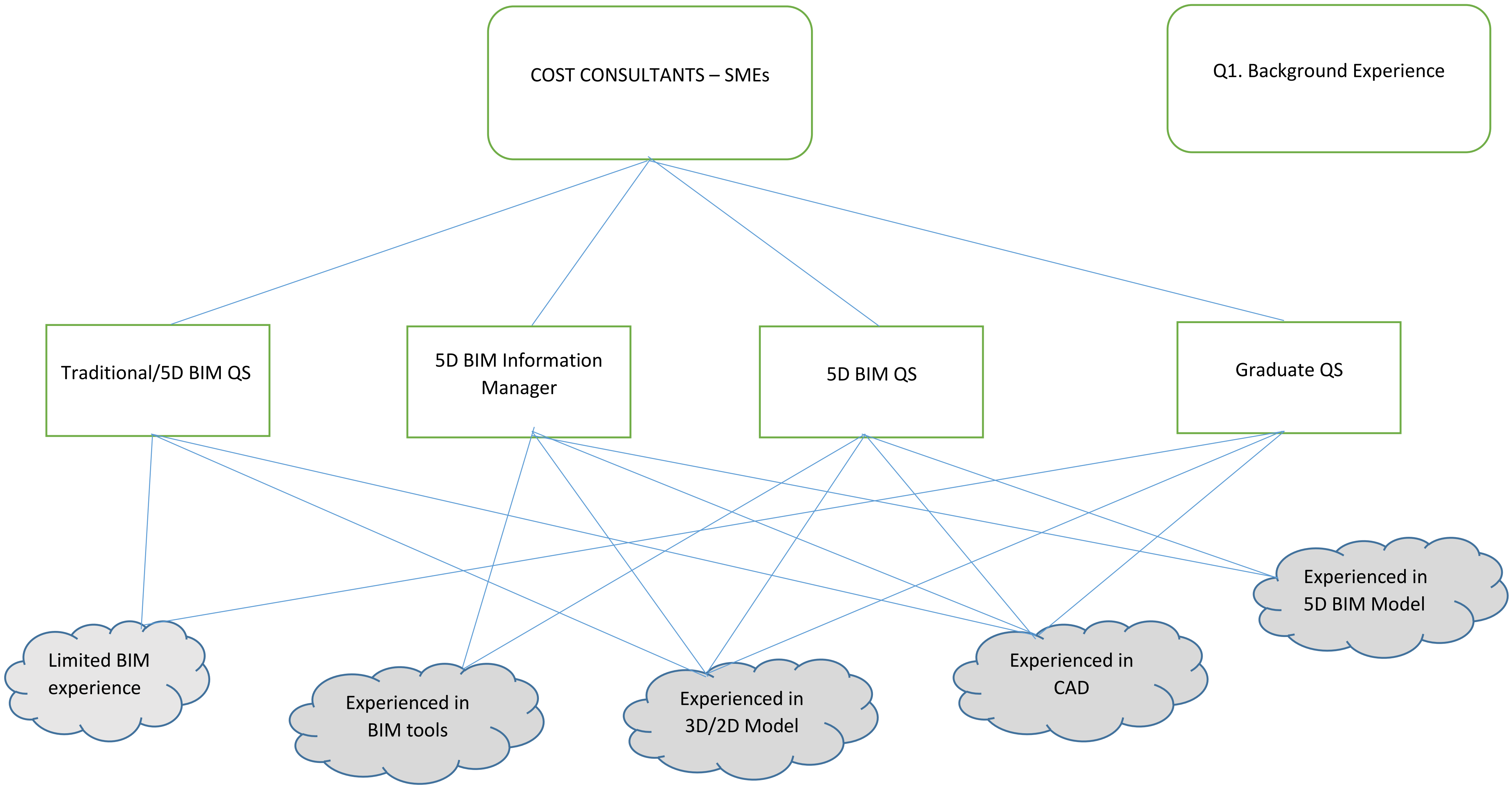


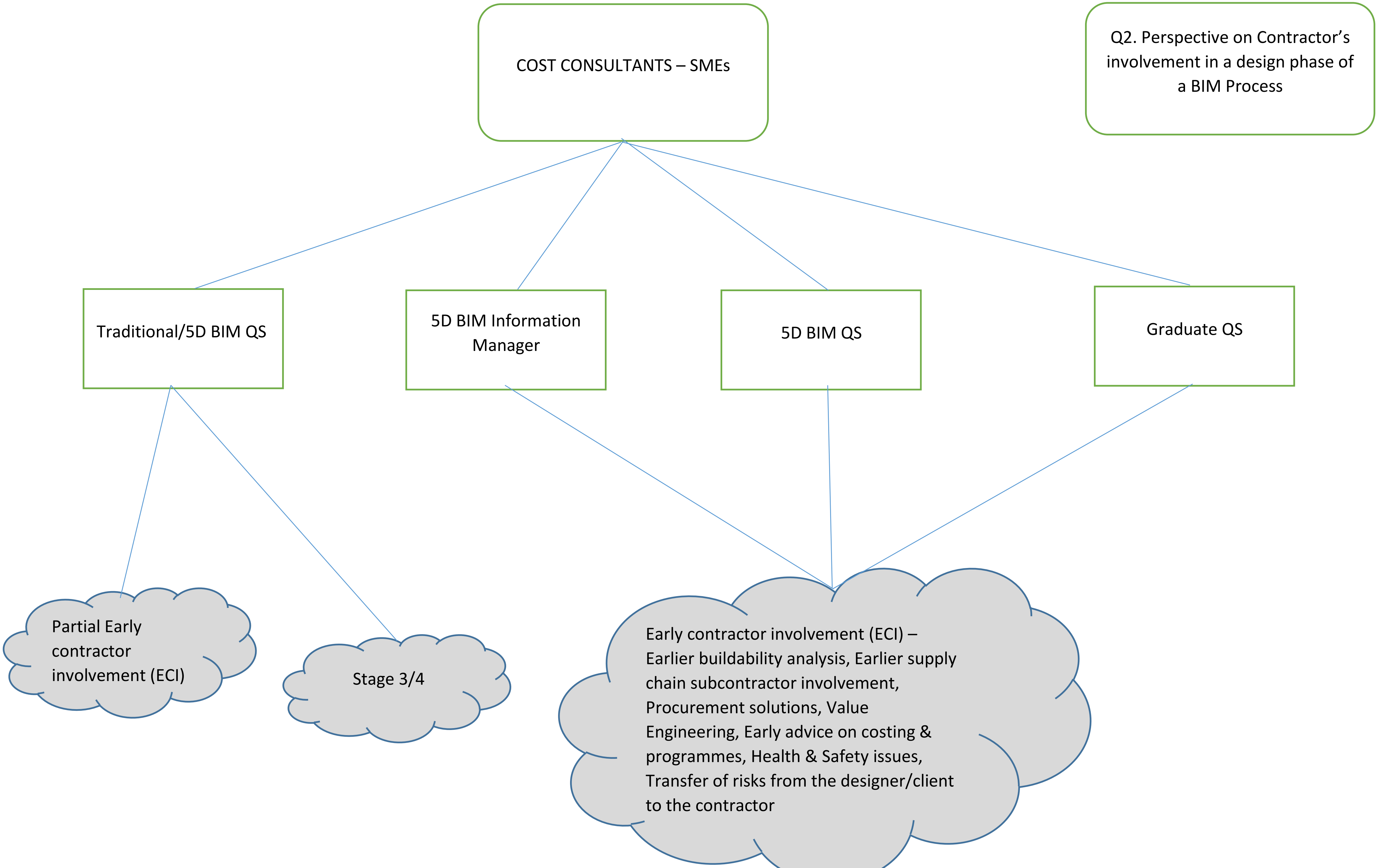
CLIENT ORGANISATION
Q10b. The risks (negative or positive) relative to cost output while engaging BIM
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Translation of data – interpretation of data from different parties
Lack of data assurance – high dependency on software outputs
Dependency of projects
People defaulting to standard way of working once problems arise
Data visibility & integrity across board/ Lack of trust within the project team
Inability to update submitted cost information with future model changes

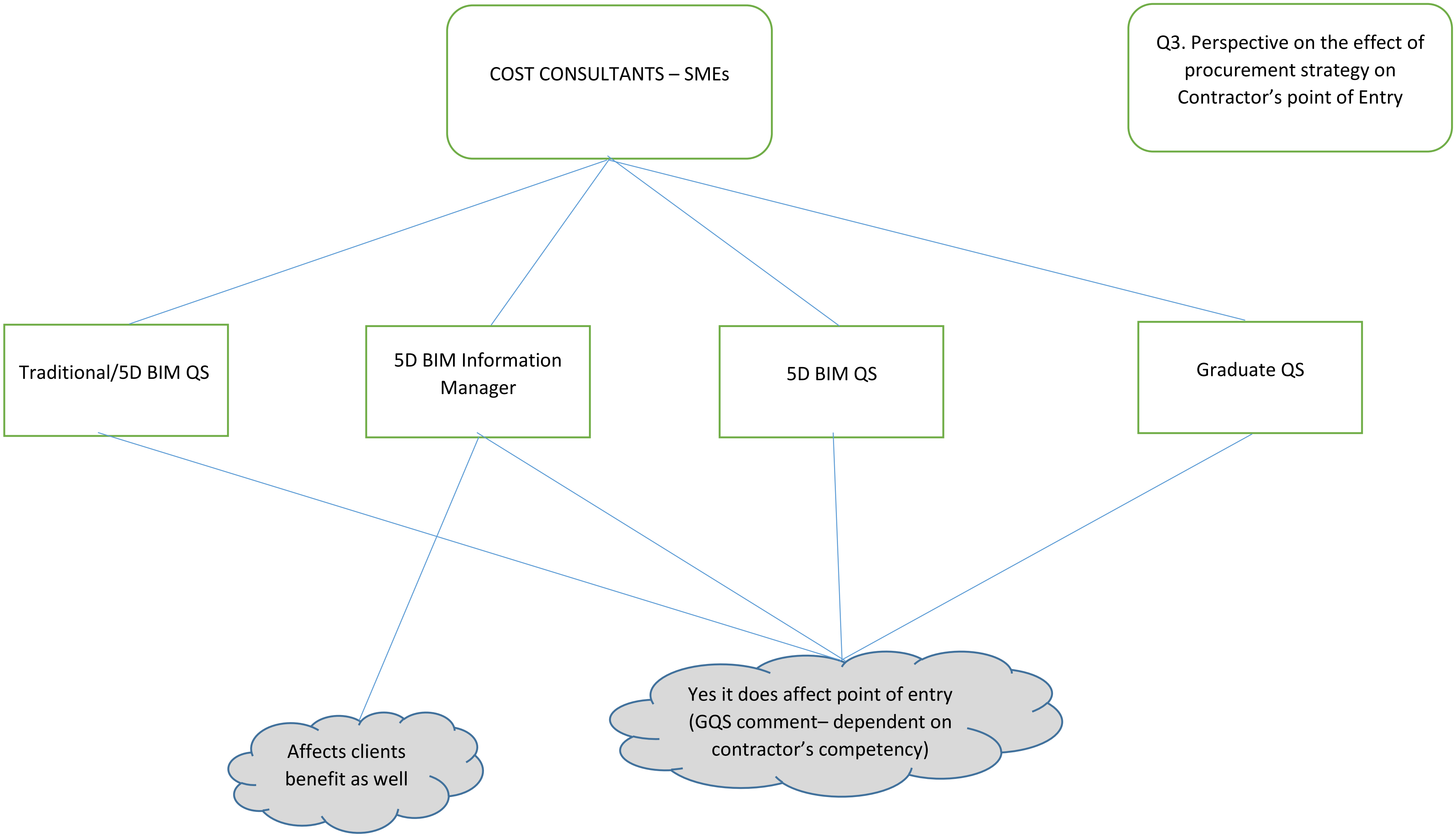

CLIENT ORGANISATION
Q11a. Future direction of 5D BIM
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Upskilling people/Value visibility of the BIM process
Integration of interphases
Automated integrated system
Common Data Environment (CDE)/Trust
Greater integration with the graphical information/schedules & better coordination
Consistency of LODs/LOIs & Consistency in requirements – cost and model development

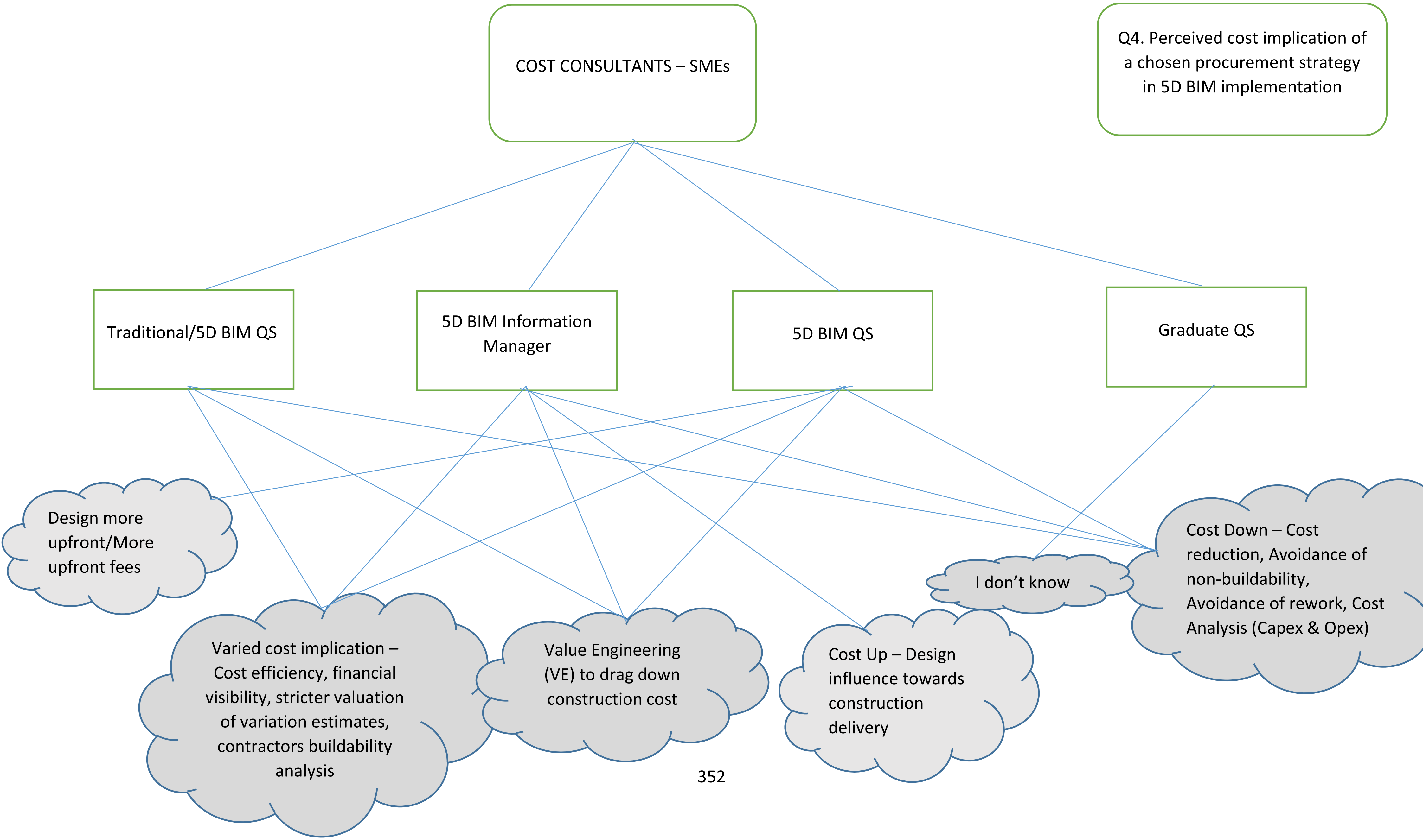

CLIENT ORGANISATION
Q11b. Benefits of 5D BIM
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Automated processes/Efficiency
Integration of interphases
Cost accuracy/Cost avoidance & savings
Common Data Environment (CDE)/Trust
Dependable processes & best practices/Working smarter
Reduced time/cost/waste
Supply chain integration, flexibility & innovation/Contractors and the supply chain driving innovation rather than consultants

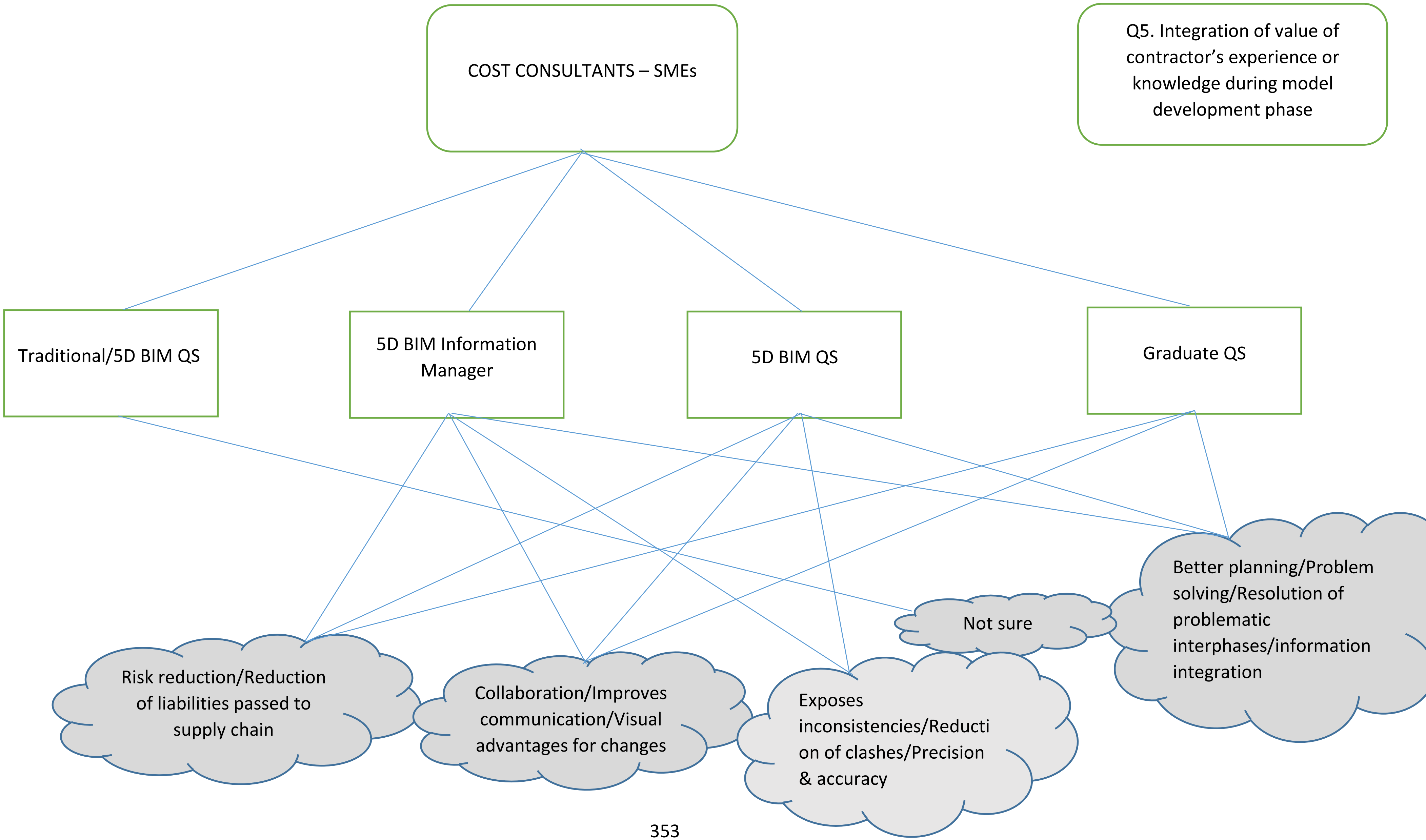

CLIENT ORGANISATION
Q11c. Immediate and future challenges of 5D BIM
BIM Systems Integrator and Support
BIM Strategy Manager
Head of BIM
BIM Programmes and Project Manager
BIM Integration Manager
Keeping information pool up to date
Cultural issues (shift)/isolated working
Lack of trust
Confidence towards process change - BIM
Consistent way of data structuring

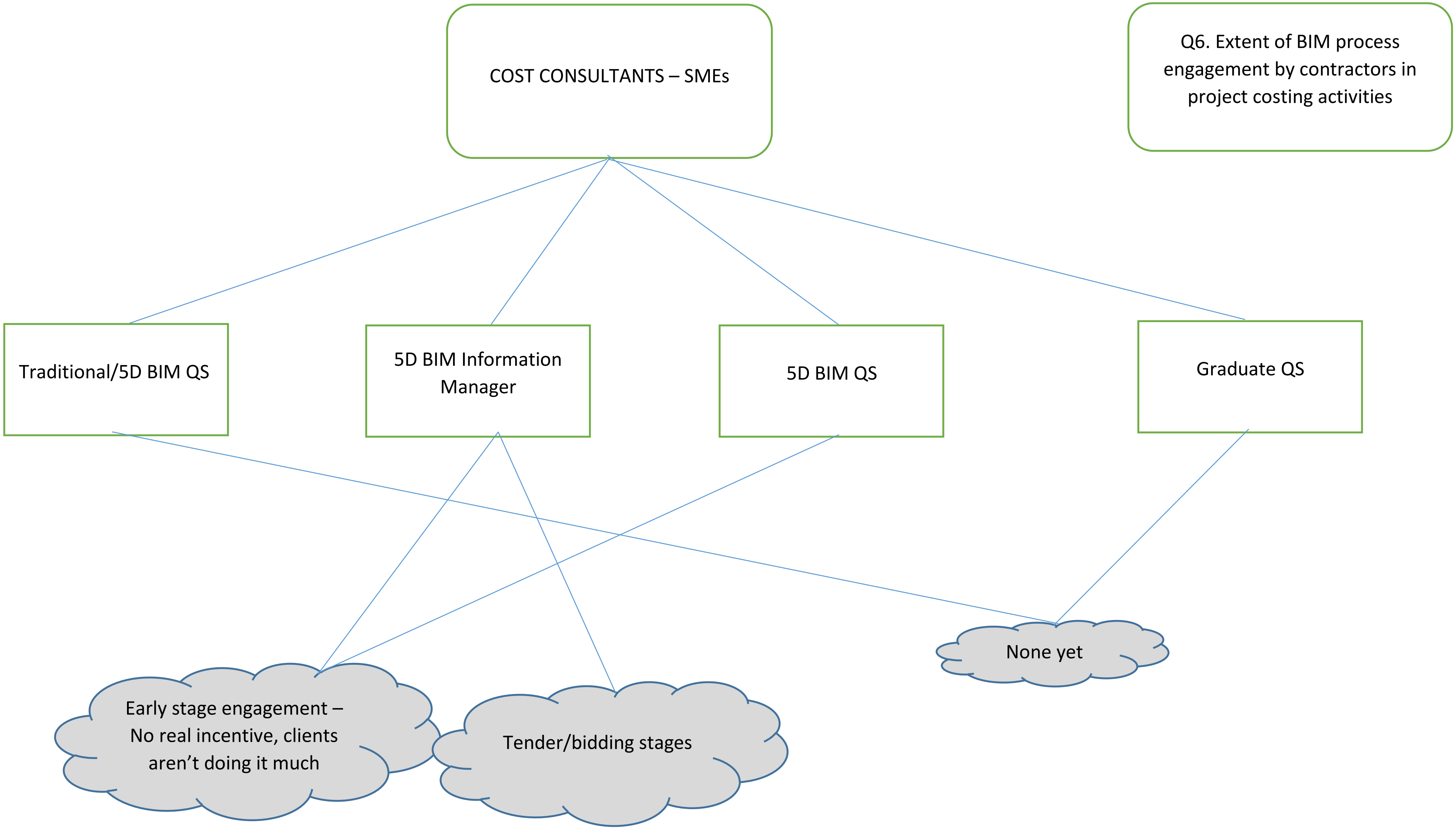

COST CONSULTANTS – SMEs
Q1. Background Experience
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Limited BIM experience
Experienced in BIM tools
Experienced in 3D/2D Model
Experienced in CAD
Experienced in 5D BIM Model

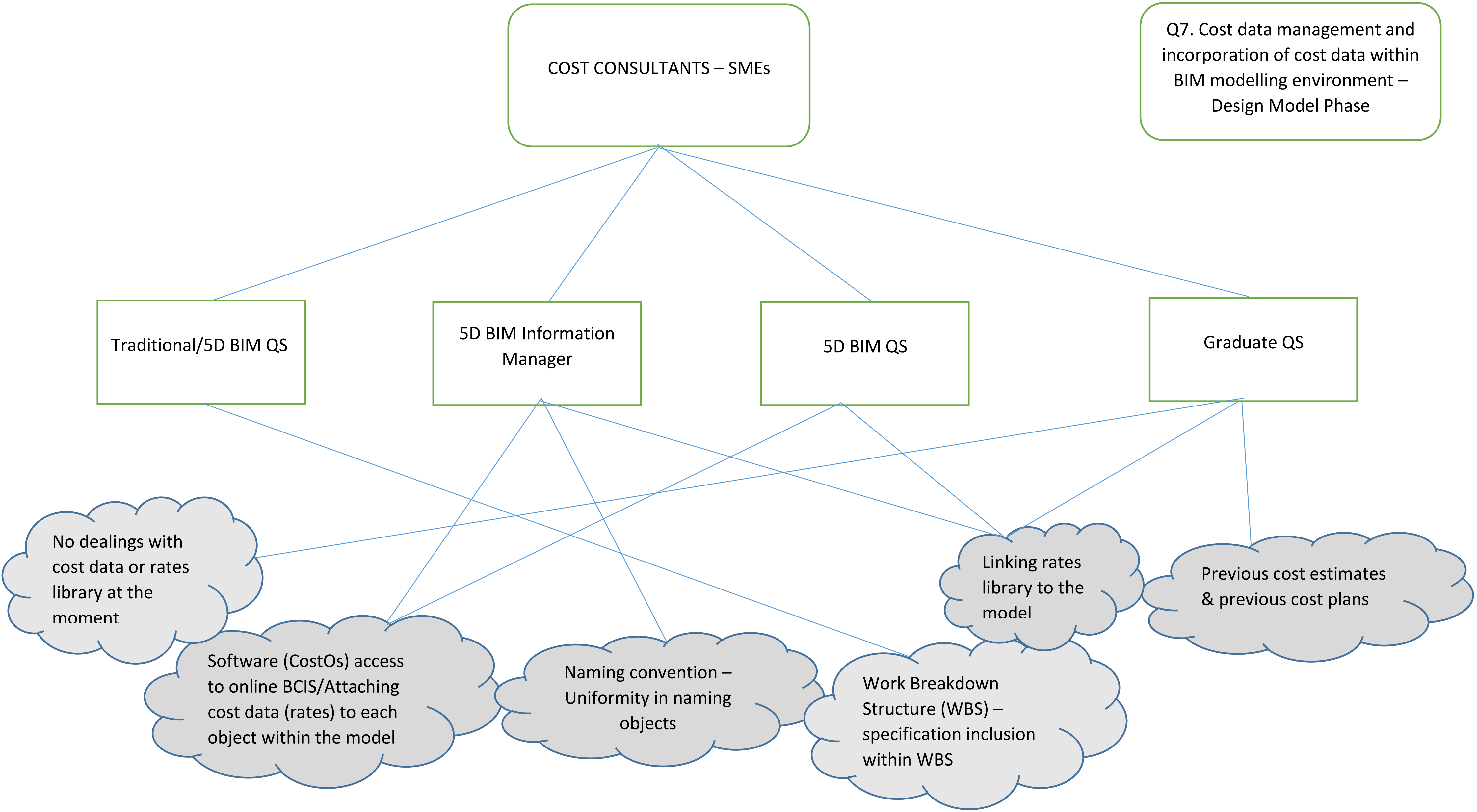

COST CONSULTANTS – SMEs
Q2. Perspective on Contractor's involvement in a design phase of a BIM Process
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Partial Early contractor involvement (ECI)
Stage 3/4
Early contractor involvement (ECI) – Earlier buildability analysis, Earlier supply chain subcontractor involvement, Procurement solutions, Value Engineering, Early advice on costing & programmes, Health & Safety issues, Transfer of risks from the designer/client to the contractor

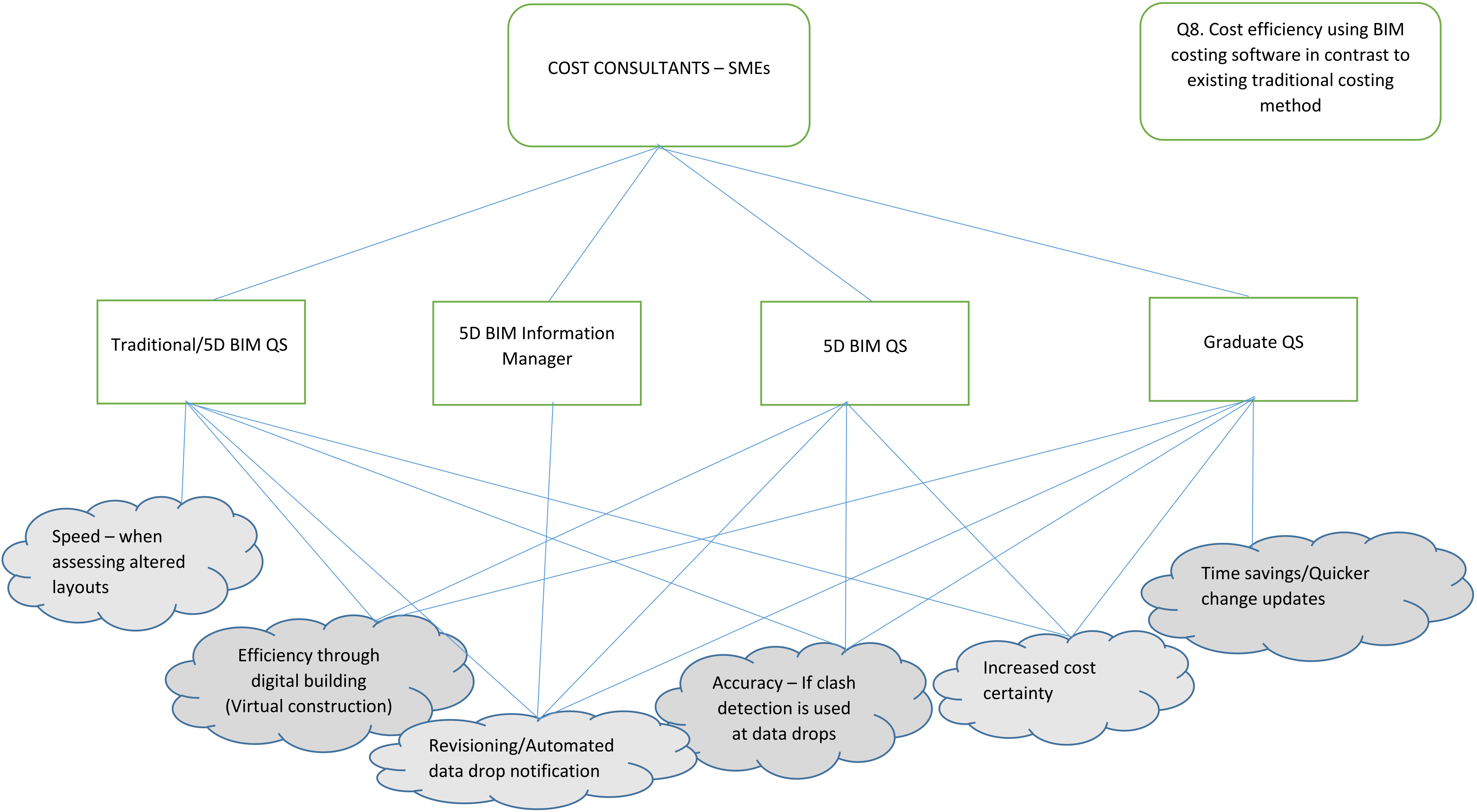

COST CONSULTANTS – SMEs
Q3. Perspective on the effect of procurement strategy on Contractor's point of Entry
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Affects clients benefit as well
Yes it does affect point of entry (GQS comment– dependent on contractor's competency)

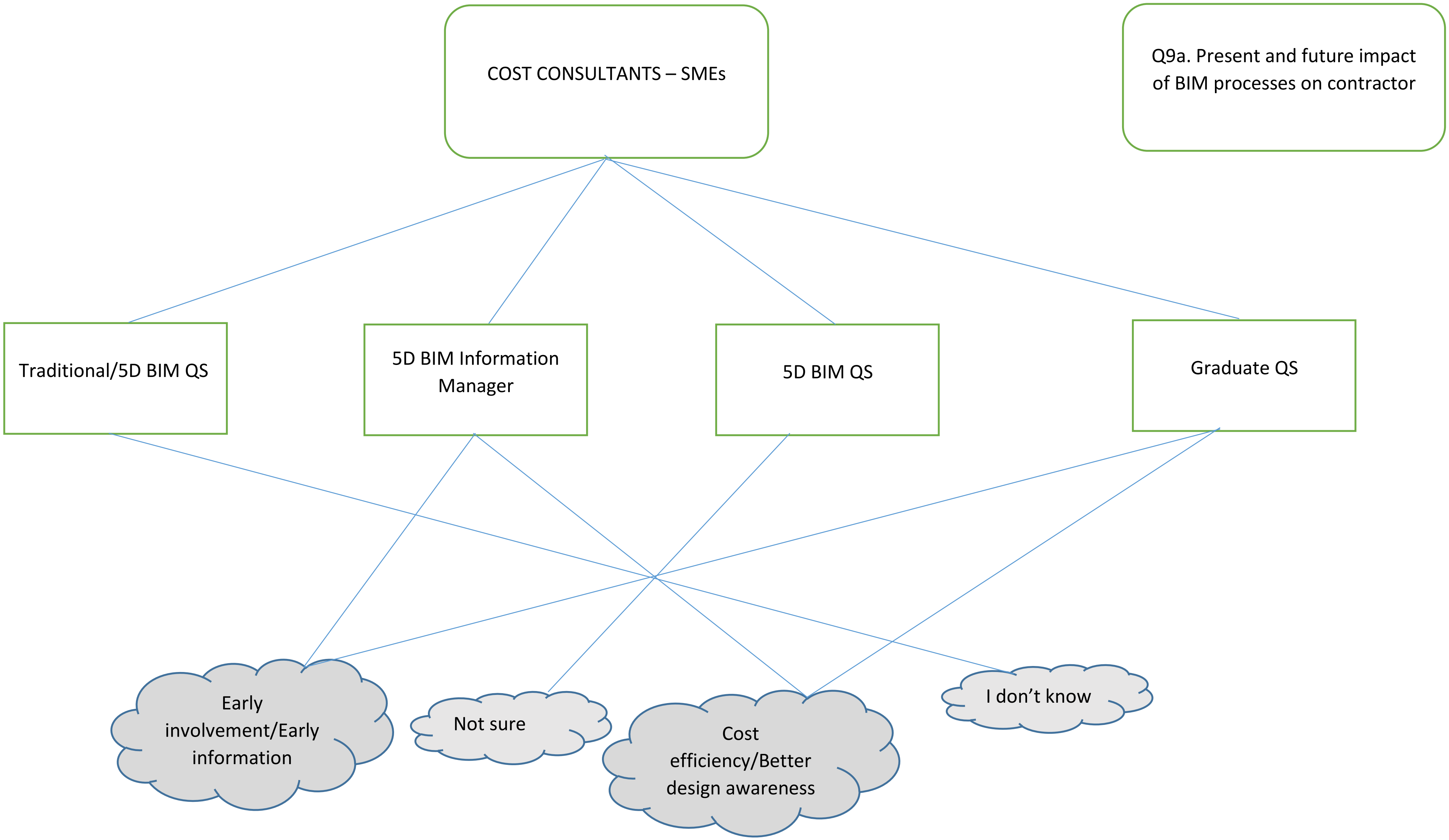

COST CONSULTANTS – SMEs
Q4. Perceived cost implication of a chosen procurement strategy in 5D BIM implementation
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Design more upfront/More upfront fees
Varied cost implication – Cost efficiency, financial visibility, stricter valuation of variation estimates, contractors buildability analysis
Value Engineering (VE) to drag down construction cost
Cost Up – Design influence towards construction delivery
I don't know
Cost Down – Cost reduction, Avoidance of non-buildability, Avoidance of rework, Cost Analysis (Capex & Opex)

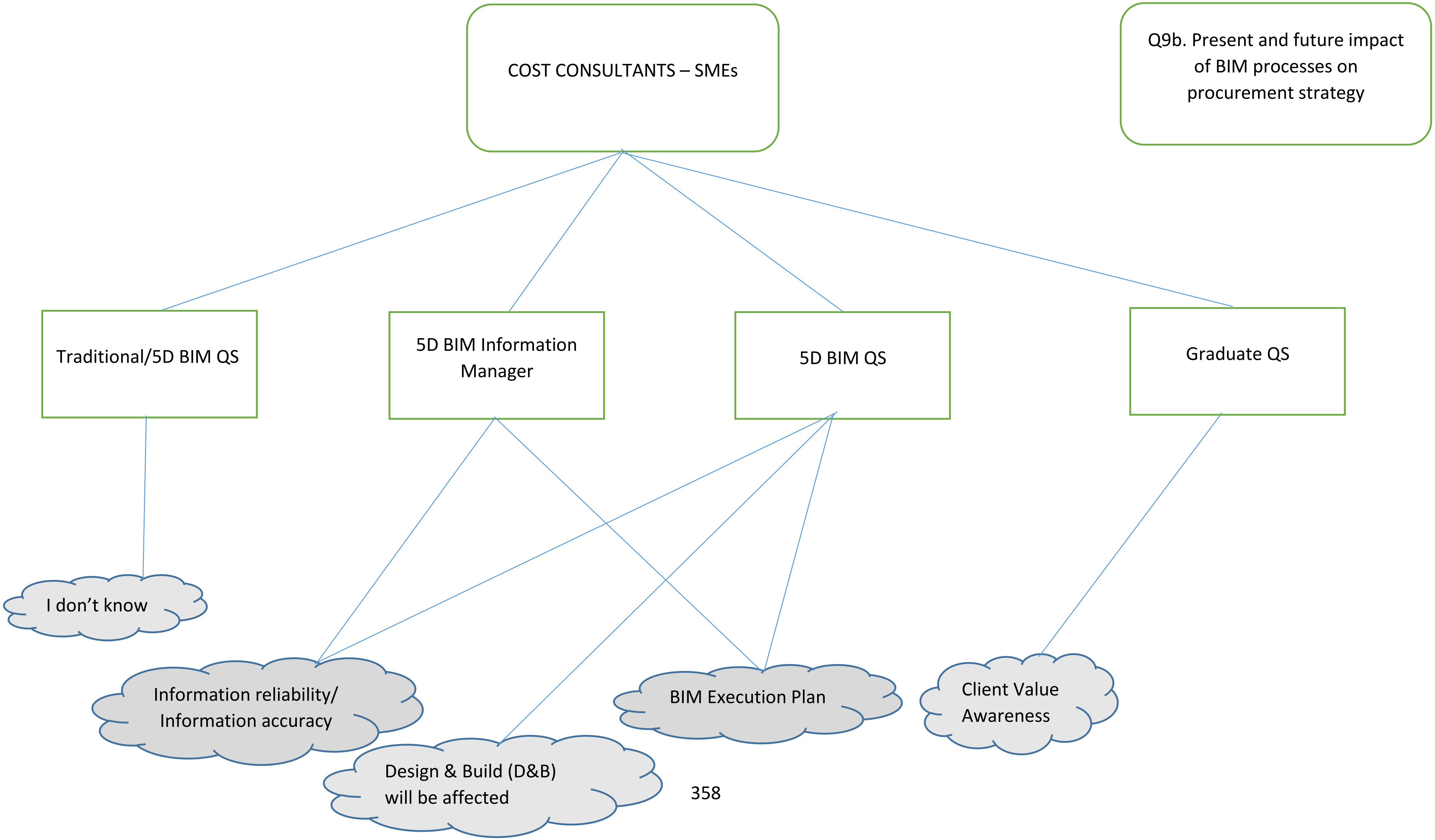

COST CONSULTANTS – SMEs
Q5. Integration of value of contractor's experience or knowledge during model development phase
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Better planning/Problem solving/Resolution of problematic interphases/information integration
Not sure
Risk reduction/Reduction of liabilities passed to supply chain
Collaboration/Improves communication/Visual advantages for changes
Exposes inconsistencies/Reduction of clashes/Precision & accuracy

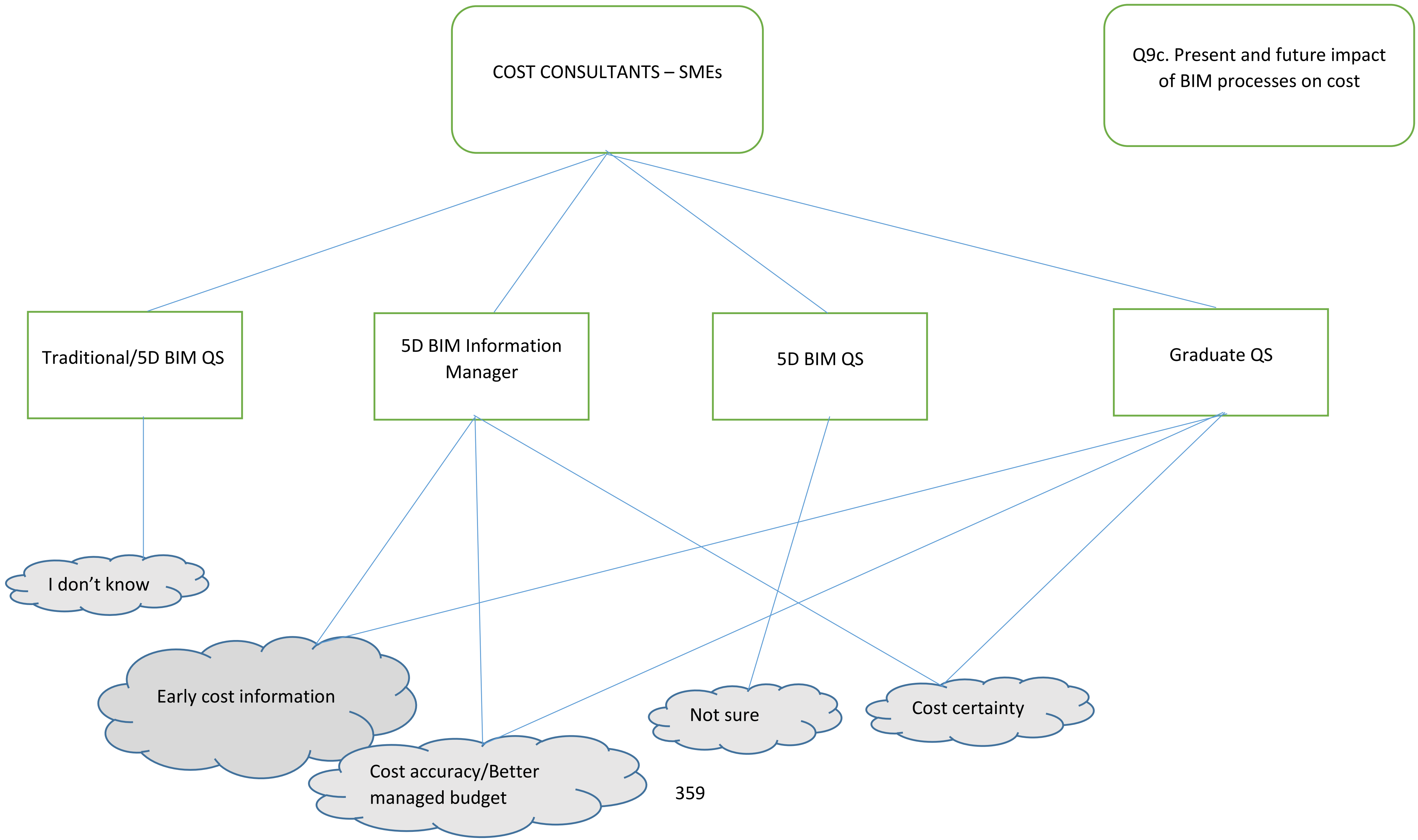

COST CONSULTANTS – SMEs
Q6. Extent of BIM process engagement by contractors in project costing activities
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
None yet
Early stage engagement – No real incentive, clients aren't doing it much
Tender/bidding stages

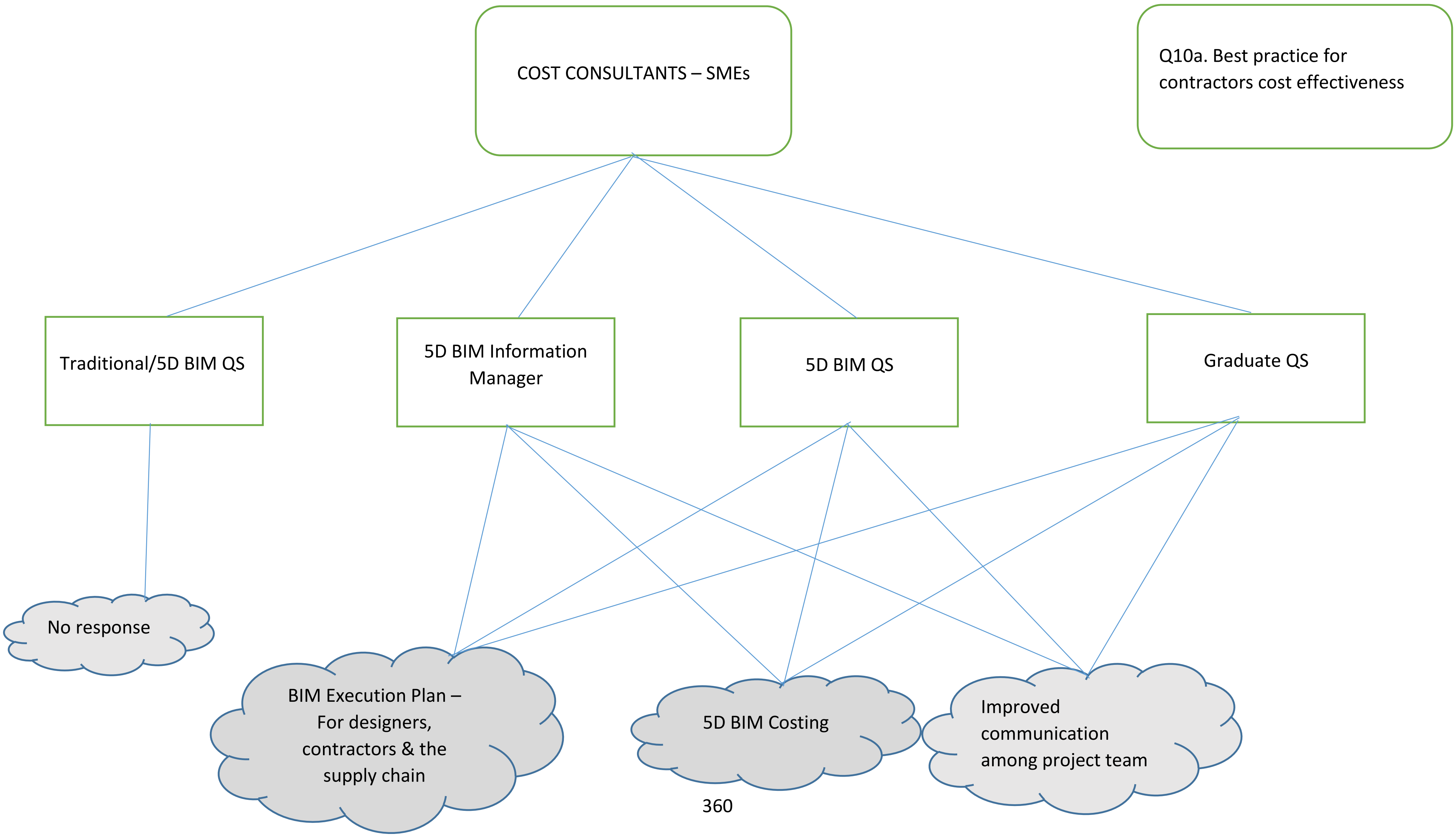

COST CONSULTANTS – SMEs
Q7. Cost data management and incorporation of cost data within BIM modelling environment – Design Model Phase
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
No dealings with cost data or rates library at the moment
Software (CostOs) access to online BCIS/Attaching cost data (rates) to each object within the model
Naming convention – Uniformity in naming objects
Work Breakdown Structure (WBS) – specification inclusion within WBS
Linking rates library to the model
Previous cost estimates & previous cost plans

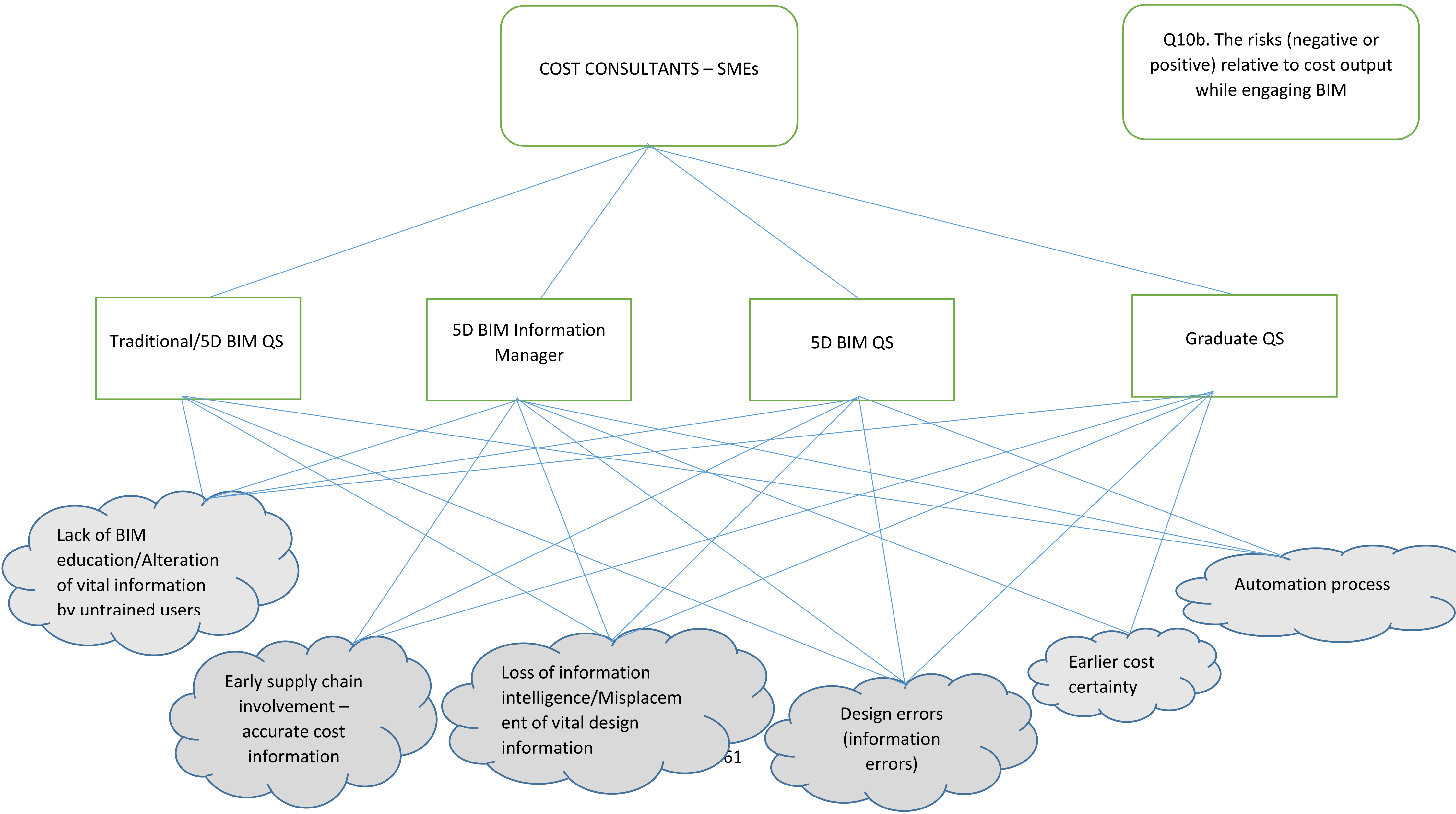

COST CONSULTANTS – SMEs
Q8. Cost efficiency using BIM costing software in contrast to existing traditional costing method
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Speed – when assessing altered layouts
Efficiency through digital building (Virtual construction)
Revisioning/Automated data drop notification
Accuracy – If clash detection is used at data drops
Increased cost certainty
Time savings/Quicker change updates

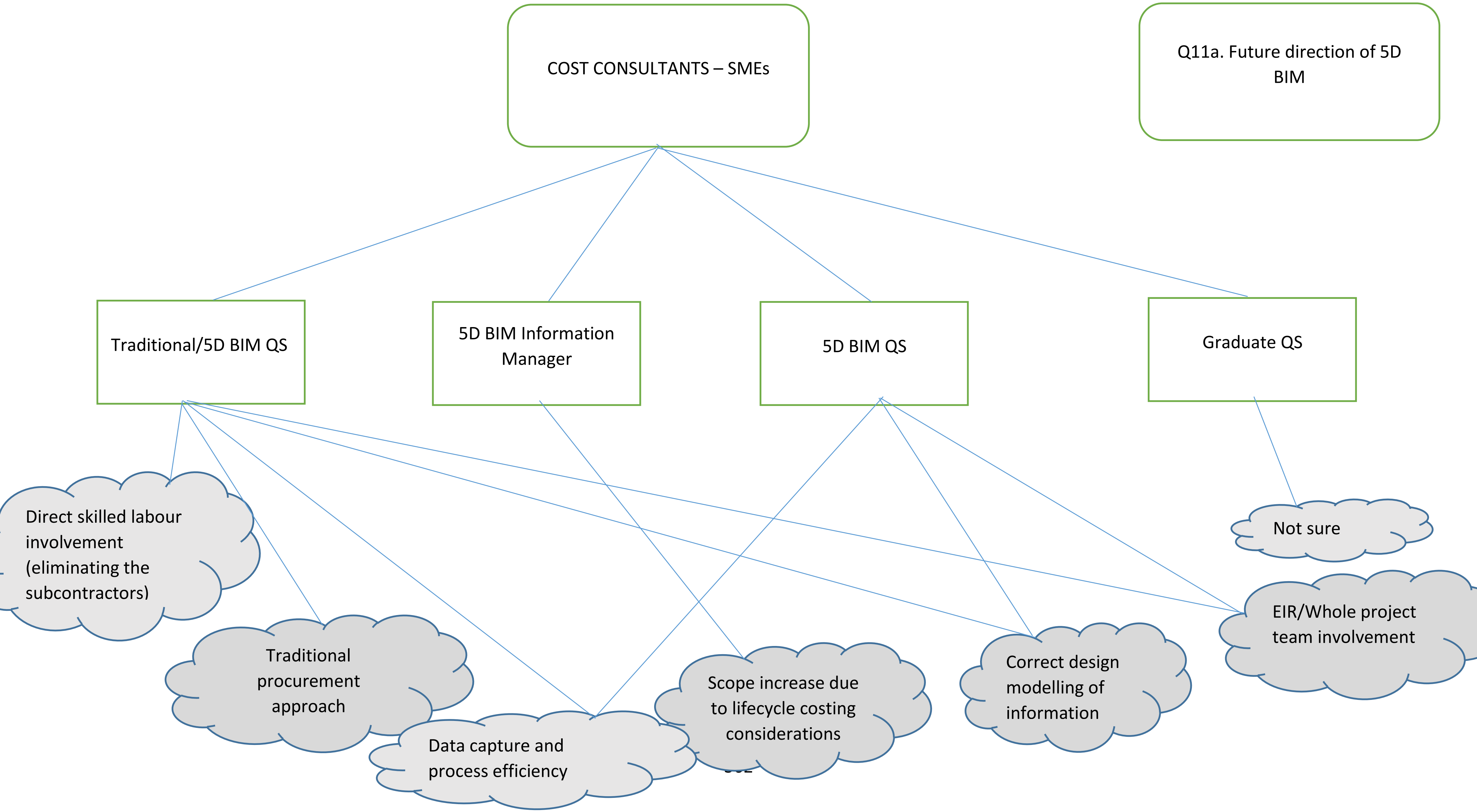

COST CONSULTANTS – SMEs
Q9a. Present and future impact of BIM processes on contractor
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Early involvement/Early information
Not sure
Cost efficiency/Better design awareness
I don't know

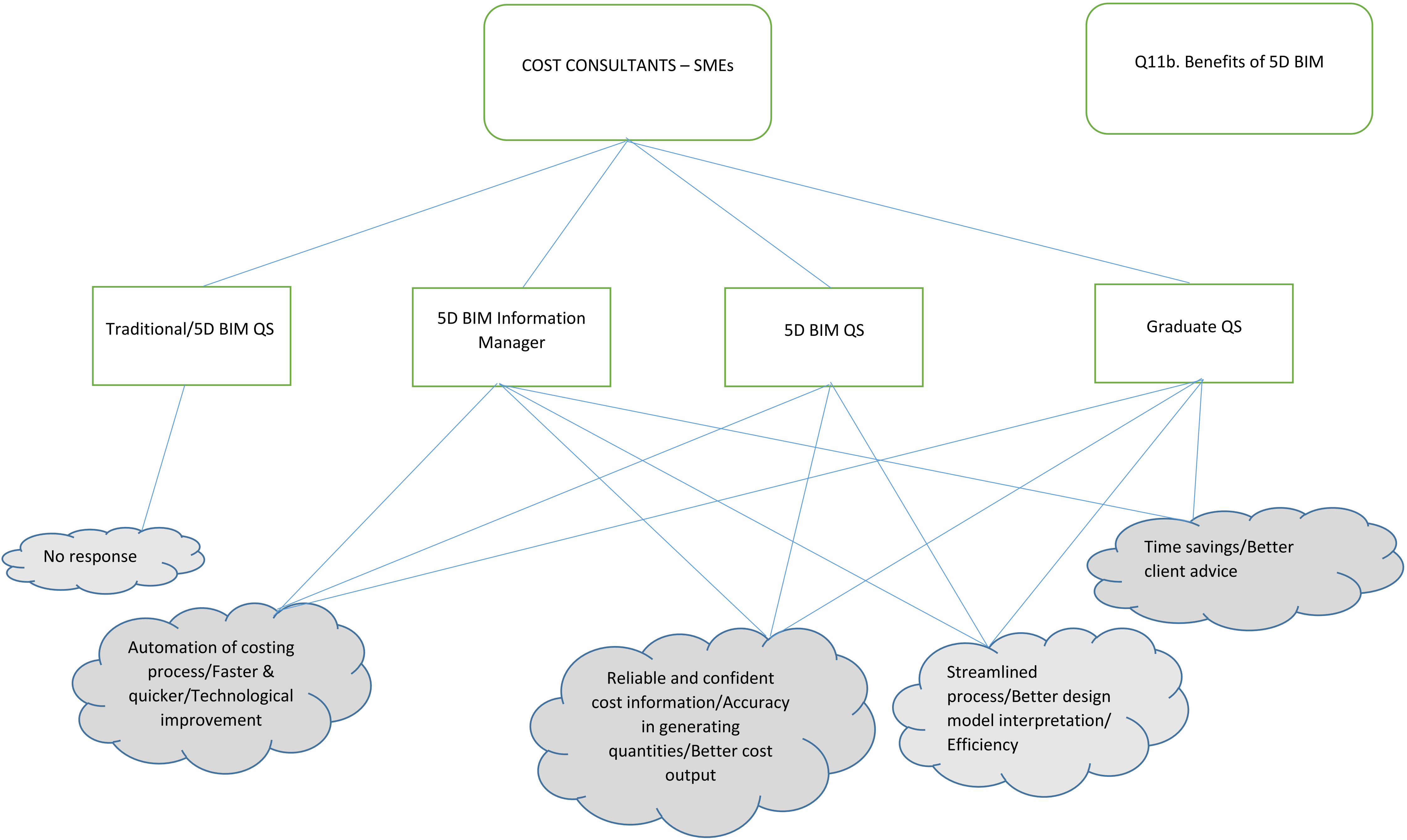

COST CONSULTANTS – SMEs
Q9b. Present and future impact of BIM processes on procurement strategy
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
I don't know
Information reliability/ Information accuracy
BIM Execution Plan
Client Value Awareness
Design & Build (D&B) will be affected

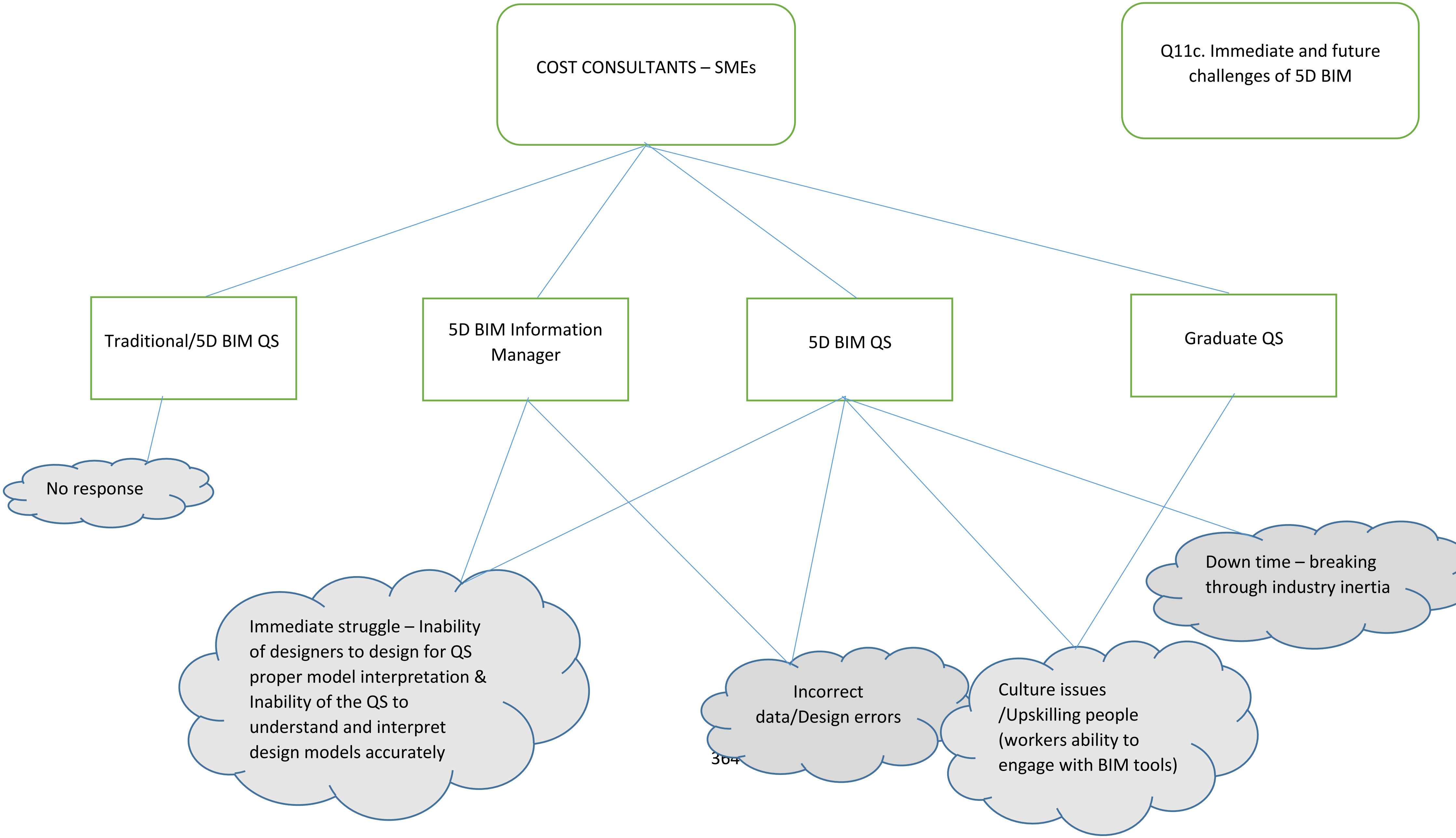

COST CONSULTANTS – SMEs
Q9c. Present and future impact of BIM processes on cost
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
I don't know
Early cost information
Cost accuracy/Better managed budget
Not sure
Cost certainty

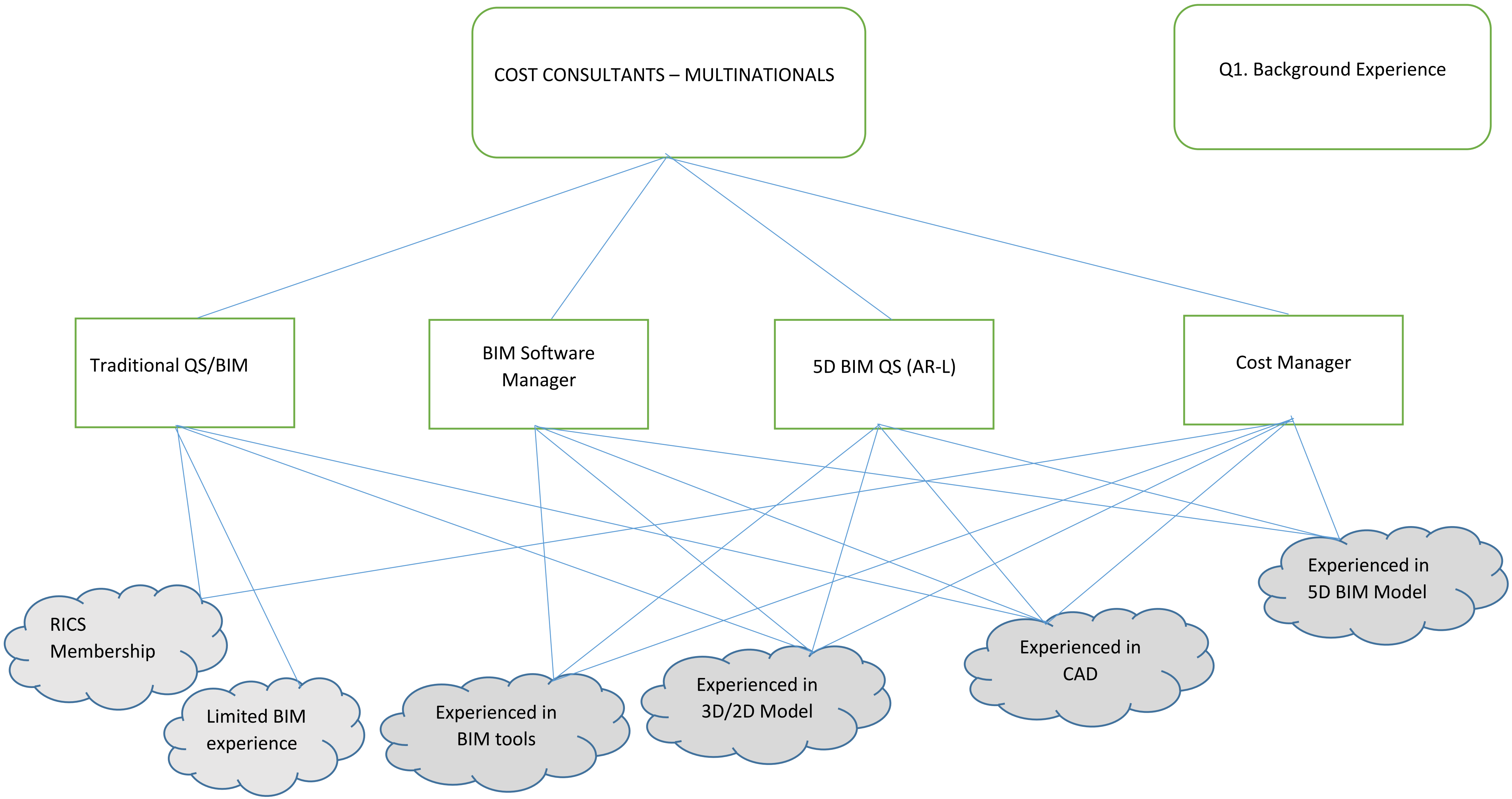

COST CONSULTANTS – SMEs
Q10a. Best practice for contractors cost effectiveness
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
No response
BIM Execution Plan – For designers, contractors & the supply chain
5D BIM Costing
Improved communication among project team

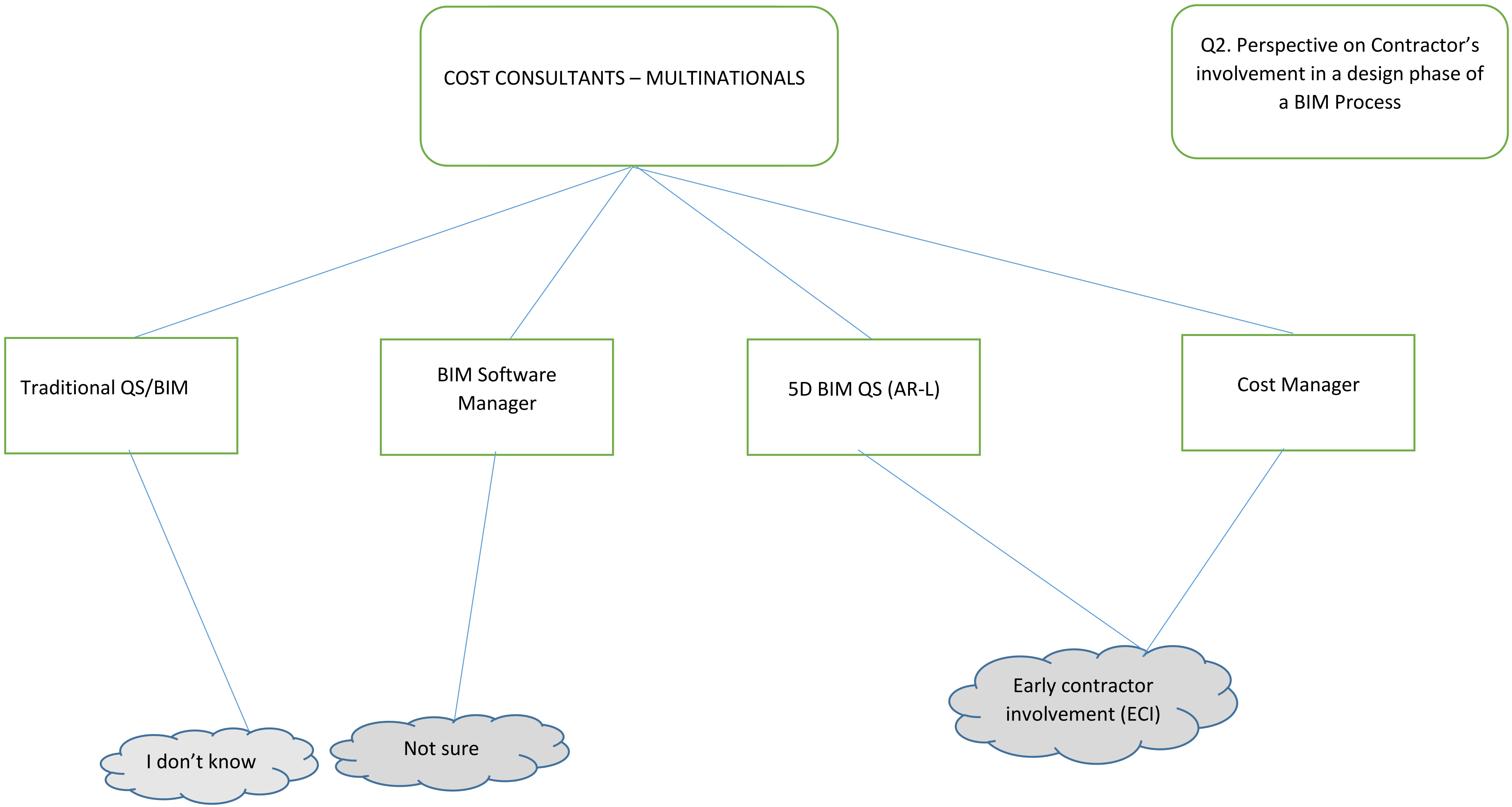

COST CONSULTANTS – SMEs
Q10b. The risks (negative or positive) relative to cost output while engaging BIM
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Lack of BIM education/Alteration of vital information by untrained users
Early supply chain involvement – accurate cost information
Loss of information intelligence/Misplacement of vital design information
Design errors (information errors)
Earlier cost certainty
Automation process

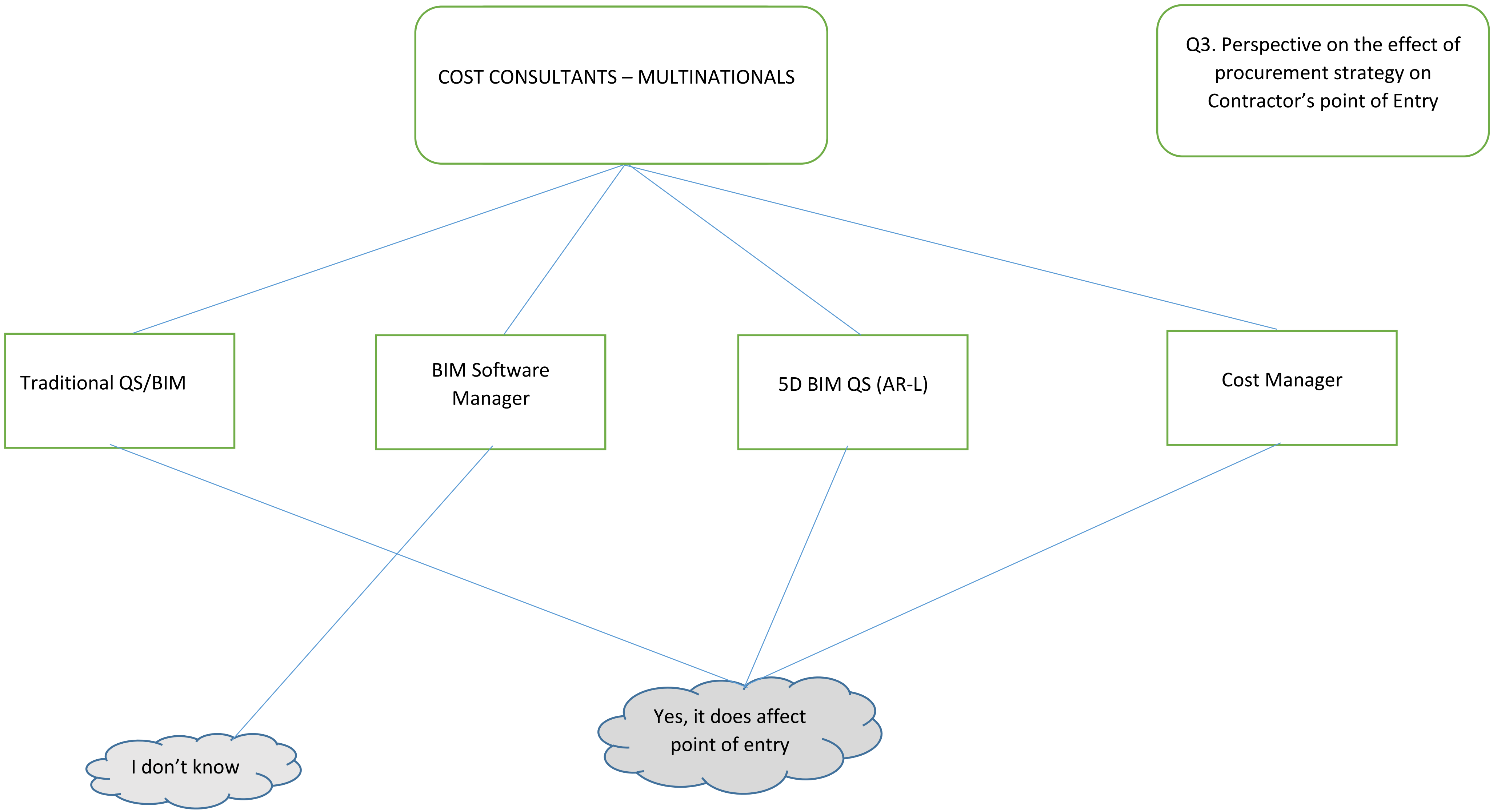

COST CONSULTANTS – SMEs
Q11a. Future direction of 5D BIM
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
Direct skilled labour involvement (eliminating the subcontractors)
Traditional procurement approach
Data capture and process efficiency
Scope increase due to lifecycle costing considerations
Correct design modelling of information
EIR/Whole project team involvement
Not sure

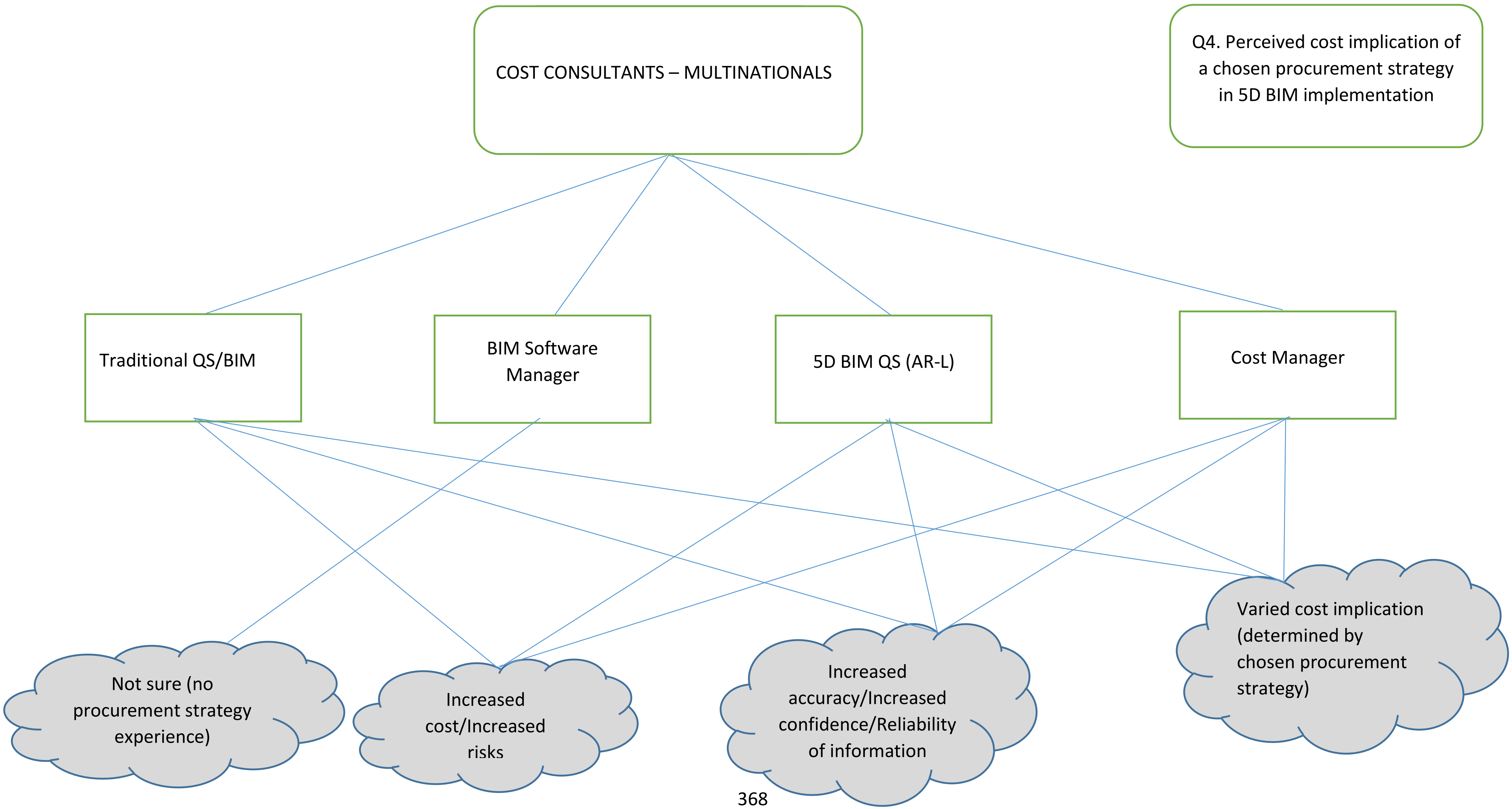

COST CONSULTANTS – SMEs
Q11b. Benefits of 5D BIM
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
No response
Automation of costing process/Faster & quicker/Technological improvement
Reliable and confident cost information/Accuracy in generating quantities/Better cost output
Streamlined process/Better design model interpretation/ Efficiency
Time savings/Better client advice

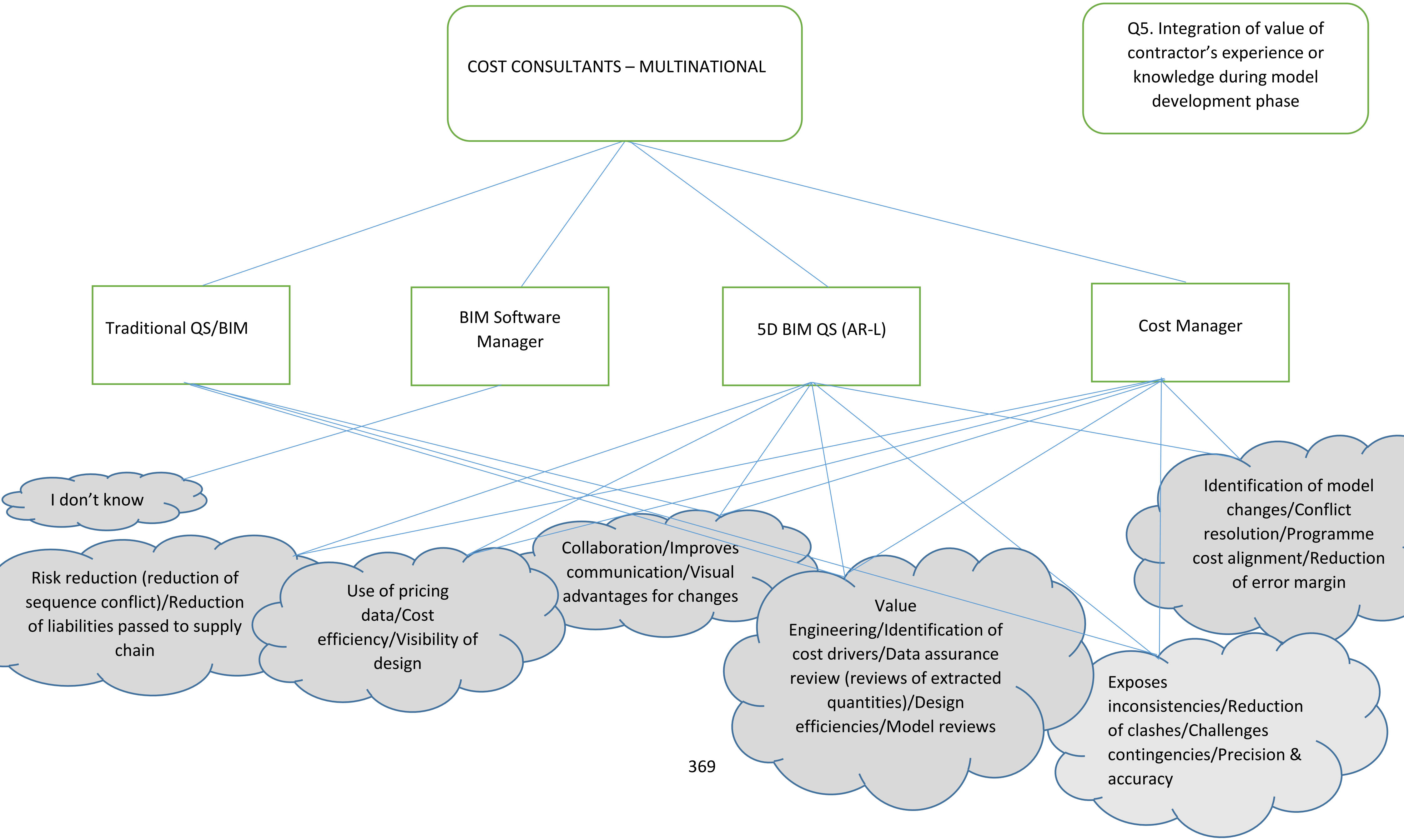

COST CONSULTANTS – SMEs
Q11c. Immediate and future challenges of 5D BIM
Traditional/5D BIM QS
5D BIM Information Manager
5D BIM QS
Graduate QS
No response
Down time – breaking through industry inertia
Immediate struggle – Inability of designers to design for QS proper model interpretation & Inability of the QS to understand and interpret design models accurately
Incorrect data/Design errors
Culture issues /Upskilling people (workers ability to engage with BIM tools)


COST CONSULTANTS – MULTINATIONALS
Q1. Background Experience
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
RICS Membership
Limited BIM experience
Experienced in BIM tools
Experienced in 3D/2D Model
Experienced in CAD
Experienced in 5D BIM Model

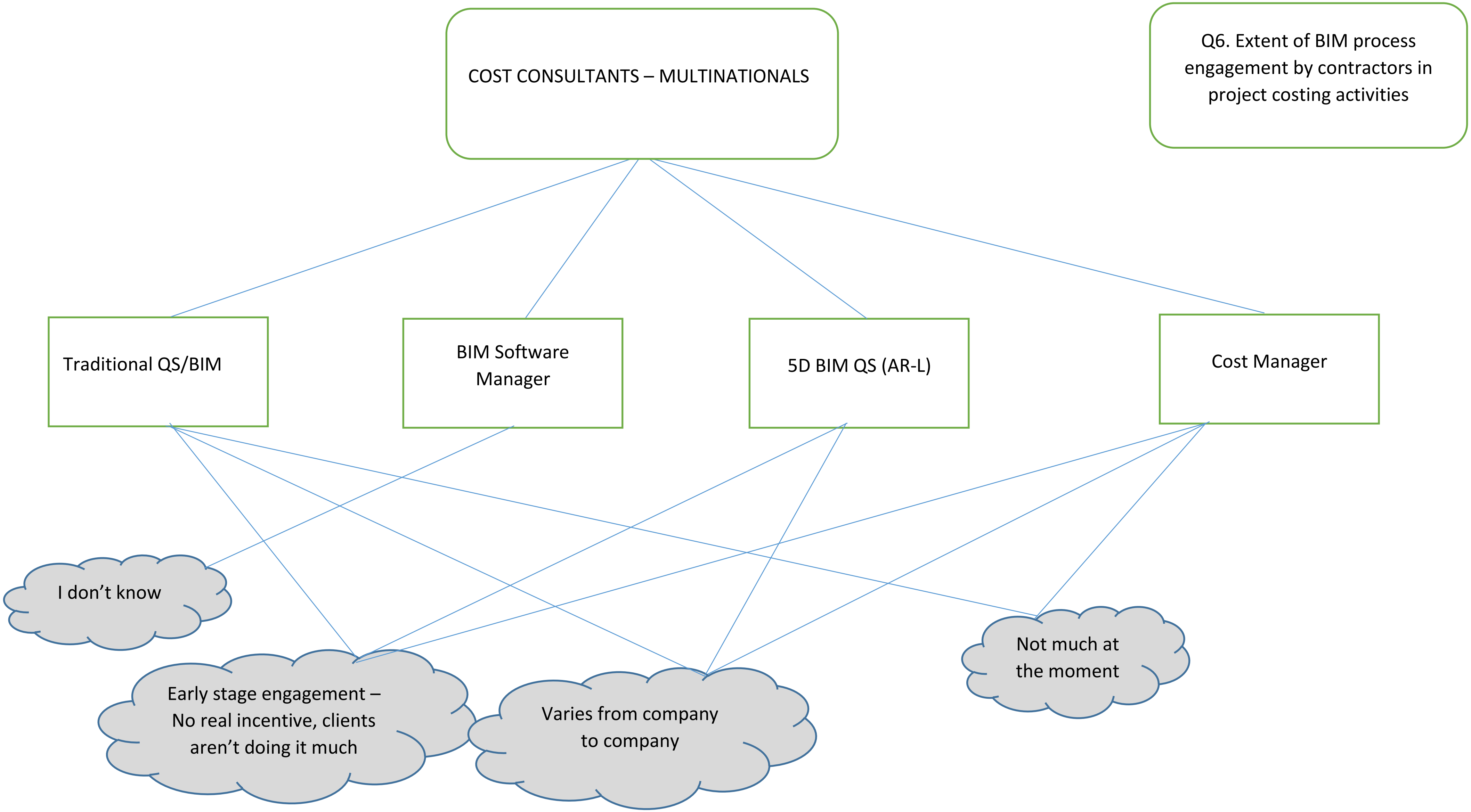

COST CONSULTANTS – MULTINATIONALS
Q2. Perspective on Contractor’s involvement in a design phase of a BIM Process
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
I don’t know
Not sure
Early contractor involvement (ECI)

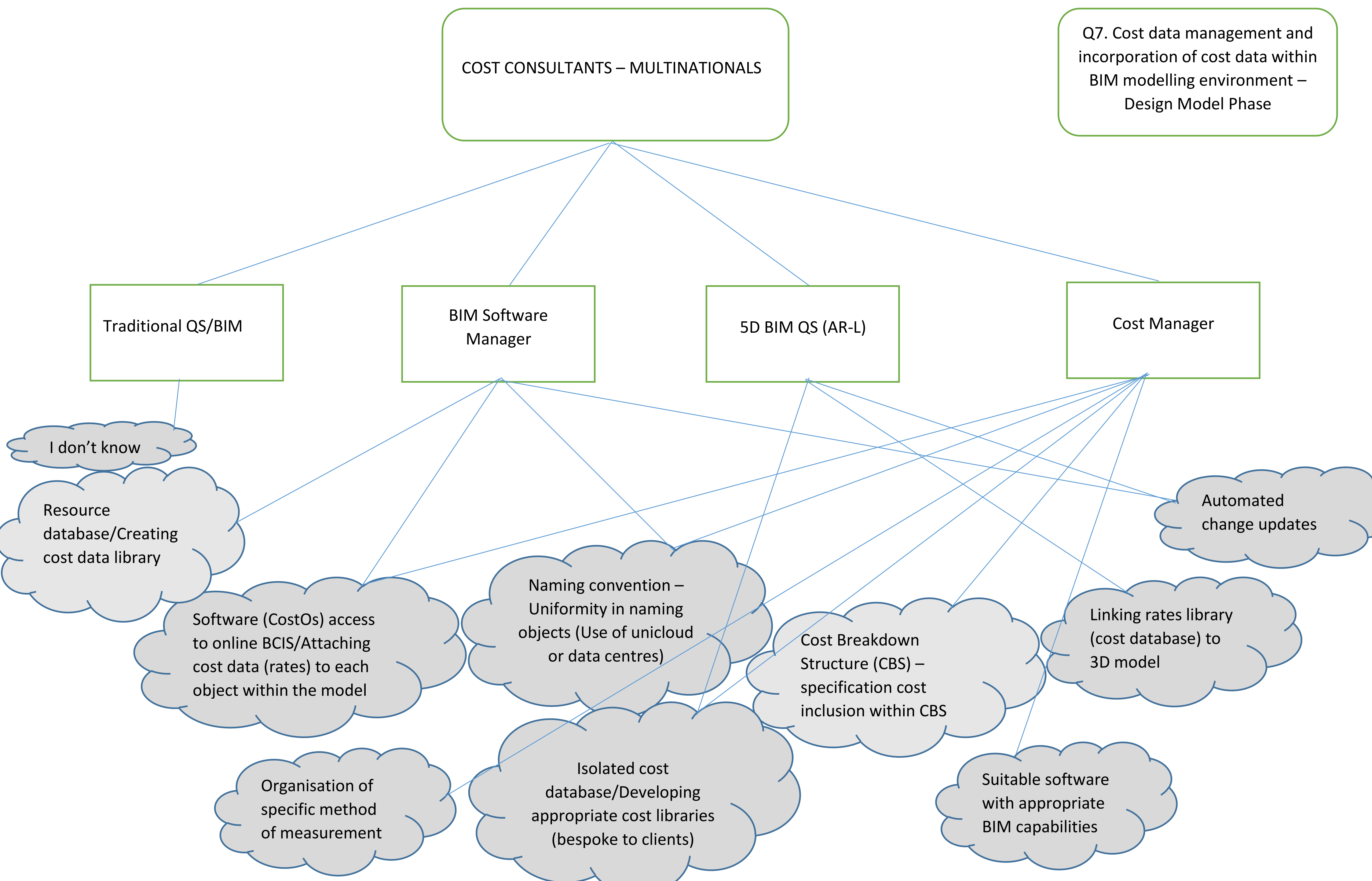

COST CONSULTANTS – MULTINATIONALS
Q3. Perspective on the effect of procurement strategy on Contractor's point of Entry
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
I don't know
Yes, it does affect point of entry


COST CONSULTANTS – MULTINATIONALS
Q4. Perceived cost implication of a chosen procurement strategy in 5D BIM implementation
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
Not sure (no procurement strategy experience)
Increased cost/Increased risks
Increased accuracy/Increased confidence/Reliability of information
Varied cost implication (determined by chosen procurement strategy)

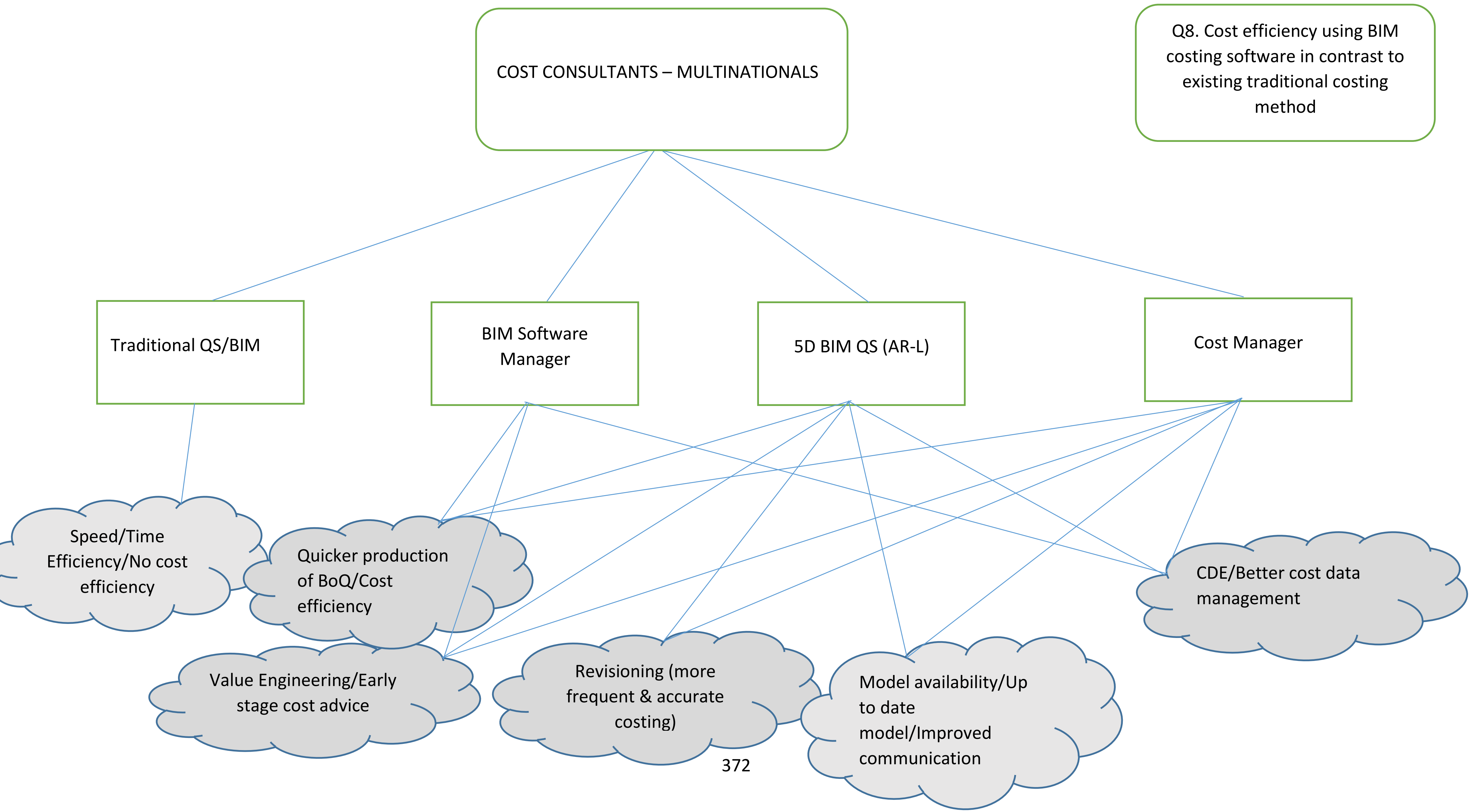


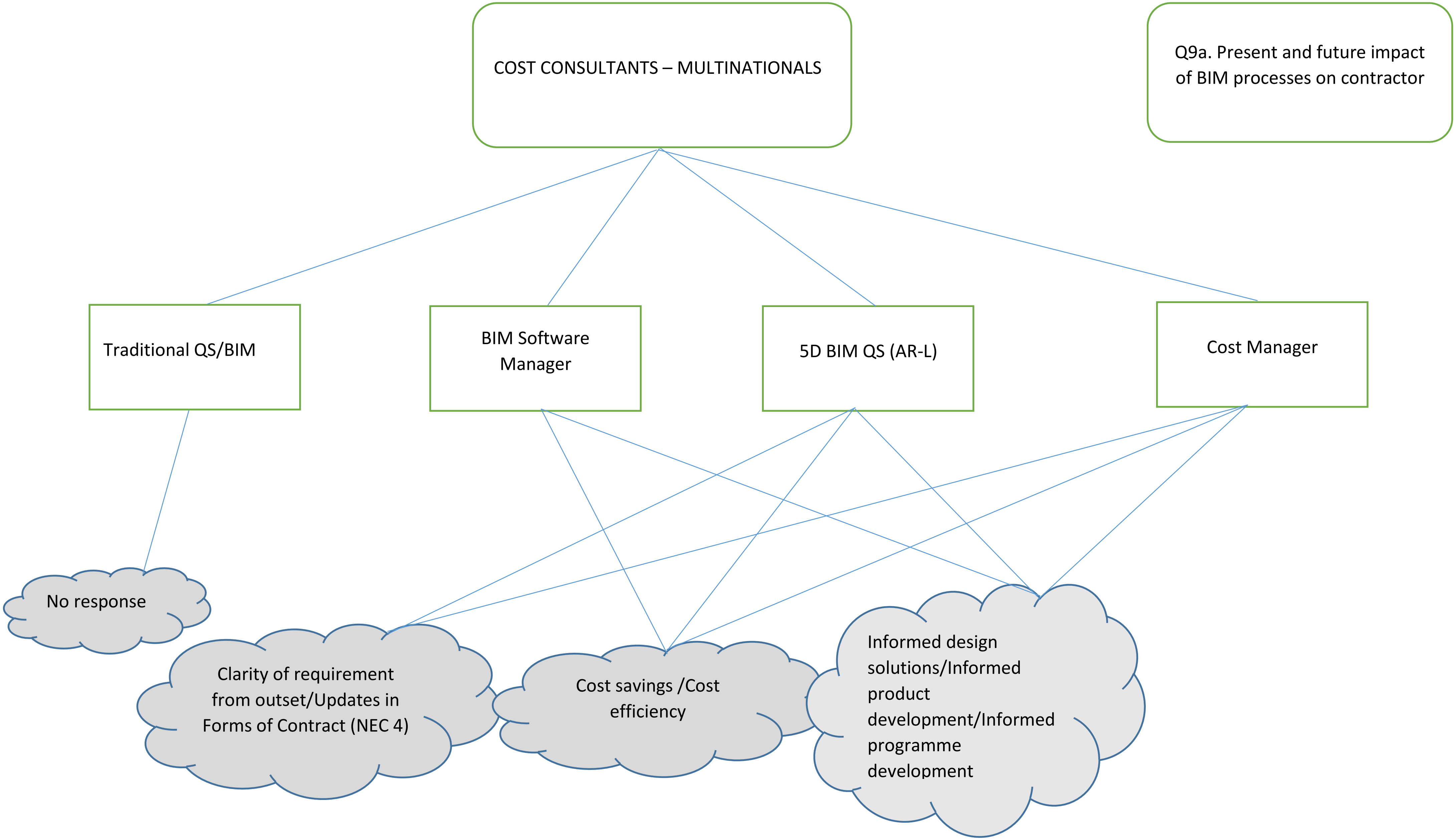
COST CONSULTANTS – MULTINATIONAL
Q5. Integration of value of contractor's experience or knowledge during model development phase
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
I don't know
Risk reduction (reduction of sequence conflict)/Reduction of liabilities passed to supply chain
Use of pricing data/Cost efficiency/Visibility of design
Collaboration/Improves communication/Visual advantages for changes
Value Engineering/Identification of cost drivers/Data assurance review (reviews of extracted quantities)/Design efficiencies/Model reviews
Identification of model changes/Conflict resolution/Programme cost alignment/Reduction of error margin
Exposes inconsistencies/Reduction of clashes/Challenges contingencies/Precision & accuracy

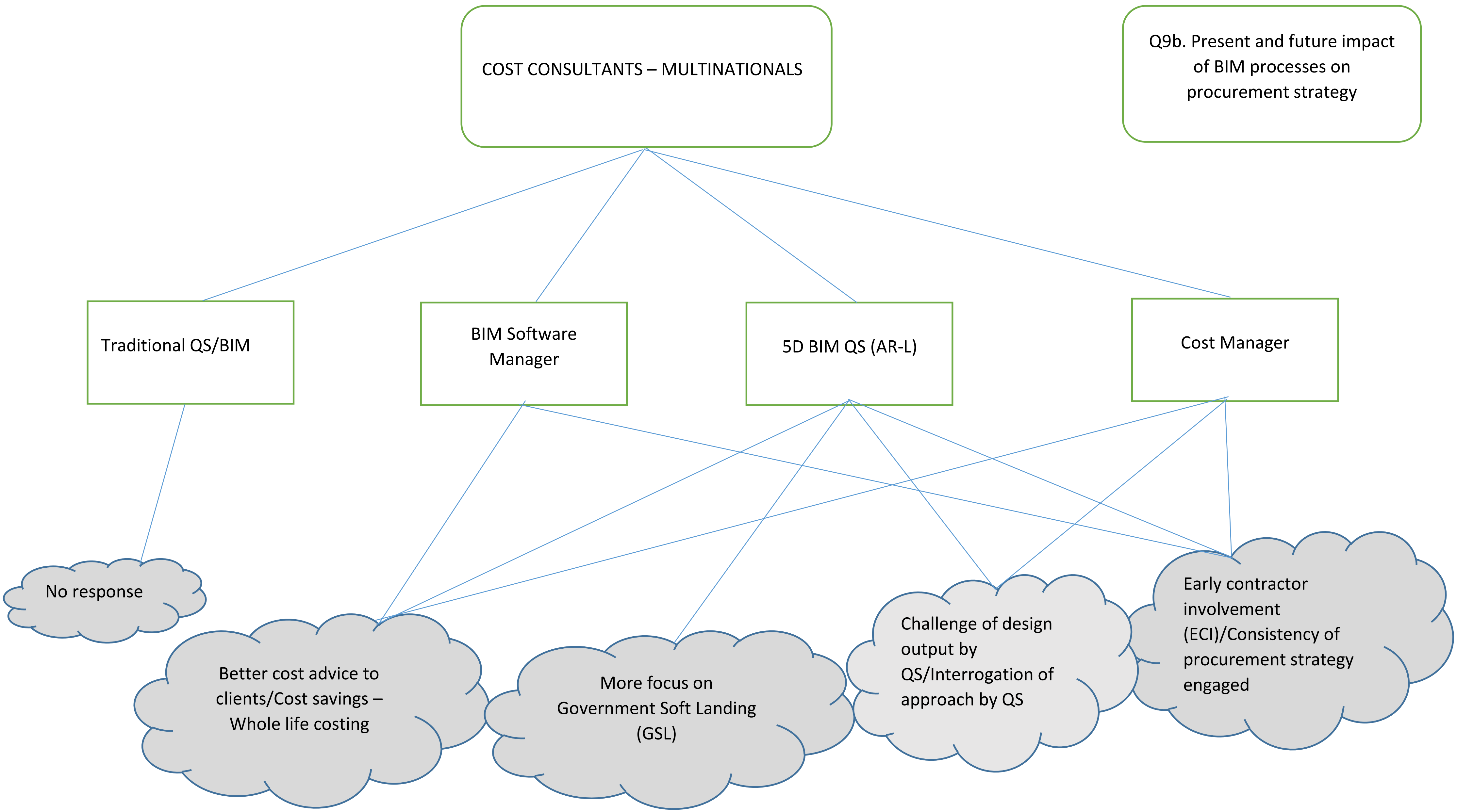

COST CONSULTANTS – MULTINATIONALS
Q6. Extent of BIM process engagement by contractors in project costing activities
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
I don't know
Early stage engagement – No real incentive, clients aren't doing it much
Varies from company to company
Not much at the moment

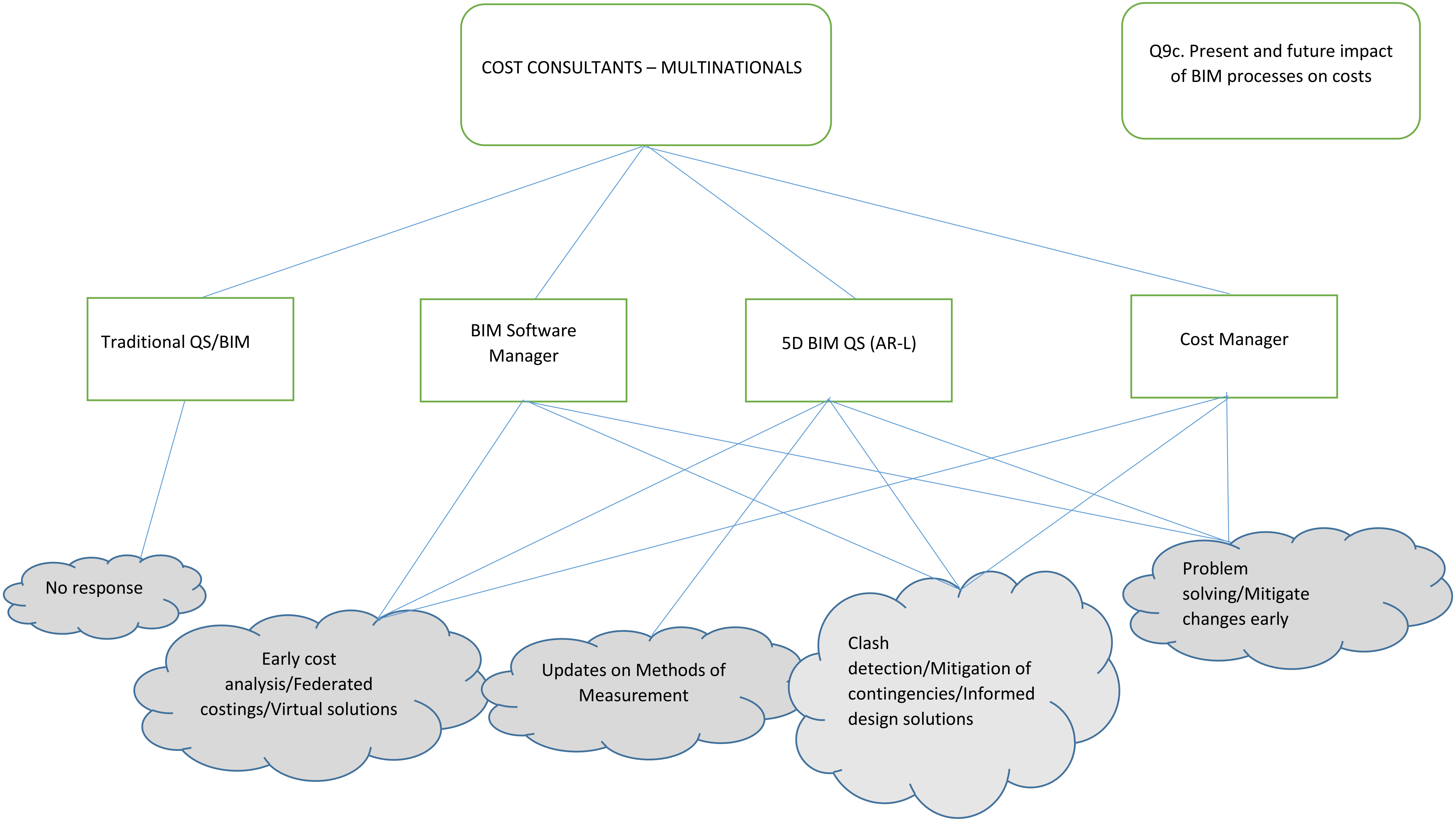


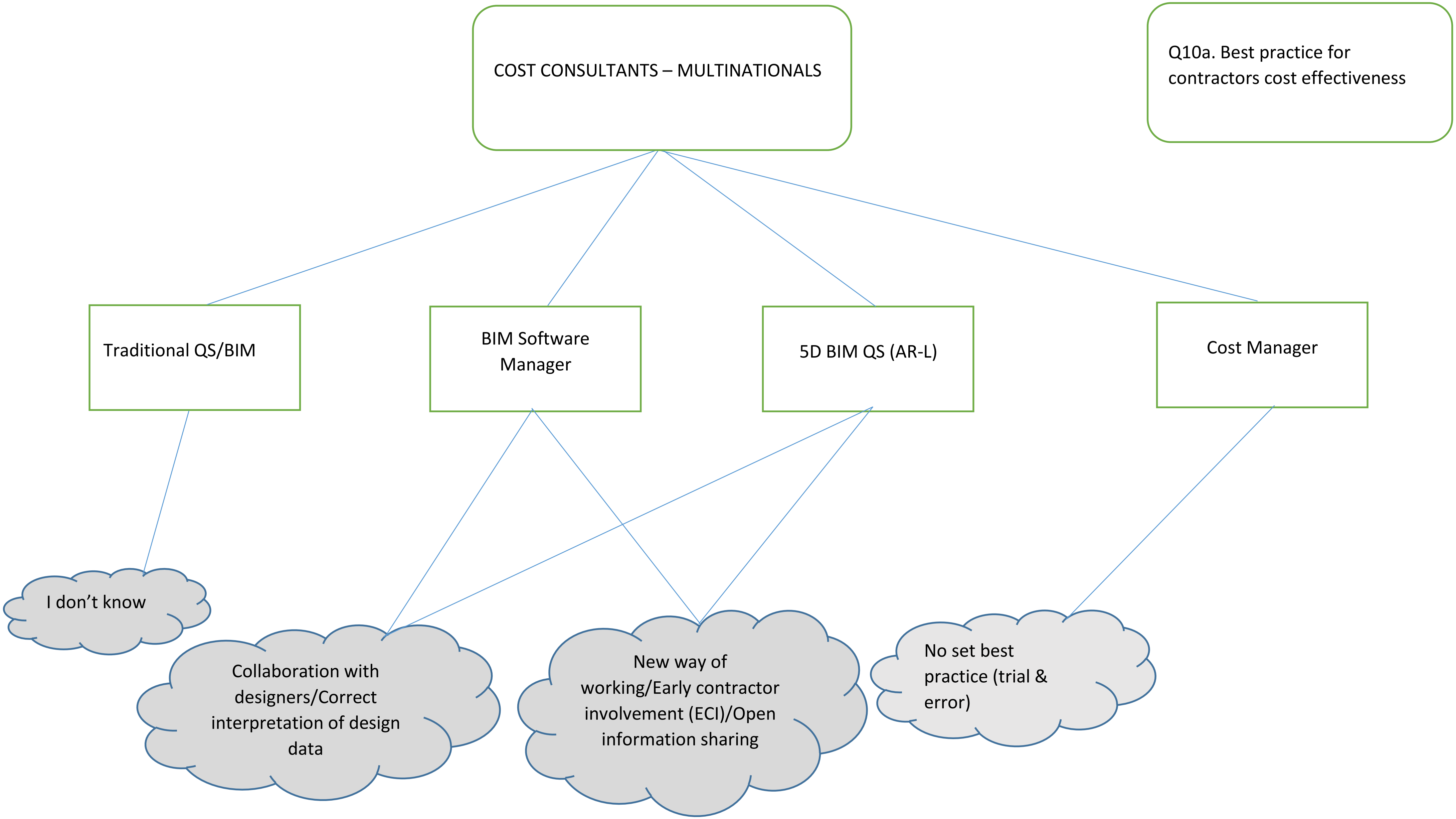
COST CONSULTANTS – MULTINATIONALS
Q7. Cost data management and incorporation of cost data within BIM modelling environment – Design Model Phase
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
I don't know
Resource database/Creating cost data library
Software (CostOs) access to online BCIS/Attaching cost data (rates) to each object within the model
Naming convention – Uniformity in naming objects (Use of unicloud or data centres)
Automated change updates
Linking rates library (cost database) to 3D model
Cost Breakdown Structure (CBS) – specification cost inclusion within CBS
Organisation of specific method of measurement
Isolated cost database/Developing appropriate cost libraries (bespoke to clients)
Suitable software with appropriate BIM capabilities


COST CONSULTANTS – MULTINATIONALS
Q8. Cost efficiency using BIM costing software in contrast to existing traditional costing method
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
Speed/Time Efficiency/No cost efficiency
Quicker production of BoQ/Cost efficiency
CDE/Better cost data management
Value Engineering/Early stage cost advice
Revisioning (more frequent & accurate costing)
Model availability/Up to date model/Improved communication

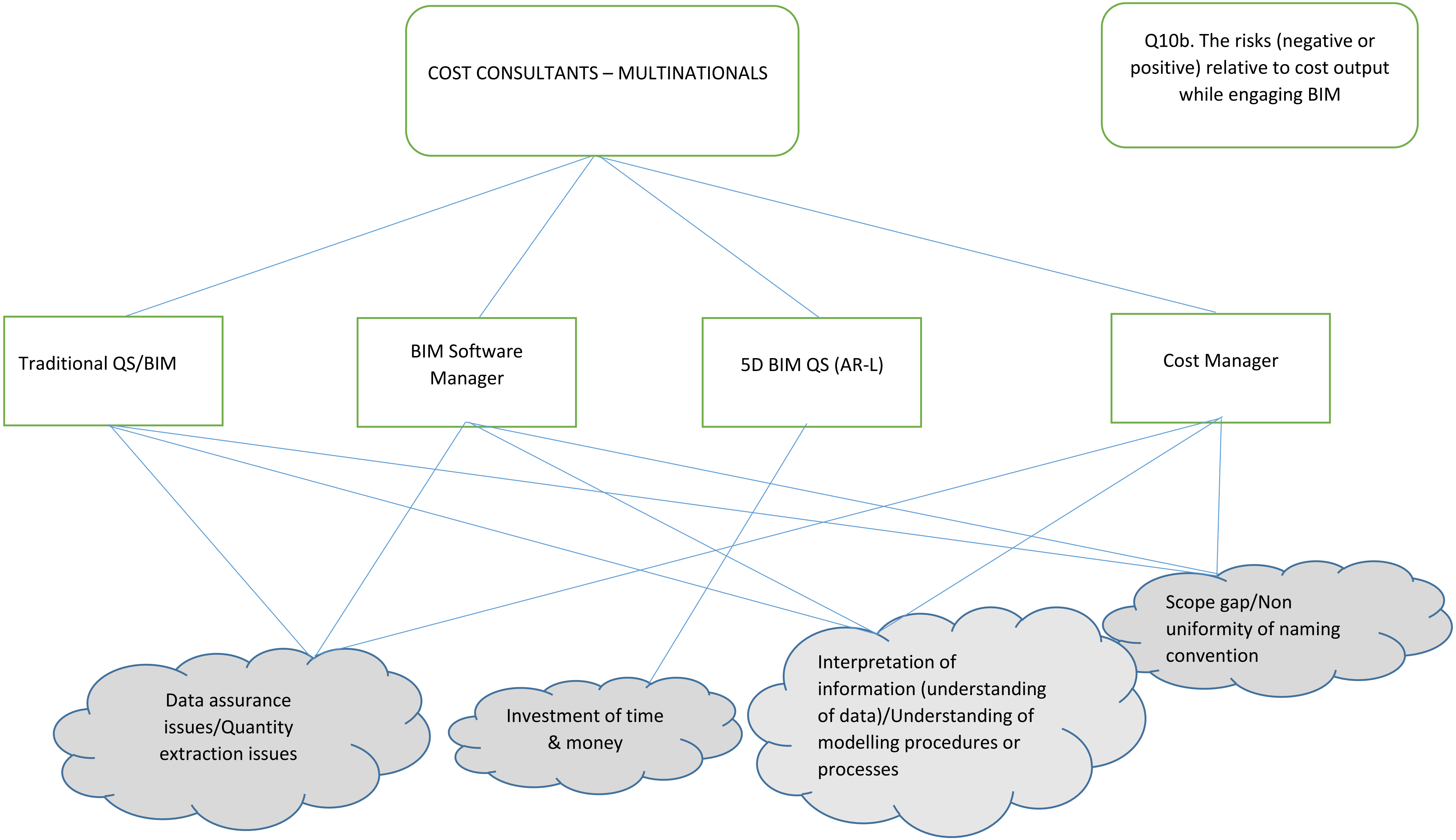

COST CONSULTANTS – MULTINATIONALS
Q9a. Present and future impact of BIM processes on contractor
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
No response
Clarity of requirement from outset/Updates in Forms of Contract (NEC 4)
Cost savings /Cost efficiency
Informed design solutions/Informed product development/Informed programme development

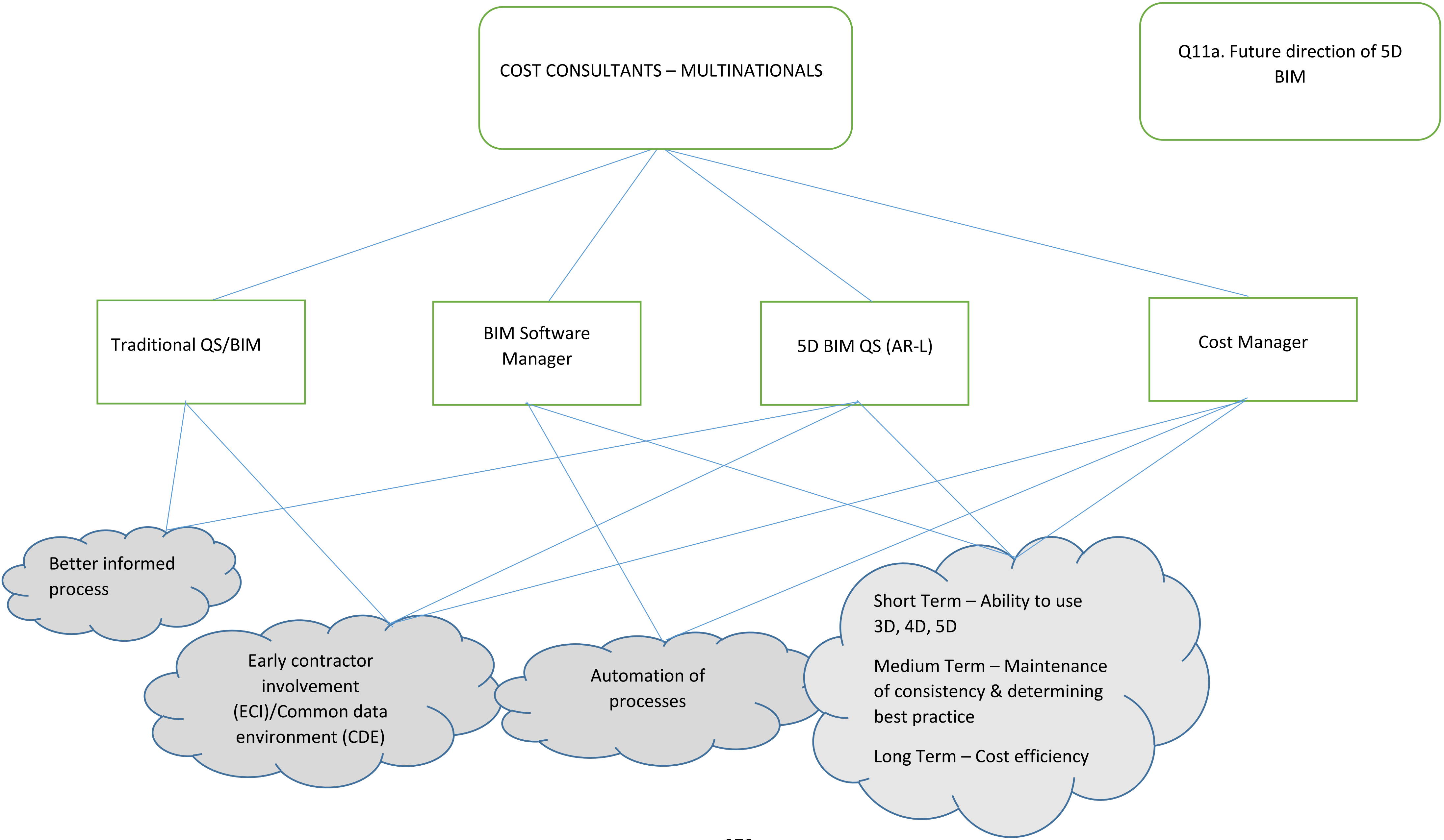

COST CONSULTANTS – MULTINATIONALS
Q9b. Present and future impact of BIM processes on procurement strategy
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
No response
Better cost advice to clients/Cost savings – Whole life costing
More focus on Government Soft Landing (GSL)
Challenge of design output by QS/Interrogation of approach by QS
Early contractor involvement (ECI)/Consistency of procurement strategy engaged


COST CONSULTANTS – MULTINATIONALS
Q9c. Present and future impact of BIM processes on costs
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
No response
Early cost analysis/Federated costings/Virtual solutions
Updates on Methods of Measurement
Clash detection/Mitigation of contingencies/Informed design solutions
Problem solving/Mitigate changes early

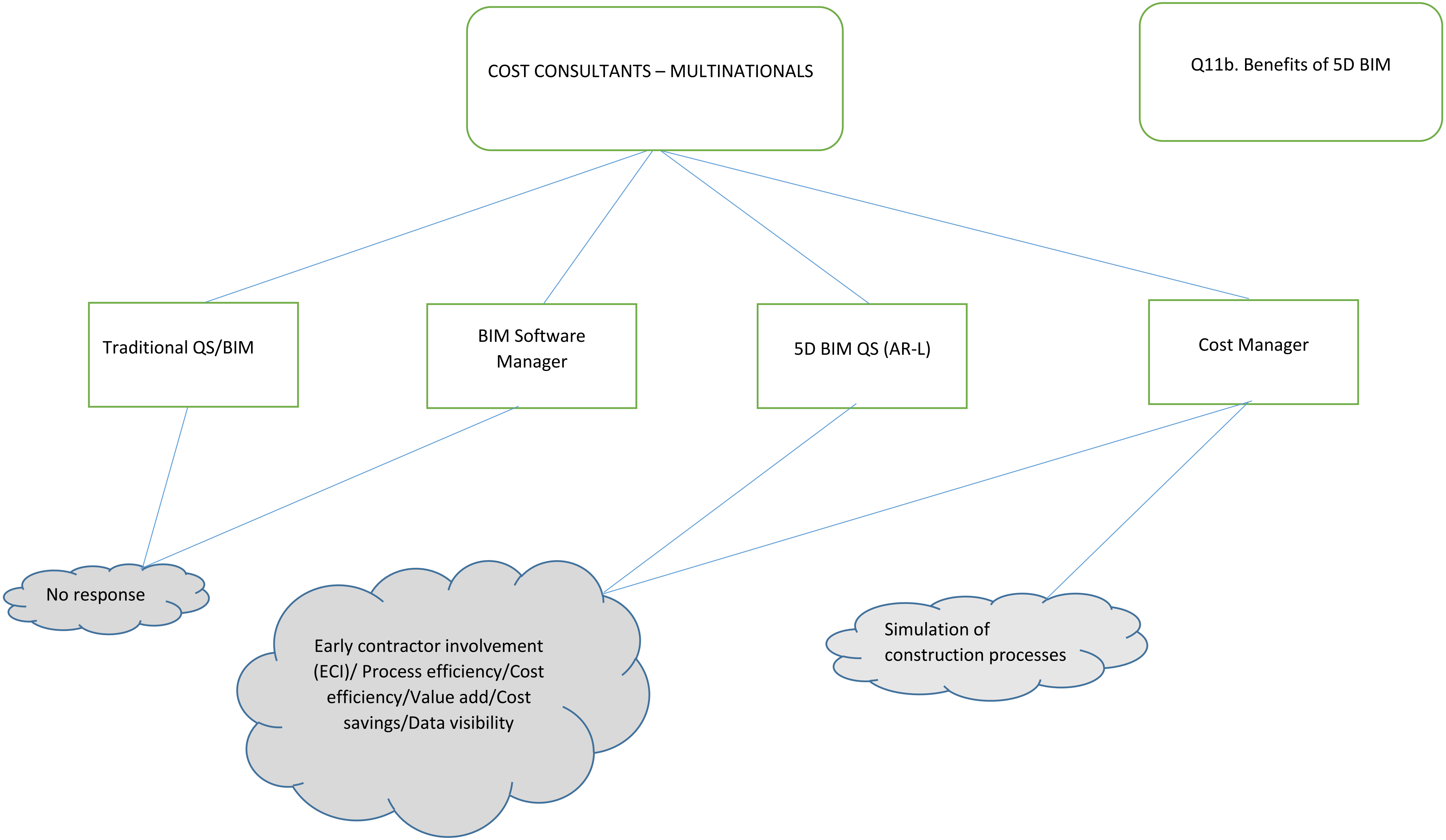


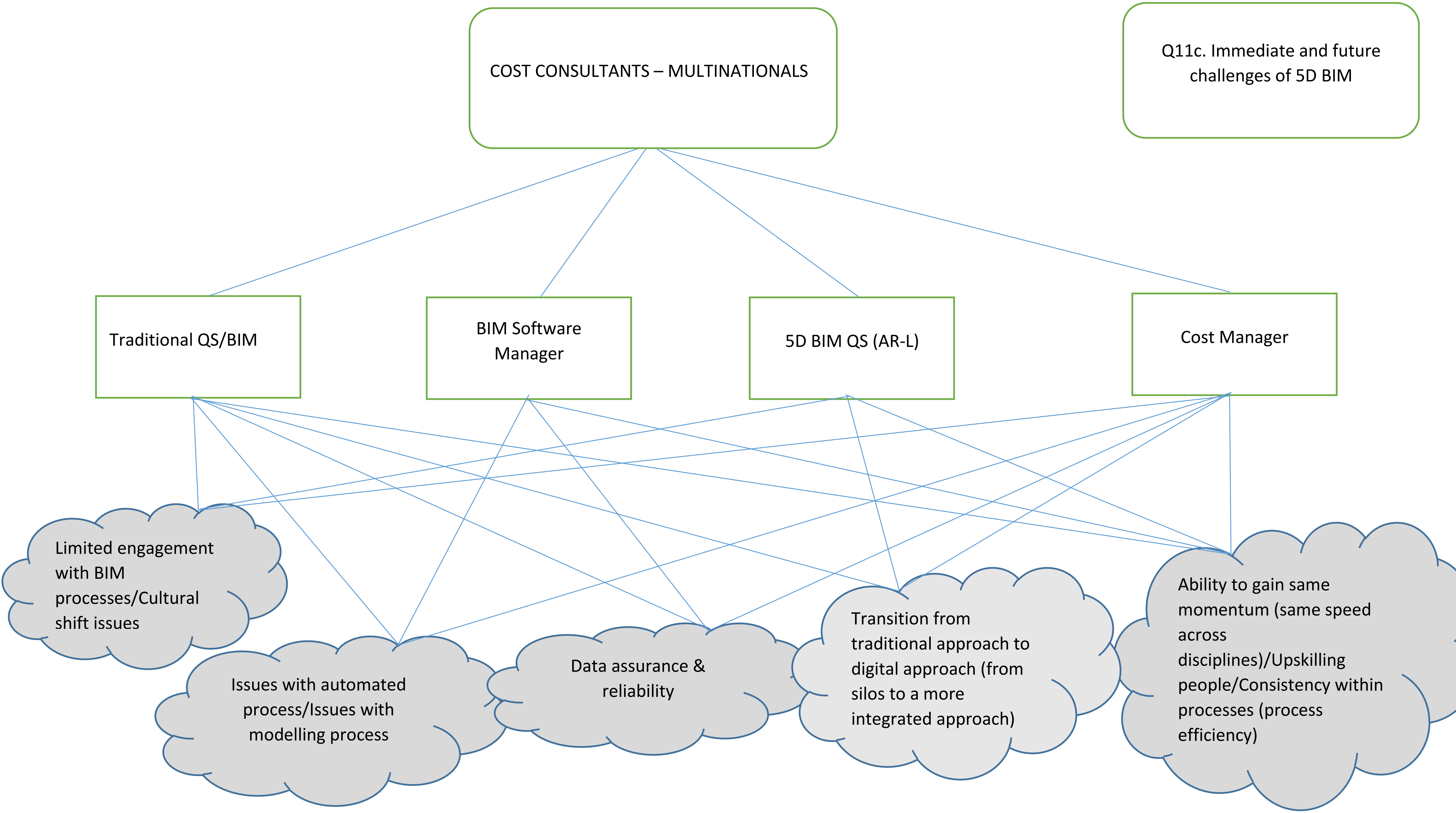
COST CONSULTANTS – MULTINATIONALS
Q10a. Best practice for contractors cost effectiveness
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
I don't know
Collaboration with designers/Correct interpretation of design data
New way of working/Early contractor involvement (ECI)/Open information sharing
No set best practice (trial & error)


COST CONSULTANTS – MULTINATIONALS
Q10b. The risks (negative or positive) relative to cost output while engaging BIM
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
Data assurance issues/Quantity extraction issues
Investment of time & money
Interpretation of information (understanding of data)/Understanding of modelling procedures or processes
Scope gap/Non uniformity of naming convention



COST CONSULTANTS – MULTINATIONALS
Q11a. Future direction of 5D BIM
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
Better informed process
Early contractor involvement (ECI)/Common data environment (CDE)
Automation of processes
Short Term – Ability to use 3D, 4D, 5D
Medium Term – Maintenance of consistency & determining best practice
Long Term – Cost efficiency


COST CONSULTANTS – MULTINATIONALS
Q11b. Benefits of 5D BIM
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
No response
Early contractor involvement (ECI)/ Process efficiency/Cost efficiency/Value add/Cost savings/Data visibility
Simulation of construction processes


COST CONSULTANTS – MULTINATIONALS
Q11c. Immediate and future challenges of 5D BIM
Traditional QS/BIM
BIM Software Manager
5D BIM QS (AR-L)
Cost Manager
Limited engagement with BIM processes/Cultural shift issues
Issues with automated process/Issues with modelling process
Data assurance & reliability
Transition from traditional approach to digital approach (from silos to a more integrated approach)
Ability to gain same momentum (same speed across disciplines)/Upskilling people/Consistency within processes (process efficiency)

APPENDIX B

Tabulated Data Analytical Process

Q1: Background Experience								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	RICS Membership			*			1	
	Experienced in BIM tools	*			*		2	
	Experienced/Limited experience in 5D	*			*		2	
	Experienced in 4D		*				1	
	Experienced in CAD	*	*	*	*	*	5	✓
	Experienced in 2D/3D	*	*	*	*	*	5	✓
	Limited BIM experience		*	*		*	3	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Experienced in BIM tools	*	*		2	
	Experienced in 5D	*	*		2	
	Experienced in CAD	*	*	*	3	✓
	Experienced in 2D/3D	*	*	*	3	✓
	Limited BIM experience			*	1	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Experienced in BIM tools	*	*	*	*	*	5	✓
	Experienced in 5D	*			*	*	3	
	Experienced in 4D				*	*	2	
	Experienced in CAD	*	*	*	*	*	5	✓
	Experienced in 2D/3D	*	*	*	*	*	5	✓
	Limited experience in 5D BIM		*	*			2	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Experienced in BIM tools		*	*		2	
	Experienced in 5D		*	*		2	
	Experienced in CAD	*	*	*	*	4	✓
	Experienced in 2D/3D	*	*	*	*	4	✓
	Limited BIM experience	*			*	2	

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	RICS Membership	*			*	2	
	Experienced in BIM tools		*	*	*	3	
	Experienced in 5D		*	*	*	3	
	Experienced in CAD	*	*	*	*	4	✓
	Experienced in 2D/3D	*	*	*	*	4	✓
	Limited BIM experience	*				1	

Q2: Perspective on Contractor's involvement in a design phase of a BIM Process

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolio					Theme Score	Highest Scoring theme
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	Early Contractor Involvement (ECI)	*	*	*	*		4	✓
	It varies – influenced by client's requirements	*				*	2	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Early Contractor Involvement (ECI)	*	*		2	
	It varies – influenced by client's requirements (chosen procurement strategy)	*	*	*	3	✓

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Early Contractor Involvement (ECI)	*	*	*	*	*	5	✓
	It varies – influenced by client's requirements/Project specific		*				1	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Partial Early contractor involvement (ECI)	*				1	
	Stage 3/4	*				1	
	Early contractor involvement (ECI)		*	*	*	3	✓

COST CONSULTANTS- Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	I don't know	*				1	
	Not sure	*				1	
	Early contractor Involvement (ECI)			*	*	2	✓

Q3: Perspective on the effect of procurement strategy on Contractor's point of Entry

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	Yes it does affect contractor's point of entry		*	*			2	✓
	Affects the contractor based on client's tender strategy					*	1	
	I don't know	*			*		2	✓

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Yes it does affect contractor's point of entry	*	*		2	✓
	Decides the contractor's behaviours as well	*			1	
	I don't know			*	1	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Yes it does affect contractor's point of entry	*	*	*	*	*	5	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Affects clients benefit as well		*			1	
	Yes it does affect point of entry (GQS comment– dependent on contractor's competency)	*	*	*	*	4	✓

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	I don't know		*			1	
	Yes, it does affect point of entry	*		*	*	3	✓

Q4: Perceived cost implication of a chosen procurement strategy in 5D BIM implementation								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	Good understanding of cost through early involvement		*		*		2	✓
	Cost transparency/accuracy of cost information		*		*		2	✓
	Standardization of costing process				*		1	
	Yes there is cost implication			*			1	
	Bespoke cost database		*				1	
	Cost differences depending on contractor's stage involvement					*	1	
	No Impact on cost	*					1	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Positive cost implications (Early access to supply chain, Buildability improvement, Cost optimization through improved use of BIM)	*	*		2	✓
	Negative cost implications (Use of traditional approach)	*	*		2	✓
	Short term initial investment (balances at the long term)		*		1	
	I don't know			*	1	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Interphase issues due to varied design details		*		*	*	3	✓
	Early detailed design (Massive changes)	*	*				2	
	Early detailed design (Rework)	*	*				2	
	Bespoke cost implication based on clients requirement			*	*	*	3	✓
	Delivery process changes			*	*	*	3	✓
	Misunderstanding of design between parties/Misunderstanding of design data by supply chain		*		*	*	3	✓
	Impact on ECI/Early decision making	*	*				2	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Design more upfront/More upfront fees		*			1	
	Varied cost implication –Cost efficiency, financial visibility, stricter valuation of variation estimates, contractors buildability analysis	*	*	*		3	✓
	Value Engineering (VE) to drag down construction cost	*	*	*		3	✓
	Cost Up – Design influence towards construction delivery		*			1	
	I don't know				*		
	Cost Down – Cost reduction, Avoidance of non-buildability, Avoidance of rework, Cost Analysis (Capex & Opex)	*	*	*		3	✓

COST CONSULTANTS- Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	Not sure (no procurement strategy experience)		*			1	
	Increased cost/Increased risks	*		*	*	3	✓
	Increased accuracy/Increased confidence/Reliability of information	*		*	*	3	✓
	Varied cost implication (determined by chosen procurement strategy)	*		*	*	3	✓

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	Mitigation of Contingencies	*		*			2	
	Conflict Resolution	*	*	*			3	✓
	Early Contractor Involvement	*	*				2	
	Quantification Information/Model for 4D		*				1	
	Informed decision/visual communication	*	*	*			3	✓
	Reduces assumptions with 2D drawings		*				1	
	Data reliability/Increased client confidence			*			1	
	Cost and Time Savings/Error Reduction	*		*			2	
	Non-Site modification of products or process			*			1	
	Risk resolution			*			1	
	Don't know					*	1	
	No it doesn't				*		1	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Optimization of design phase/Mitigation of Contingencies/Conflict resolution	*	*		2	✓
	Early Contractor Involvement/Collaboration	*	*		2	✓
	Optimization of construction programme/Shortens approval timescale	*	*		2	✓
	Good understanding of building & 3D model		*		1	
	Informed decision/visual communication (virtual world)	*	*		2	✓
	Improves communication	*	*		2	✓
	Data reliability/Increased client confidence & Trust	*			1	
	Cost and Time optimization/Error Reduction	*	*		2	✓
	Construction methodologies – evaluation of construction alternatives	*			1	
	Model interphase clarity	*			1	
	Don't know			*	1	

CLIENT ORGANISATION		Respondent's Portfolios						
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager	Theme Score	Highest Scoring theme(s)
	Mitigation of Contingencies/Reduction of errors passed to supply chain	*	*	*	*	*	5	✓
	Conflict Resolution			*	*	*	3	
	Clash detection/Efficiency	*					1	
	Data reliability/Transparency	*					1	
	High data confidence/Quality assurance of data/Control of data workflow/data integrity	*	*	*			3	
	Visibility of data/CDE/Uniformity of data/naming convention		*				1	
	Design reviews/Constructability	*		*			2	
	Stage visibility	*					1	
	Data drops to specific design gates/Reduces assumptions with 2D drawings		*				1	
	Incentivization				*	*	1	

	Cost & time benefits/Integration of project interphases	*			*	*	3	
	Streamlined way of working/Contractor driven processes as opposed to consultants driven processes	*			*	*	3	
	Risk Mgt/Design change impact - cost, risks, & schedule				*	*	2	
	Sharing of information/Communication improvement	*	*	*			3	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Risk reduction/Reduction of liabilities passed to supply chain		*	*	*	3	✓
	Collaboration/Improves communication/Visual advantages for changes		*	*	*	3	✓
	Exposes inconsistencies/Reduction of clashes/Precision & accuracy		*	*		2	
	Not sure	*				1	
	Better planning/Problem solving/Resolution of problematic interphases/information integration		*	*	*	3	✓

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	I don't know		*			1	
	Risk reduction (reduction of sequence conflict)/Reduction of liabilities passed to supply chain			*	*	2	
	Use of pricing data/Cost efficiency/Visibility of design			*	*	2	
	Collaboration/Improves communication/Visual advantages for changes	*		*	*	3	
	Value Engineering/Identification of cost drivers/Data assurance review (reviews of extracted quantities)/Design efficiencies/Model reviews	*		*	*	3	
	Exposes inconsistencies/Reduction of clashes/Challenges contingencies/Precision & accuracy	*		*	*	3	
	Identification of model changes/Conflict resolution/Programme cost alignment/Reduction of error margin			*	*	2	

Q6: Extent of BIM process engagement by contractors in project costing activities								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	BIM design coordination			*		*	2	✓
	Not used yet as a pricing tool			*			1	
	None				*		1	
	Identification of missing information					*	1	
	Mitigation of contingencies			*		*	2	✓
	Integration of Information within the model			*		*	2	✓
	I don't know	*	*				2	✓
	Visual communication/model understanding			*		*	2	✓

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Early stages of BIM engagement	*	*		2	✓
	Uniformity of data/High confidence in data			*	1	
	Greater reliability & availability of data			*	1	
	Real time updates			*	1	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	I don't know/none at the moment	*					1	
	Varies from contractor to contractor			*			1	
	Not as much				*	*	2	✓
	Early stages of engagement		*				1	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Early stage engagement – No real incentive, clients aren't doing it much		*	*		2	✓
	Tender/bidding stages		*			1	
	None yet	*			*	2	✓

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	I don't know		*			1	
	Early stage engagement – No real incentive, clients aren't doing it much	*		*	*	3	
	Varies from company to company	*		*	*	3	
	Not much at the moment	*			*	2	

Q7: Cost data management and incorporation of cost data within BIM modelling environment – Design Model Phase

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios						
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator	Theme Score	Highest Scoring theme(s)
	Automated quantification/accurate material quantification			*	*	*	3	✓
	Detection of cost changes and spotting of variations		*				1	
	Uniqueness of products makes it difficult to build up cost database	*					1	
	Interim applications			*			1	
	BIM will support cost data management				*	*	2	
	Cost restriction considerations					*	1	
	Linking cost data to the 3D model (on process				*	*	2	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Automated quantification/accurate material quantification	*	*		2	
	Training requirement for upskilling			*	1	
	Shrinking cost estimation bureaucracies/Time reduction/Increased speed			*	1	
	Cost efficiency	*	*	*	3	✓
	BIM will support cost data management		*	*	2	
	Traditional input for cost accuracy		*		1	
	Linking cost data to the 3D model (on process)	*	*		2	

CLIENT ORGANISATION		Respondent's Portfolios						
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager	Theme Score	Highest Scoring theme(s)
	Integrated managed platforms/Data interrogation			*			1	
	Cost breakdown structure		*				1	
	Common view of design & cost models			*	*	*	3	
	Keep graphical data as light as possible		*				1	
	Systems integration – Linkage and integration between systems/Users access CDE			*	*	*	3	
	Linking asset information within model to unit rate information			*	*	*	3	
	Data uniformity – unified industry agreement on data dictionary (CDE)/Users access to CDE			*	*	*	3	
	Use of single piece of software – adding cost schedules within a			*	*	*	3	

	software							
	Linking cost data to the 3D model (data library)/Component mapping to cost database	*	*	*	*	*	5	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	No dealings with cost data or rates library at the moment				*	1	
	Software (CostOs) access to online BCIS/Attaching cost data (rates) to each object within the model		*	*		2	
	Naming convention – Uniformity in naming objects		*			1	
	Work Breakdown Structure (WBS) – specification inclusion within WBS	*				1	
	Linking rates library to the model		*	*	*	3	✓
	Previous cost estimates & previous cost plans				*	1	

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	I don't know	*				1	
	Resource database/Creating cost data library		*			1	
	Software (CostOs) access to online BCIS/Attaching cost data (rates) to each object within the model		*		*	2	✓
	Organisation of specific method of measurement				*	1	
	Naming convention – Uniformity in naming objects (Use of unicloud or data centres)		*		*	2	✓
	Isolated cost database/Developing appropriate cost libraries (bespoke to clients)			*	*	2	✓
	Cost Breakdown Structure (CBS) – specification cost inclusion within CBS				*	1	
	Suitable software with appropriate BIM capabilities				*	1	
	Linking rates library (cost database) to 3D model			*		1	
	Automated change updates		*	*		2	✓

Q8: Cost efficiency using BIM costing software in contrast to existing traditional costing method								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	More accuracy and speed/quicker			*	*	*	3	✓
	I don't know		*				1	
	Cost efficiency/effectiveness			*		*	2	
	Information quality/less site clashes/less rework and errors			*			1	
	Easier to measure/Better coordination					*	1	
	Design influences cost based on design parameters used					*	1	
	Cost savings if used to full potential	*					1	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Cost efficiency	*	*		2	✓
	Accelerated process	*			1	
	High confidence		*		1	
	Time to fix cost related issues	*			1	
	Correct codification of quantities		*		1	
	Refining/modification of cost planning as data drop increases		*		1	
	I don't know			*	1	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Time savings/Cost loaded schedules	*			*	*	3	
	Bulk materials procurement/Elimination of resource smoothening				*	*	2	
	Visualisation		*	*			2	

	Elimination of manual works/waste			*			1	
	Linking programme schedules 4D into 5D using P6 & CostOs				*	*	2	
	Data reliability/Data assurance/Quicker data extraction of quantities information/Automation processes		*	*			2	
	Workflow efficiency/Cost efficiency/Cost accuracy/Rate & quantities accuracy	*	*	*	*	*	5	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Speed – when assessing altered layouts	*				1	
	Efficiency through digital building (Virtual construction)	*		*	*	3	
	Revisioning/Automated data drop notification	*	*	*	*	4	✓
	Accuracy – If clash detection is used at data drops	*		*	*	3	

	Increased cost certainty	*		*	*	3	
	Time savings/Quicker change updates				*	1	

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	Speed/Time Efficiency/No cost efficiency	*				1	
	Quicker production of BoQ/Cost efficiency		*	*	*	3	✓
	Value Engineering/Early stage cost advice		*	*	*	3	✓
	Revisioning (more frequent & accurate costing)			*	*	2	
	Model availability/Up to date model/Improved communication			*	*	2	
	CDE/Better cost data management		*	*	*	3	✓

Q9a: Present and future impact of BIM processes on contractor								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios						
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator	Theme Score	Highest Scoring theme(s)
	Accuracy of design information/detailed design provision showing attributes	*	*				2	✓
	Cost efficiency		*				1	
	Visual advantages/Reducing rework	*					1	
	Pricing accuracy/better project understanding			*			1	
	Model coordination/clash detection/sources of conflict	*					1	
	Good understanding of required work scope			*			1	
	Reduction of workforce			*			1	
	Comparative rate advantages/Better and quicker pricing processes			*	*		2	✓
	Reduced risks/less contingencies/less waste			*			1	
	I don't know					*	1	
	Efficient design solutions (Getting it right the first time)	*	*				2	✓

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Cost savings			*	1	
	Reduction in work force			*	1	
	Data accuracy			*	1	
	BIM literacy	*	*		2	✓

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Collaborative working/Information specification requirements/Better products		*		*	*	3	
	Change in working relations with the supply chain			*			1	
	Identification of design errors		*		*	*	3	
	Workflow efficiency/Cost efficiency/Cost accuracy/Rate & quantities accuracy	*	*		*	*	4	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5 D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Early involvement/Early information		*		*	2	✓
	Not sure			*		1	
	Cost efficiency/Better design awareness		*		*	2	✓
	I don't know	*				1	

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	No response	*				1	
	Clarity of requirement from outset/Updates in Forms of Contract (NEC 4)			*	*	2	
	Cost savings /Cost efficiency		*	*	*	3	✓
	Informed design solutions/Informed product development/Informed programme development		*	*	*	3	✓

Q9b: Present and future impact of BIM processes on procurement strategy								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios						
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator	Theme Score	Highest Scoring theme(s)
	Accuracy of design information/detailed design provision showing attributes	*	*				2	✓
	Cost efficiency		*				1	
	Visual advantages/Reducing rework	*					1	
	Pricing accuracy/better project understanding			*			1	
	Model coordination/clash detection/sources of conflict	*					1	
	Good understanding of required work scope			*			1	
	Reduction of workforce			*			1	
	Comparative rate advantages/Better and quicker pricing processes			*	*		2	✓
	Reduced risks/less contingencies/less waste			*			1	
	I don't know					*	1	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Engagement of various disciplines/Better quality projects	*		*	2	✓
	Innovation on procurement strategies	*	*		2	✓
	Early contractor involvement (D&B)	*	*		2	✓
	Less errors & Safety projects	*			1	
	Impact on cost	*		*	2	✓
	Cost savings/Better decision making	*		*	2	✓

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Reliability of data	*			*	*	3	
	BIM education				*	*	2	
	Change in procurement method			*			1	
	Accurate requirement specification (EIR)/Understanding of requirements	*	*		*	*	4	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	I don't know	*				1	
	Information reliability/ Information accuracy		*	*		2	✓
	Design & Build (D&B) will be affected			*		1	
	BIM Execution Plan		*	*		2	✓
	Client Value Awareness				*	1	

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	No response	*				1	
	Better cost advice to clients/Cost savings – Whole life costing		*	*	*	3	✓
	More focus on Government Soft Landing (GSL)			*		1	
	Challenge of design output by QS/Interrogation of approach by QS			*	*	2	
	Early contractor involvement (ECI)/Consistency of procurement strategy engaged		*	*	*	3	✓

Q9c: Present and future impact of BIM processes on costing activities								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios						
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator	Theme Score	Highest Scoring theme(s)
	Accuracy of design information/detailed design provision showing attributes	*	*				2	✓
	Cost efficiency		*				1	
	Visual advantages/Reducing rework	*					1	
	Pricing accuracy/better project understanding			*			1	
	Model coordination/clash detection/sources of conflict	*					1	
	Good understanding of required work scope			*			1	
	Reduction of workforce			*			1	
	Comparative rate advantages/Better and quicker pricing processes			*	*		2	✓
	Reduced risks/less contingencies/less waste			*			1	
	I don't know					*	1	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Cost & Programme reduction	*	*		2	
	Generation of cost data		*	*	2	
	Cost savings	*	*	*	3	
	Cost forecasting/Cash flow monitoring		*	*	2	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Cost savings	*		*	*	*	4	
	Payment culture change			*			1	
	Management of cost changes	*		*	*	*	4	
	Avoidance of rework		*				1	
	Mitigation of schedule slip				*	*	2	
	Improved productivity/Improved working relations (Client & Contractor, Contractor & supply chain)/Collaborative working	*	*	*	*	*	5	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	I don't know	*				1	
	Early cost information		*		*	2	✓
	Cost accuracy/Better managed budget		*		*	2	✓
	Not sure			*		1	
	Cost certainty		*		*	2	✓

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	No response	*				1	
	Early cost analysis/Federated costings/Virtual solutions		*	*	*	3	✓
	Updates on Methods of Measurement			*		1	
	Clash detection/Mitigation of contingencies/Informed design solutions		*	*	*	3	✓
	Problem solving/Mitigate changes early		*	*	*	3	✓

Q10a: Best practice for contractors cost effectiveness								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios						
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator	Theme Score	Highest Scoring theme(s)
	Autodesk based process	*					1	
	Investing money & time	*					1	
	Early career BIM engagement			*			1	
	More detailed/accurate design information with ability to influence cost outcomes		*			*	2	✓
	Full integration of project team in BIM processes/Better understanding of the entire process			*		*	2	✓
	Speeding up processes/design software to interrogate or talk to each other	*				*	2	✓
	Common Data Environment (CDE)/Efficient model design			*		*	2	✓

	Client involvement in D&B/Early engagement in BIM process/understanding BIM benefits			*		*	2	✓
	I don’t know				*		1	

MAIN CONTRACTOR		Respondent’s Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Quality of design		*	*	2	✓
	I don’t know	*			1	
	BIM Literacy or education			*	1	
	Uniformity of data/Correct process engagement from the outset		*	*	2	✓
	Cost database		*	*	2	✓

CLIENT ORGANISATION		Respondent's Portfolios						
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager	Theme Score	Highest Scoring theme(s)
	No response			*			1	
	Visualization/Uniformity of standards	*	*		*	*	4	✓
	Common Data Environment (CDE)/Trust	*	*		*	*	4	✓
	Targeting cost drivers/Putting cost certainties in place		*				1	
	Right information spec/Uniformity in design progression with all stakeholders/Collaborative pace working	*	*		*	*	4	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	No response	*				1	
	BIM Execution Plan – For designers, contractors & the supply chain		*	*	*	3	✓
	5D BIM Costing		*	*	*	3	✓
	Improved communication among project team		*	*	*	3	✓

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	I don't know	*				1	
	Collaboration with designers/Correct interpretation of design data		*	*		2	✓
	New way of working/Early contractor involvement (ECI)/Open information sharing		*	*		2	✓
	No set best practice (trial & error)				*	1	

Q10b: The risks (negative or positive) relative to cost output while engaging BIM								
SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	No risks	*					1	
	Buildability issues due to lack of site labour involvement			*			1	
	Cultural shift/lack of interest in BIM processes			*			1	
	I don't know				*		1	
	No response		*			*	2	✓

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Ineffective BIM use/Non exploitation of BIM real value	*	*	*	3	✓
	Culture change issues	*	*		2	
	Oversight on important information		*		1	
	Lack of interest in BIM	*	*	*	3	✓
	Over confidence on model information		*		1	
	Variation of costing approaches			*	1	
	Cost autonomy approaches			*	1	
	Increased error margin			*	1	

CLIENT ORGANISATION		Respondent's Portfolios						
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager	Theme Score	Highest Scoring theme(s)
	Translation of data – interpretation of data from different parties	*			*	*	3	✓
	Dependency of projects				*	*	2	
	People defaulting to standard way of working once problems arise				*	*	2	
	Data visibility & integrity across board/ Lack of trust within the project team	*			*	*	3	✓
	Inability to update submitted cost information with future model changes			*			1	
	Lack of data assurance – high dependency on software outputs		*				1	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Lack of BIM education/Alteration of vital information by untrained users	*	*	*	*	4	✓
	Early supply chain involvement – accurate cost information		*	*	*	3	
	Loss of information intelligence/Misplacement of vital design information	*	*	*	*	4	✓
	Design errors (information errors)	*	*	*	*	4	✓
	Earlier cost certainty		*		*	2	
	Automation process	*	*	*		3	

COST CONSULTANTS- Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	Data assurance issues/Quantity extraction issues	*	*		*	3	✓
	Investment of time & money			*		1	
	Interpretation of information (understanding of data)/Understanding of modelling procedures or processes	*	*		*	3	✓
	Scope gap/Non uniformity of naming convention	*	*		*	3	✓

Q11a: Future direction of 5D BIM

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	Not Certain	*					1	
	Transparency/Efficiency process improvement		*			*	2	✓
	Uniformity of cost database (Naming convention)/Standardization		*		*		2	✓
	BIM models and company specific software			*			1	
	Integration of cost data & 3D BIM model			*			1	
	WBS to support Digital quantification & Cost estimation		*		*		2	✓
	Accelerated processes					*	1	
	Creating database of elemental rates with links		*		*		2	✓
	Cost-Load BIM models			*			1	

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Emergence of BIM 'cost champions'/QSs with good BIM skills sets	*			1	
	Slow and painful process	*	*		2	✓
	Making 5D model a requirement	*	*		2	✓
	Cementing BIM Level 2 before Level 3		*		1	
	Don't know			*	1	

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Upskilling people/Value visibility of the BIM process	*					1	
	Integration of interphases	*		*			2	
	Automated integrated system	*		*			2	
	Common Data Environment (CDE)/Trust	*	*	*			3	✓
	Greater integration with the graphical information/schedules & better coordination				*	*	2	
	Consistency of LODs/LOIs & Consistency in requirements – cost and model development	*	*	*			3	✓

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	Direct skilled labour involvement (eliminating the subcontractors)	*				1	
	Traditional procurement approach	*				1	
	Data capture and process efficiency	*		*		2	✓
	Scope increase due to lifecycle costing considerations		*			1	
	Correct design modelling of information	*		*		2	✓
	EIR/Whole project team involvement	*		*		2	✓
	Not sure				*	1	

COST CONSULTANTS- Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	Better informed process	*		*		2	
	Early contractor involvement (ECI)/Common data environment (CDE)	*		*	*	3	✓
	Automation of processes		*		*	2	
	Short Term – Ability to use 3D, 4D, 5D Medium Term – Maintenance of consistency & determining best practice Long Term – Cost efficiency		*	*	*	3	✓

Q11b: Benefits of 5D BIM

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	No response	*	*	*	*	*	5	✓

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Services integration & coordination	*	*		2	✓
	Risk reduction/Improves design coordination	*	*		2	✓
	Expedites clients confidence & decision making/reduces timescale for approval	*			1	
	Efficiency – Cost & Time savings	*	*		2	✓
	Resource management and savings	*	*		2	✓
	Monitoring cash flow (aligning BIM models to timescale programme – 4D)	*			1	
	Sustainable industry/Managing design waste	*	*		2	✓
	Early contractor involvement	*	*		2	✓
	Construction change claims	*			1	
	I don't know			*	1	

CLIENT ORGANISATION		Respondent's Portfolios						
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager	Theme Score	Highest Scoring theme(s)
	Automated processes/Efficiency		*	*			2	
	Integration of interphases	*					1	
	Cost accuracy/Cost avoidance & savings	*					1	
	Common Data Environment (CDE)/Trust	*	*		*	*	4	✓
	Reduced time/cost/waste		*	*			2	
	Dependable processes & best practices/Working smarter				*	*	2	
	Supply chain integration, flexibility & innovation/Contractors and the supply chain driving innovation rather than consultants				*	*	2	

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	No response	*				1	
	Automation of costing process/Faster & quicker/Technological improvement		*	*	*	3	✓
	Reliable and confident cost information/Accuracy in generating quantities/Better cost output		*	*	*	3	✓
	Streamlined process/Better design model interpretation/ Efficiency		*	*	*	3	✓
	Time savings/Better client advice		*		*	2	

COST CONSULTANTS- Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	No response	*	*			2	✓
	Early contractor involvement (ECI)/ Process efficiency/Cost efficiency/Value add/Cost savings/Data visibility			*	*	2	✓
	Simulation of construction processes				*	1	

Q11c: Immediate and future challenges of 5D BIM

SUB CONTRACTORS/ FABRICATORS		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Design Manager	BIM Project Planner	Traditional QS	BIM Information Manager	Cost Estimator		
	Uniqueness of products/Rate variation based on the project type	*					1	
	Manual data input still needed (to interrogate model data)				*		1	
	No response		*	*		*	3	✓

MAIN CONTRACTOR		Respondent's Portfolios			Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Director	Head of BIM	Traditional QS		
	Cost software integration/Integrating BIM cost processes rather developing new ones	*			1	
	Lack of 5D BIM cost champions	*	*	*	3	✓
	Educating clients & workforce/Adopting new workflow	*	*	*	3	✓
	Lack of substantial BIM enforcement from the Government (Clients driving force needed)			*	1	
	Upskilling employees due to down time and price tag		*	*	2	
	Inability to use BIM across company departments due to infancy stage	*	*	*	3	✓

CLIENT ORGANISATION		Respondent's Portfolios					Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	BIM Systems Integrator and Support	Head of BIM	BIM Strategy Manager	BIM Programmes and Project Manager	BIM Integration Manager		
	Keeping information pool up to date			*				
	Cultural issues (shift)/isolated working	*	*	*	*	*	5	✓
	Lack of trust	*						
	Confidence towards process change - BIM				*	*		
	Consistent way of data structuring			*				

COST CONSULTANTS-SMEs		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional/5D BIM QS	5D BIM Information Manager	5D BIM QS	Graduate QS		
	No response	*				1	
	Immediate struggle – Inability of designers to design for QS proper model interpretation & Inability of the QS to understand and interpret design models accurately		*	*		2	✓
	Incorrect data/Design errors		*	*		2	✓
	Culture issues /Upskilling people (workers ability to engage with BIM tools)			*	*	2	✓
	Down time – breaking through industry inertia			*		1	

COST CONSULTANTS-Multinational		Respondent's Portfolios				Theme Score	Highest Scoring theme(s)
	Predominant Theme(s)	Traditional QS/BIM	BIM Software Manager	5D BIM QS (AR-L)	Cost Manager		
	Limited engagement with BIM processes/Cultural shift issues	*		*	*	3	
	Issues with automated process/Issues with modelling process	*	*		*	3	
	Data assurance & reliability	*	*		*	3	
	Transition from traditional approach to digital approach (from silos to a more integrated approach)	*		*	*	3	
	Ability to gain same momentum (same speed across disciplines)/Upskilling people/Consistency within processes (process efficiency)	*	*	*	*	4	✓

APPENDIX C

Industry Framework Evaluation

INDUSTRY FRAMEWORK EVALUATION QUESTIONS/COMMENTS

After conducting a qualitative interview with the Industry practitioners who had an experience with BIM projects or Level 2 BIM implementation; data transcription, analysis and interpretation of data followed. At the end of the research study, a framework has been developed with an intent to improve 5D BIM costing processes in a Contractor-Led Procurement project. The framework comprise three main themes as Strategic (Management), Operational (Process) and Technological (Technology) with sub-themes under each of the main themes.

The framework is proposing a concept that the Strategic Level (Management) of a contractor organisation would make strategic decisions based on the assessed needs, benefits and value add, the employees at the operational level (Process) would implement those decisions using appropriate technology (Technological Level), since BIM is about Management (people), Process and Technology.

Consider a typical Contractor-Led Procurement project (Contractor-Led Project Team), let us say a design and build procurement BIM project. The researcher would like to know how the attached framework for 'contractor costing using 5D BIM' to generate cost information on different work stages of a BIM project can support to facilitate the uptake of 5D BIM and BIM workflow within the UK construction industry. Secondly, the overall expected impact on industry practice looking at BIM projects in the UK construction industry.

The following closed-ended set of criteria questions will guide your responses and in the end the researcher would appreciate an overall comment regarding the framework and its impact to the UK construction industry if applied:

Tick as appropriate….

Questions	Yes	No
1. Will a decision for an Early Contractor Involvement (ECI) facilitate the uptake of 5D BIM in a BIM project? Yes/No	Yes	
2. Will a decision to work in a Common Data Environment (CDE) support the implementation of 5D BIM in a BIM project?	Yes	
3. Does an appropriate decided chosen procurement strategy support 5D BIM costing processes?	Yes	
4. Will a well-defined Employers Information Requirement (EIR) for collaborative working facilitate 5D BIM implementation?	Yes	
5. Can a decision for BIM literacy/trainings among employees at the operational level support 5D BIM costing processes?	Yes	
6. Does the contractor's BIM Execution Plan (BEP) help 5D BIM implementation processes?	Yes	
7. Will value engineering implemented at the operational level support to optimise 5D BIM outputs?	Yes	
8. Will design optimisation support 5D processes?	Yes	

9. Will input of reliable and accurate data into design BIM model facilitate the uptake of 5D BIM?	Yes	
10. Can integration of process information in various project stages support 5D BIM processes?	Yes	
11. Will working in a Common Data Environment at the operational level support 5D cost output?	Yes	
12. Will the resolution of cultural issues in contractor organisations support 5D BIM processes?	Yes	
13. Will using software tools for value engineering support 5D cost output?	Yes	
14. Will automated quantification using BIM tools facilitate the generation of accurate cost information?	Yes	
15. Can interoperability of file formats in a Common Data Environment support 5D BIM uptake?	Yes	
16. Will BIM design coordination help 5D process efficiency?	Yes	

Thank you so much for your participation in this research study.

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Tick as appropriate….

Questions	Yes	No
1. Will a decision for an Early Contractor Involvement (ECI) facilitate the uptake of 5D BIM in a BIM project? Yes/No	X	
2. Will a decision to work in a Common Data Environment (CDE) support the implementation of 5D BIM in a BIM project?	X	
3. Does an appropriate decided chosen procurement strategy support 5D BIM costing processes?	X	
4. Will a well-defined Employers Information Requirement (EIR) for collaborative working facilitate 5D BIM implementation?	X	
5. Can a decision for BIM literacy/trainings among employees at the operational level support 5D BIM costing processes?	X	
6. Does the contractor's BIM Execution Plan (BEP) help 5D BIM implementation processes?	X	
7. Will value engineering implemented at the operational level support to optimise 5D BIM outputs?	X	
8. Will design optimisation support 5D processes?		X

9. Will input of reliable and accurate data into design BIM model facilitate the uptake of 5D BIM?	X	
10. Can integration of process information in various project stages support 5D BIM processes?	X	
11. Will working in a Common Data Environment at the operational level support 5D cost output?	X	
12. Will the resolution of cultural issues in contractor organisations support 5D BIM processes?	X	
13. Will using software tools for value engineering support 5D cost output?	X	
14. Will automated quantification using BIM tools facilitate the generation of accurate cost information?	X	
15. Can interoperability of file formats in a Common Data Environment support 5D BIM uptake?	X	
16. Will BIM design coordination help 5D process efficiency?	X	

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The following closed-ended set of criteria questions will guide your responses and in the end the researcher would appreciate an overall comment regarding the framework and its impact to the UK construction industry if applied:

Tick as appropriate….

Questions	**Yes**	**No**
1. Will a decision for an Early Contractor Involvement (ECI) facilitate the uptake of 5D BIM in a BIM project? Yes/No	Yes	
2. Will a decision to work in a Common Data Environment (CDE) support the implementation of 5D BIM in a BIM project?	Yes	
3. Does an appropriate decided chosen procurement strategy support 5D BIM costing processes?	Yes	
4. Will a well-defined Employers Information Requirement (EIR) for collaborative working facilitate 5D BIM implementation?	Yes	
5. Can a decision for BIM literacy/trainings among employees at the operational level support 5D BIM costing processes?	Yes	
6. Does the contractor’s BIM Execution Plan (BEP) help 5D BIM implementation processes?	Yes	
7. Will value engineering implemented at the operational level support to optimise 5D BIM outputs?		No
8. Will design optimisation support 5D processes?	Yes	

9. Will input of reliable and accurate data into design BIM model facilitate the uptake of 5D BIM?	Yes	
10. Can integration of process information in various project stages support 5D BIM processes?	Yes	
11. Will working in a Common Data Environment at the operational level support 5D cost output?		No
12. Will the resolution of cultural issues in contractor organisations support 5D BIM processes?	Yes	
13. Will using software tools for value engineering support 5D cost output?	Yes	
14. Will automated quantification using BIM tools facilitate the generation of accurate cost information?	Yes	
15. Can interoperability of file formats in a Common Data Environment support 5D BIM uptake?	Yes	
16. Will BIM design coordination help 5D process efficiency?	Yes	

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The following closed-ended set of criteria questions will guide your responses and in the end the researcher would appreciate an overall comment regarding the framework and its impact to the UK construction industry if applied:

Tick as appropriate….

Questions	Yes	No
1. Will a decision for an Early Contractor Involvement (ECI) facilitate the uptake of 5D BIM in a BIM project? Yes/No	x	
2. Will a decision to work in a Common Data Environment (CDE) support the implementation of 5D BIM in a BIM project?	x	
3. Does an appropriate decided chosen procurement strategy support 5D BIM costing processes?	Unsure	
4. Will a well-defined Employers Information Requirement (EIR) for collaborative working facilitate 5D BIM implementation?		x
5. Can a decision for BIM literacy/trainings among employees at the operational level support 5D BIM costing processes?		x
6. Does the contractor’s BIM Execution Plan (BEP) help 5D BIM implementation processes?	x	
7. Will value engineering implemented at the operational level support to optimise 5D BIM outputs?	x	
8. Will design optimisation support 5D processes?	x	

9. Will input of reliable and accurate data into design BIM model facilitate the uptake of 5D BIM?	x	
10. Can integration of process information in various project stages support 5D BIM processes?	x	
11. Will working in a Common Data Environment at the operational level support 5D cost output?	Unsure	
12. Will the resolution of cultural issues in contractor organisations support 5D BIM processes?	x	
13. Will using software tools for value engineering support 5D cost output?	x	
14. Will automated quantification using BIM tools facilitate the generation of accurate cost information?	x	
15. Can interoperability of file formats in a Common Data Environment support 5D BIM uptake?	x	
16. Will BIM design coordination help 5D process efficiency?	Unsure	

Thank you so much for your participation in this research study.

APPENDIX D

Highest Scoring Themes from Data Analysis Table

HIGHEST SCORING THEMES FROM DATA ANALYSIS

- ✓ Early Contractor Involvement (ECI)
- ✓ It varies – influenced by client's requirements (chosen procurement strategy)
- ✓ Early Contractor Involvement (ECI)
- ✓ Yes it does affect contractor's point of entry
- ✓ Yes it does affect point of entry (GQS comment– dependent on contractor's competency)
- ✓ Good understanding of cost through early involvement
- ✓ Cost transparency/accuracy of cost information
- ✓ Positive cost implications (Early access to supply chain, Buildability improvement, Cost optimization through improved use of BIM)
- ✓ Negative cost implications (Use of traditional approach)
- ✓ Interphase issues due to varied design details
- ✓ Bespoke cost implication based on clients requirement
- ✓ Delivery process changes
- ✓ Misunderstanding of design between parties/Misunderstanding of design data by supply chain
- ✓ Varied cost implication –Cost efficiency, financial visibility, stricter valuation of variation estimates, contractors buildability analysis
- ✓ Value Engineering (VE) to drag down construction cost
- ✓ Cost Down – Cost reduction, Avoidance of non-buildability, Avoidance of rework, Cost Analysis (Capex & Opex)
- ✓ Increased cost/Increased risks
- ✓ Increased accuracy/Increased confidence/Reliability of information
- ✓ Varied cost implication (determined by chosen procurement strategy)
- ✓ Conflict Resolution
- ✓ Informed decision/visual communication
- ✓ Optimization of design phase/Mitigation of Contingencies/Conflict resolution
- ✓ Early Contractor Involvement/Collaboration
- ✓ Optimization of construction programme/Shortens approval timescale
- ✓ Informed decision/visual communication (virtual world)
- ✓ Improves communication
- ✓ Cost and Time optimization/Error Reduction
- ✓ Mitigation of Contingencies/Reduction of errors passed to supply chain

- ✓ Risk reduction/Reduction of liabilities passed to supply chain
- ✓ Collaboration/Improves communication/Visual advantages for changes
- ✓ Better planning/Problem solving/Resolution of problematic interphases/information integration
- ✓ Collaboration/Improves communication/Visual advantages for changes
- ✓ Value Engineering/Identification of cost drivers/Data assurance review (reviews of extracted quantities)/Design efficiencies/Model reviews
- ✓ Exposes inconsistencies/Reduction of clashes/Challenges contingencies/Precision & accuracy
- ✓ BIM design coordination
- ✓ Mitigation of contingencies
- ✓ Integration of Information within the model
- ✓ Visual communication/model understanding
- ✓ Early stages of BIM engagement
- ✓ None yet
- ✓ Early stage engagement – No real incentive, clients aren't doing it much
- ✓ Varies from company to company
- ✓ Automated quantification/accurate material quantification
- ✓ Cost efficiency
- ✓ Linking cost data to the 3D model (data library)/Component mapping to cost database
- ✓ Linking rates library to the model
- ✓ Software (CostOs) access to online BCIS/Attaching cost data (rates) to each object within the model
- ✓ Naming convention – Uniformity in naming objects (Use of unicloud or data centres)
- ✓ Isolated cost database/Developing appropriate cost libraries (bespoke to clients)
- ✓ Automated change updates
- ✓ More accuracy and speed/quicker
- ✓ Cost efficiency
- ✓ Workflow efficiency/Cost efficiency/Cost accuracy/Rate & quantities accuracy
- ✓ Revisioning/Automated data drop notification
- ✓ Quicker production of BoQ/Cost efficiency
- ✓ Value Engineering/Early stage cost advice
- ✓ CDE/Better cost data management
- ✓ Accuracy of design information/detailed design provision showing attributes

- ✓ Comparative rate advantages/Better and quicker pricing processes
- ✓ Efficient design solutions (Getting it right the first time)
- ✓ BIM literacy
- ✓ Workflow efficiency/Cost efficiency/Cost accuracy/Rate & quantities accuracy
- ✓ Early involvement/Early information
- ✓ Cost efficiency/Better design awareness
- ✓ Cost savings /Cost efficiency
- ✓ Informed design solutions/Informed product development/Informed programme development
- ✓ Accuracy of design information/detailed design provision showing attributes
- ✓ Comparative rate advantages/Better and quicker pricing processes
- ✓ Engagement of various disciplines/Better quality projects
- ✓ Innovation on procurement strategies
- ✓ Early contractor involvement (D&B)
- ✓ Impact on cost
- ✓ Cost savings/Better decision making
- ✓ Accurate requirement specification (EIR)/Understanding of requirements
- ✓ Information reliability/ Information accuracy
- ✓ BIM Execution Plan
- ✓ Better cost advice to clients/Cost savings – Whole life costing
- ✓ Early contractor involvement (ECI)/Consistency of procurement strategy engaged
- ✓ Accuracy of design information/detailed design provision showing attributes
- ✓ Comparative rate advantages/Better and quicker pricing processes
- ✓ Cost savings
- ✓ Improved productivity/Improved working relations (Client & Contractor, Contractor & supply chain)/Collaborative working
- ✓ Early cost information
- ✓ Cost accuracy/Better managed budget
- ✓ Cost certainty
- ✓ Early cost analysis/Federated costings/Virtual solutions
- ✓ Clash detection/Mitigation of contingencies/Informed design solutions
- ✓ Problem solving/Mitigate changes early
- ✓ More detailed/accurate design information with ability to influence cost outcomes

- ✓ Full integration of project team in BIM processes/Better understanding of the entire process
- ✓ Speeding up processes/design software to interrogate or talk to each other
- ✓ Common Data Environment (CDE)/Efficient model design
- ✓ Client involvement in D&B/Early engagement in BIM process/understanding BIM benefits
- ✓ Quality of design
- ✓ Uniformity of data/Correct process engagement from the outset
- ✓ Cost database
- ✓ Visualization/Uniformity of standards
- ✓ Common Data Environment (CDE)/Trust
- ✓ Right information spec/Uniformity in design progression with all stakeholders/Collaborative pace working
- ✓ BIM Execution Plan – For designers, contractors & the supply chain
- ✓ 5D BIM Costing
- ✓ Improved communication among project team
- ✓ Collaboration with designers/Correct interpretation of design data
- ✓ New way of working/Early contractor involvement (ECI)/Open information sharing
- ✓ Ineffective BIM use/Non exploitation of BIM real value
- ✓ Lack of interest in BIM
- ✓ Translation of data – interpretation of data from different parties
- ✓ Data visibility & integrity across board/ Lack of trust within the project team
- ✓ Lack of BIM education/Alteration of vital information by untrained users
- ✓ Loss of information intelligence/Misplacement of vital design information
- ✓ Design errors (information errors)
- ✓ Data assurance issues/Quantity extraction issues
- ✓ Interpretation of information (understanding of data)/Understanding of modelling procedures or processes
- ✓ Scope gap/Non uniformity of naming convention
- ✓ Transparency/Efficiency process improvement
- ✓ Uniformity of cost database (Naming convention)/Standardization
- ✓ WBS to support Digital quantification & Cost estimation
- ✓ Creating database of elemental rates with links
- ✓ Slow and painful process

- ✓ Making 5D model a requirement
- ✓ Common Data Environment (CDE)/Trust
- ✓ Consistency of LODs/LOIs & Consistency in requirements – cost and model development
- ✓ Data capture and process efficiency
- ✓ Correct design modelling of information
- ✓ EIR/Whole project team involvement
- ✓ Early contractor involvement (ECI)/Common data environment (CDE)
- ✓ Short Term – Ability to use 3D, 4D, 5D; Medium Term – Maintenance of consistency & determining best practice; Long Term – Cost efficiency
- ✓ Services integration & coordination
- ✓ Risk reduction/Improves design coordination
- ✓ Efficiency – Cost & Time savings
- ✓ Resource management and savings
- ✓ Sustainable industry/Managing design waste
- ✓ Early contractor involvement
- ✓ Common Data Environment (CDE)/Trust
- ✓ Automation of costing process/Faster & quicker/Technological improvement
- ✓ Reliable and confident cost information/Accuracy in generating quantities/Better cost output
- ✓ Streamlined process/Better design model interpretation/ Efficiency
- ✓ Early contractor involvement (ECI)/ Process efficiency/Cost efficiency/Value add/Cost savings/Data visibility
- ✓ Lack of 5D BIM cost champions
- ✓ Educating clients & workforce/Adopting new workflow
- ✓ Inability to use BIM across company departments due to infancy stage
- ✓ Cultural issues (shift)/isolated working
- ✓ Immediate struggle – Inability of designers to design for QS proper model interpretation & Inability of the QS to understand and interpret design models accurately
- ✓ Incorrect data/Design errors
- ✓ Culture issues /Upskilling people (workers ability to engage with BIM tools)
- ✓ Ability to gain same momentum (same speed across disciplines)/Upskilling people/Consistency within processes (process efficiency)

STRATEGIC (MANAGEMENT)	OPERATIONAL (PROCESS)	TECHNOLOGICAL (TECHNOLOGY)
Early contractor Involvement (ECI)	Early Involvement cost advice	Varied design details
Chosen Procurement Strategy	Cost Transparency/ Accuracy of Cost Information	Value Engineering
Early Involvement Cost Advice	Buildability Improvement and cost optimization	BIM design coordination
Cost optimization through improved use of BIM	Use of Traditional Approach	Visual communication
Client's requirement	Varied Design Details	Automated quantification
Delivery Process changes	Delivery Process changes	Linking rates library to the model
Visual advantages for design changes	Misunderstanding of design data	Linking cost data to design model- mapping components (elements) to cost database
Better planning	Cost efficiency-financial visibility	Software access to online BCIS attaching cost data (rates) to each object within model
Problem solving-early change mitigation	Valuation of variation estimates	Automated change updates
Collaboration	Value engineering	Revisioning / Automated data drop notification
Design efficiencies	Cost analysis (CAPEX and OPEX)	Common Data Environment (CDE)
Model reviews	Avoidance of rework (Waste reduction)	Process Efficiency
Data assurance review	Increased reliability of information	Services integration and coordination
Identification of cost drivers	Conflict resolution	Automation of costing process
BIM design coordination	Mitigation of contingencies	Technological improvement
Early stages of BIM engagement	Optimization of construction programmes	Upskilling workers to engage BIM tools
Naming convention - uniformity in naming objects	Communication improvement (visual)	Incorrect data input
Bespoke cost libraries	Error reduction /waste reduction	Interoperability
Timescale reduction (speed/quicker)	Risk reduction /reduction of liabilities	LOD/LOI/ Data drops
CDE/ cost data management	Resolution of problematic interphases	
Efficient Design Solutions	Integration of information (Process info)	
BIM literacy/lack of BIM	Clash detection/exposure of	

Education	inconsistencies	
Engagement of separate disciplines	Challenges contingencies	
Innovation of procurement strategies	Data precision	
Employers Information Requirement (EIR) - Information specification	Linking cost data to design model-mapping components (elements) to cost database	
BIM Execution Plan	Developing appropriate cost libraries (Bespoke to clients)	
Whole Life Costing	Rate and quantities accuracy (Quicker production)	
Early Cost Information	Work efficiency	
Early cost analysis/ Federated costings / virtual solutions	Accuracy of design information/ Detailed design provision	
Integration of Project team in BIM process	Comparative rate advantages / Better and quicker pricing processes	
Design software to talk to each other (interoperability)	Efficient design solution	
Common data environment (CDE) / Efficient design model	Better design awareness	
Client Involvement in D & B	Cost savings	
Early Engagement in BIM processes	Informed design solutions/ Informed product development/ Informed programme development	
Quality of design	Detailed design and accuracy of design information	
Understanding of BIM benefits	Better decision making	
Uniformity of data/correct process engagement	Information Reliability and accuracy	
Cost Database	Improved productivity/ working relations	
Uniformity of standards	Cost accuracy/managed budget	
Right Information specification	Cost certainty	
5D BIM costing	Design information with ability to influence cost outcomes	
Open Information sharing	Trust /CDE	
Process Efficiency/ Transparency of process	Correct interpretation of design data	

Standardization of naming convention	Ineffective BIM use/ Lack of BIM interest	
Uniformity of cost database	Translation of data accurate data interpretation	
Creating database of elemental rates with links	Data visibility of Data Integrity (Data assurance issues)	
Making 5D model a requirement	Alteration of vital data by untrained users	
Resource management and savings	Loss of information intelligence/misplacement of vital design information	
Sustainability/managing design waste	Design errors (input errors) /incorrect data	
Faster/ quicker process	Quantity extraction issues/ data assurance issues	
Streamlined process/ Better design model Interpretation	Data interpretation / understanding of modelling processes	
Value add	Scope gap/ non-uniformity of naming convention	
Lack of 5D BIM cost champions	Transparency of Processes	
Educating clients and workforce/ Adopting new workflow	WBS to support Digital quantification and cost estimation	
Cultural issues	Consistency in LODs/LOIs	
Inability to use BIM across company departments due to infancy stage	Data capture and Process efficiency	
Upskilling workers to engage BIM tools	Design Coordination	
	Managing Design waste	
	Data visibility	
	Cultural issues/isolated working	
	Inability of designers to design for QS model interpretation/inability of the QS to interpret design models accurately	
	Ability to gain same momentum across disciplines in BIM use	

STRATEGIC (MANAGEMENT)	OPERATIONAL (PROCESS)	TECHNOLOGICAL (TECHNOLOGY)
Early contractor Involvement (ECI)	Buildability Improvement	Value Engineering
Chosen Procurement Strategy	Data Accuracy/ Transparency	Automated Quantification
Employers Information Requirement (EIR)	Varied design details- LOD/LOI	Common Data Environment (CDE)
Visual communication of Design Process	Cost Efficiency	Process Efficiency (BIM design coordination)
Collaboration	Value Engineering	Interoperability
Cost Optimization -Whole life Cost	Waste Reduction	LOD/LOI/ Data Drops
BIM Design Coordination	Design Optimization	
Agreed Naming Convention	Informed decision/ visual communication	
Common Data Environment (CDE)	Integration of process information	
Efficient Design Solutions	Clash detection	
BIM Literacy	Challenges contingencies	
BIM Design Solutions	Linking cost data to design model	
BIM Literacy	Process efficiency (workflow)	
BIM Execution Plan (BEP)	Informed Product development and Programme development (Design team and QS)	
Interoperability	Cost certainty	
Uniformity of Data/ Standards	Improved Productivity/ working relations	
Uniformity of cost database	Accurate Integration of design data	
Streamlined Process-value add	Lack of BIM interest	
Cultural Issues	Alteration of vital data by untrained users	
	Loss of information intelligence	
	Misplacement of vital design information	
	Scope gap/ non-uniformity of naming convention	
	WBS to support automated digital quantification and cost estimation	
	Design coordination	
	Cultural issues/isolated working	

	Gaining same momentum across company disciplines in BIM use	

STRATEGIC (MANAGEMENT)	**OPERATIONAL (PROCESS)**	**TECHNOLOGICAL (TECHNOLOGY)**
Early contractor Involvement (ECI)	Value Engineering	Value Engineering
Chosen Procurement Strategy	Design Optimization	Automated Quantification
Employers Information Requirement (EIR)	Data Reliability, accuracy and integrity	Common Data Environment (CDE)
BIM Literacy	Integration of process information	Process Design Coordination – Process Efficiency
BIM Execution Plan (BEP)	Common Data Environment (CDE)	
Common Data Environment (CDE)	Cultural issues - Isolated working	

APPENDIX E

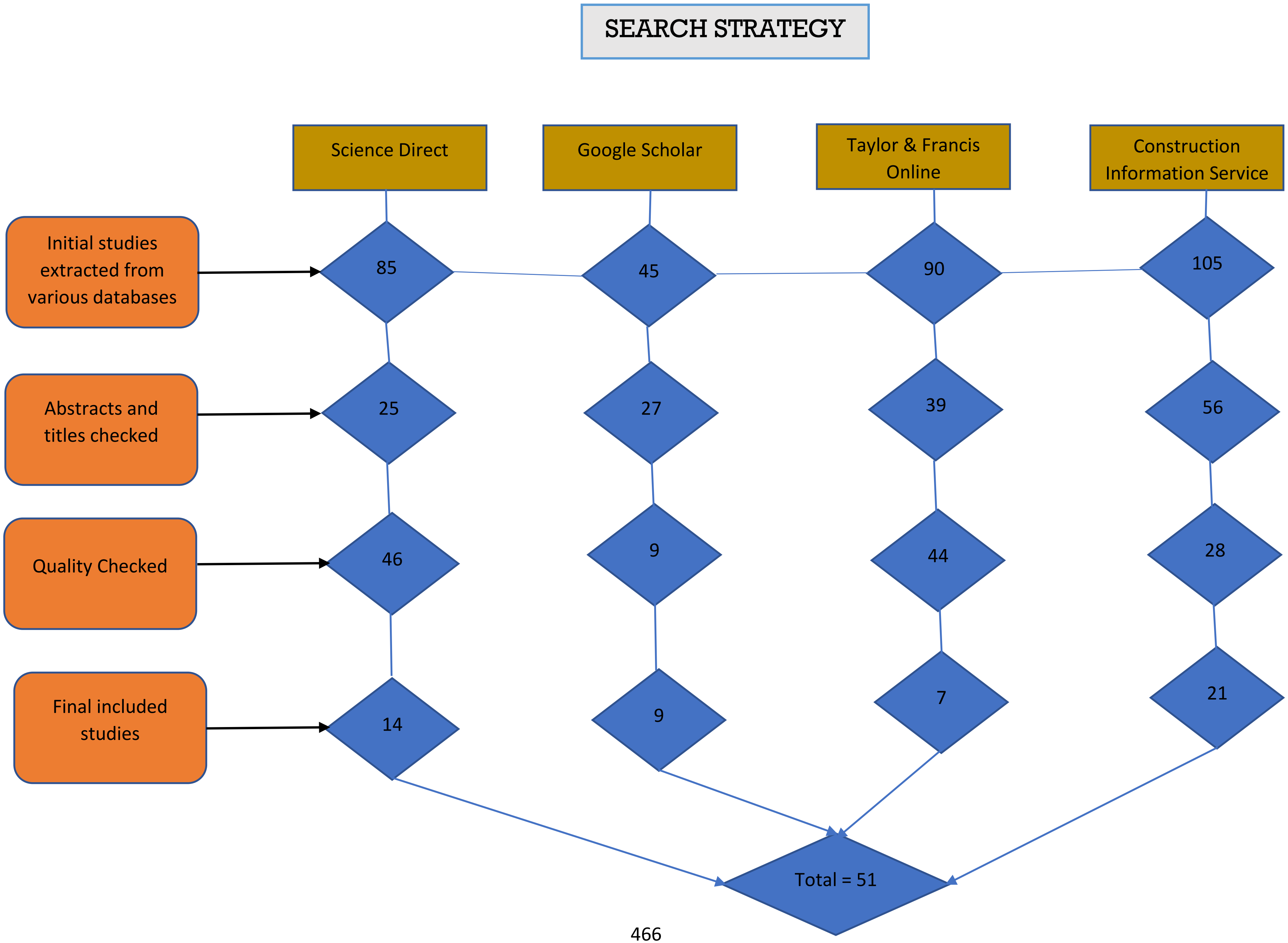
Mapping Relationship between RIBA 2013 and NRM Classification

Mapping Relationship between RIBA- DPoW Stages and NRM Classification (RICS, 2014)

DPoW Stage / Definition	Stage 1 Brief//Preparation	Stage 2 Concept	Stage 3 Definition	Stage 4 Design	Stage 5 Build and Commission	Stage 6 Handover and closeout	Operation and end of life (In use)
Model	Professional design team model		Specialist design/construction model		Construction record model		
BIM Execution Plan	Pre-contract BEP			Post-contract BEP		**Operation BEP**	
Measurement details	.RICS NRM1 .GFA/functional unit order of cost estimate .RICS NRM3 .WLC	.RICS NRM1 .Elemental cost plan . RICS NRM3 .WLC	.RICS NRM1 .Elemental cost plan /approx.Quantity. .RICS NRM3 .WLC	.RICS NRM1 .Detailed Cost plan/approx. Quantity .RICS NRM2 Trade /work .RICS NRM3 .WLC	.RICS NRM 2 trade/work package/contract BQ/schedules	..RICS NRM 3 .WLC	.RICS NRM 3 .WLC
Cost-consultancy outputs	.Schedule /verification of accommodation types .Schedule/testing of any feasibility solution key quantities .Commercial COBie requirements and input to the overarching strategy	.Schedule/ verification of accommo-dation types .Model-linked costs for rapid iteration/ updates	.Schedule/verification of accommodation types .Model-linked costs for rapid iteration/updates .Life cycle costing quantity extraction/costing	.Schedule/verification of accommodation types .Model-linked costs for rapid iteration/updates .Life cycle costing quantity extraction/costing .As-designed vs as –tendered analysis (assuming model enabled procurement)	.Ongoing validation of area and quantum .Change control		.As-build life cycle costing

APPENDIX F

Search Strategy


SEARCH STRATEGY
Science Direct
Google Scholar
Taylor & Francis Online
Construction Information Service
Initial studies extracted from various databases
Abstracts and titles checked
Quality Checked
Final included studies
85
45
90
105
25
27
39
56
46
9
44
28
14
9
7
21
Total = 51

APPENDIX G

Sample Transcript

5D BIM Information Manager

RQ: Just to start, I would just like to know your background and experiences, knowledge of BIM and how long you've been working on BIM.

PR: I've got a masters in mechanical engineering from France, then I moved on to Canada to do a masters degree in civil engineering where I did some research on BIM related technology, so more specifically, I was interested in laser scanning point cloud used on site and then compare the BIM model the way it was created and then the detail that we got from the site.

So we compared the laser scanning point clouds to the BIM model and then we were running some comparisons with some clever algorithm, to see what was actually built on site was what was planned, so we compared it that way, so it's a bit of basically where BIM comes from for me, at least, so that's what I did for two years to get my masters there.

So it was technology BIM rather than standards and processes, like no cost consultant stuff whatsoever, so that's where I come from and then to get this job, which is how to apply BIM, or more specifically, BIM Level 2 for my company which is cost consulting in project management.

So like I said, they wanted somebody who didn't have any preconceptions, or misconceptions about what cost consulting was, they wanted somebody who had an overview of BIM and understood where it was going and was interested in it and then could apply that more specifically for cost consulting. So they wanted somebody from the outside to come in, rather than somebody from the inside, to look at BIM that way.

RQ: Just before we get into the questions, definition of BIM Level 2 is not clear. What do you think is the right definition for BIM Level 2?

PR: So it's a good question. It's a funny coincidence, in my mind, until literally two days ago, we did not know what BIM Level 2 was and I'll tell you why and I'm sure you'll see where I'm going with this, the mandate just came into action two days ago precisely and finally, the BIM task group has put online, the website called BIM-Level2.org, so it finally came out; we've been asking for this for ages and it basically tells you what BIM Level 2 is in terms of the standards that are inside the bubble called BIM Level 2.

Until literally two days ago, we sort of had a hunch of what was BIM Level 2 in terms of the standards, but we were not sure of what the picture was. For example, the standard code, the government's Soft Landing - which I always assumed was going to be BIM Level 2 because that's what we've been told for months and months - actually is not in BIM Level 2 according to the website that came live 48 hours ago.

So what it's got is the BIM Level 1 standard BS 2007, so that's not really BIM Level 2, but I guess we could put it in anyway and then you've got the usual PAS 2, PAS 3, BS4, so we always knew that these were going to be BIM Level 2, but outside of that, we were not really sure. So now we kind of know what BIM Level 2 is in terms of the standards, so it's a bit clearer for everyone now.

RQ: So in terms of the standards, but the outputs of BIM Level 2, what could that be? What would organisations have done at the end of a project and that the client would say 'yeah, that was BIM Level 2 in that project.'

PR: To me, there's a few things. Where BIM Level 2 starts is basically just everyone acknowledging that sharing information and collaborating is the best way of doing things because in my mind, in the construction industry pre-BIM Level 2, the way things were run was trying to omit some information for somebody to bid too low and lose some money - to me that's how it was before - so basically, omitting information to screw somebody over and BIM Level 2 is trying to take the way the construction is being run and just turn it on its head and say 'from now on, we're going to collaborate and the information is going to be transparent for everyone.' So no-one gets screwed over and we all know where this is going. So to me, that's it, collaboration in terms of sharing information, so that's where it comes from. — Common Data Environment (CDE)

Now, the second thing that BIM Level 2 is to me and what you can see in the output that you're asking for, the input first is clients' requirement - if you don't have that, you don't have BIM Level 2 - so it's got to be client driven; if it's not client driven, it's not BIM Level 2; it could be BIM, but it's not BIM Level 2 and the output is basically, you've got your asset built and then you've got the asset information model which is the BIM model as it was designed and within it, all the information that you will need in order to run your asset properly.

So we've got the 3D model of the building with all the information that you need and that is stuff like warranty information for every, single object in the model, the cost information for every, single object in the model, all the information that your facility management team will need in order to run that asset properly.

RQ: Has that been possible for the model to hold that complexity of information?

PR: What do you mean by that?

RQ: Is there any test where the model is able to hold all this complex information because the information is quite complex. Has there been any case study where it's possible for the model to hold all this information electronically?

PR: Yeah. So in my mind, or as far as I know, there hasn't been any case studies that I've seen where that has been achieved. A lot of people you can talk to at conferences and BIM events and stuff will tell you that they've been doing BIM Level 2 and that just drives me mad because they don't actually provide any proof that they have - they say they have, but I'm sceptical - so to answer your question, I've never seen any asset information model, like I was so describing, so I guess the 3D model, plus all the information, non-graphical information that goes with it, I've never seen it. So as a cost consultant, maybe I worked on projects that actually achieve that, but I didn't see it. I'm not saying that it doesn't exist, I just haven't seen it.

RQ: Eastman Charles he did a definition of BIM Level 2, so I just want to know if you agree with that. It says 3D managed environment using separate discipline BIM tools.

PR: I would disagree with that. I would disagree with the 3D aspect of it. So environment, yes; disciplines, yes; but not the 3D because my main point being that when people think of BIM, they mostly focus on what the M in BIM means, so they see model, therefore it must be a 3D model. They're partly right, but it's not what BIM is about. So there's 3D stuff I would eliminate, to me, it's not 3D, it's multiple dimensions, it's not just 3 ... so obviously, if you're doing 5D stuff, but it's not just that, there's the 4D planning, there's the 6D life cycle costing and then there's the sustainability, there's the risk assessment, there's plenty of things, so 3D I would get rid of, immediately.

RQ: So you better go by a file based collaboration of library management, would you agree with that?

PR: The BIM Library, yes, that's part of it. I'm not sure which definition I would go for, but I would definitely have something like digital environment, something like that, something along those lines.

RQ: Than being specific of 3D, right?

PR: Yeah, get rid of the 3D, that's misleading and it's not helpful.

RQ: At what phase of design model development is the contractors' knowledge and involvement needed in BIM?

PR: I don't have a definitive answer ... in my experience, unfortunately, it's stage 4, stage 4 being the last stage of design in terms of the RIBA stages.

RQ: That's technical design?

PR: Yes, I think it is, yeah. So in my experience, that's where the contractor on D&B projects comes in, takes over the design and carry it to completion and then does the whole QS thing along.

RQ: Why not from the outset?

PR: So that's the second part of my answer. When I said 'unfortunately,' that's because of the way things are currently, he comes in at stage 4 and then does his job. To me, that's good, but it's not enough; I would rather see contractors coming in earlier than stage 4 in a two stage D&B tender would be my preference because having a contractor involved with the project earlier than stage 4 has benefits, to me, so we're talking earlier buildability analysis, we're talking earlier supply chain sub-contractor procurement solutions - basically, all of it earlier - so I would rather see the contractor on board at stage 2 or 3, rather than 4, but it is currently, usually 4. — Early Contractor Involvement (ECI)

RQ: So what is happening now, the entry point is 4.

PR: Yes.

RQ: What you're suggesting is the ideal should be 2.

PR: Yes.

RQ: Beside the benefits just mentioned, any other benefits?

Early Contractor Involvement (ECI)

PR: I've actually got a list ... so we're talking advice on buildability, advice on value engineering, stuff like early procurement, like I was mentioning, with the whole supply chain of sub-contractors and their solutions. So rather than the architect sitting in his office and coming up with some solutions that won't actually work when it comes down to build; you've got your sub-contractor very early saying 'actually, that's not the way it's going to work, I've got my solution, here it is.'

So value engineering, buildability, procurement, early advice on costing and programme because he knows how it usually runs because it's got the experience of early advice on programme cost; health and safety issues, that's going to be a problem down the line in stage 5, so if you take care of that as early as possible, that's fantastic and I think the biggest advantage of an early contractors involvement in the project is the transfer of risk from the designer and the client over to the contractor. So he basically takes the risk for all of the design early on which is great for the client and the design team, it's the biggest advantage.

RQ: So the advantage will reduce the design errors passed to sub-contractors.

PR: Yeah. It's transfer of the risk.

RQ: Does procurement strategy chosen by a client affect contractors' point of entry? You just mentioned D&B and currently, what's happening is from stage 4, that's their point of entry, but assuming the client has chosen traditional method or construction management, or PFI, or other forms of procurement strategy with different contractor administration, so does that procurement strategy chosen, or decided by the client affect contractors' point of entry, or involvement into the model development and to what extent, considering RIBA Plan of Work 2013?

PR: If we're taking a traditional method, the contractor is gonna come in at stage 5 which is way too late to do any design work, so all he's gonna have to do is literally take the model and build it, that's it. So there's no design solutions from the contractor, he's just got to build it; there's no advice of any kind, so to me, that's bad because the contractor knows better than the design team, how to build an asset and so if he doesn't have any design input because he came in at stage 5 which is construction, you don't benefit from that. — ECI

RQ: So who bears that risks that are encountered at stage 5?

PR: That's a good question and I actually don't know the answer to that. I guess it's the design team, but if the contractor signed on to what they knew they were building ... again, the whole transparency thing of information that I was mentioning earlier, when you're a contractor and you're bidding on a project, that's because you've been given all of the information that you needed, so if the contractor said 'I'd build it for £50 million, well then it's his problem.

RQ: Looking at your response on procurement strategy chosen by the client, do you see BIM rewriting some procurement strategies like affecting the concept or the idea behind traditional procurement? Do you see BIM affecting the procurement route at all in terms of what their content are since the benefit in BIM wont be achieved if they use traditional procurement is used? Will it be written, or tweaked, or altered, adjusted? What do you think? Because at the moment, the traditional methods seem to be the most used strategy than D&B.

PR: Yes, exactly. So to that point, to me, the use of BIM is going to encourage design and build, rather than traditional, so yes, traditional is the way that things are being done right now, mostly and I think that it's going to slowly transfer to D&B being the major way of doing things because it encourages the early involvement of the contractor through the transparency of information, so to me, that's where it is going to go ... more D&B rather than traditional.

RQ: So do you see traditional being scrapped later on.

PR: I wouldn't say scrapped ... it would be fantastic in my opinion, but unfortunately, it's still gonna stick around because let's face it, the construction industry is not all that smart.

RQ: I'm just wondering again, what would be the perceived cost implication of a chosen procurement strategy in 5D BIM implementation?

PR: So to me, having a contrac[illegible] on board earlier, so that's D&B, should reduce the cost of delivering the building for several reasons; first because you'll be on site earlier which means that you can invest immediately, you don't have to wait and sit around with that pot of money not being used, so you'll get on site earlier, so that's one. Two, having the contractor on board earlier, like I was mentioning, you will avoid problems of non-buildability because he knows how to build his building and he'll see immediately if there's a problem in the design, so that's fixed before getting on site which means that you don't get problems later on on site like crash detection and just general buildability issues, so you don't have to spend the money on that, so that's two reasons why the cost should go down for delivering a building that way.

Now, there's also a reason why it could go up because if you've got the contractor on the project earlier, he will sort of try and influence the way you build your asset by encouraging your design to spend more on the delivery aspect because that's in his interest. So you've got to weigh those two aspects, but just generally, in terms of BIM, which I think was more your question, employing BIM, you should, as a cost consultant, now be able to do two different cost analyses; you should be able to do the delivery as usual, to CAPEX cost analysis and then, if we talk about 6D BIM a little bit, you should now start to be able to do the life cycle costing analysis for the building and as a client, if you had both, 'this is how much it's gonna cost me up front to build the building and then how much it's going to cost me over time for the next 30 years for maintaining my building?' Maybe now, I can weigh in those two and adjust the design to make sure that the upfront cost is not too high, but allows for a building that you don't need to maintain all that much. — Employer's Information Requirement (EIR)

RQ: So you still go for D&B as the best solution.

PR: Definitely, no question.

RQ: From the contractors' perspective, how has BIM been able to integrate the value of contractors' knowledge during model development phase, from the cost angle? Looking at some factors, improving communication, mitigating contingencies, possible reduction of constructional sequence conflicts and errors passed to the sub-contractor ... that is the question I told you we would come to later on ?? So how, from the contractors side, how has BIM been able to integrate the value of contractors knowledge to mitigate some of these factors?

PR: So that's where I get less experienced, so Joe will know more about this sort of stuff, but I can certainly try and answer. Like you were saying, having sub-contractors on board, along with the contractor and passing along the design aspect for their particular field, well then the risk is passed on to the sub-contractor, so in terms of cost, if there's a problem, that's not your problem in terms of you being the contractor in this case.

So in terms of liability, it passes on to the sub-contractor, which I think is being addressed in the CIC BIM protocol in terms of design and procurement when you have a sub-contractor on board, everyone's liable for their part of the project, or the model. So that's in terms of liability and in terms of costs, it's basically attached to the same issue of risk being passed on to whoever is responsible.

Employers Information Requirement (EIR)

RQ: Presently, to what extent are the contractors engaging BIM in their project costing related activities?

PR: In my experience, the way it's been run, you've got us, the cost consultants who take the model from the designers, we then run our 5D BIM capability, so we'll take apart the model, make sure that we investigate it from our angle, come up with our cost estimate, based on the quantities that we found in the model, then when the design team and the client is happy to move on to tender stage, what we do to give the information to the contractor is we will give our information to the contractors, but the way we do it is, instead of just saying 'this is the model, this is the cost estimate attached to the model, now investigate it yourself as the contractor to put in your bid.' Then what we will do is detach the two, the model and the cost estimate ...

RQ: ... that's the cost estimate with the rates attached.

PR: Exactly, so we don't put in the rates and we don't even put in the quantities, but I'll explain ... the way the software works, the one that we're using, CostX, the way it works is you've got your model inside the software and then you write your templates for quantity extraction, whatever it's called, so you write your code - we call it model mapping - you write it and then that's going to investigate the model and give you the quantities on the other side.

So the way we do it, well we deliver the cost information to the contractors for them to bid on a project, we'll give them the model inside CostX and then we'll give them the template to use to extract the quantities.

RQ: Who develops the template?

PR: We do. So it's a file produced by us on CostX, basically, the way it works, if you have CostX, on our end, we have all the information, so we've got the model, we've got the estimate and we've got the link between the two.

When we give it to the contractors, we'll get rid of the quantities on the cost estimate, but we'll give them what does the job of extracting the quantities and put them in the cost estimate. So essentially, the reason for doing that is the risk is transferred to the contractor, for two reasons, 1) if we made a mistake, well that way, it doesn't actually show the quantities in our cost estimate when we give it to the contractor, so we didn't make a mistake in that sense and 2) if the contactor chooses to use our template, they'll get our solution anyway, but it's their choice, so if they do not choose to use the template and they just want to do the job themselves to find out the quantities and then rate, then it's their problem, they can choose to use their template, or they can't, it's entirely their choice.

RQ: The model inside CostX, where do you get it from? Do you import the model from ...?

PR: ... yes, the design team. There's two formats that we can use, one is DWFX which comes from Revit Autodesk and the other one is IFC which can come from anywhere. We usually ask for both of them and we usually try to use the IFC first because IFC is where BIM is going in terms of the open BIM idea, so we always try to use the IFC first and if the information is not in the IFC, then we move on to the DWFX which usually does the job.

RQ: What about the issue of transportation of files? Have your organisation been able to resolve that problem of losing intelligence when you are transporting files?

PR: There are some issues around using, first DWFX because ... well, first it comes from Revit which means that if you've got some designers working on Archicad, they won't be able to produce a DWFX because that's purely Autodesk and so that's one issue. The second issue is that DWFX is basically a watered down version of the Revit model, so there is some information that will not transfer from the Revit model into the DWFX file that we use, some information will simply disappear.

RQ: So you lose some intelligence.

PR: Yes, you lose some data; so not the graphical data, but the data that's embedded in the graphical information.

RQ: Would that not affect ...?

PR: ... it does, yeah, so that's why we mostly try and use IFC first because IFC is supposedly better at preserving the information that was created. Now, the issue is, although IFC is supposed to be better, it all depends on how you export the IFC model; when you export the DWFX model, you've got no options whatsoever, you'll get whatever the software gives you.

When you export an IFC model, you've got more options, so it depends on the quality of the template, the export template, that the designer has in terms of he's gonna have some options that says 'I want to export this data, etc.,' so he's got plenty of options to tweak, to make sure that the IFC model that he exports and gives to us contains the information that we will need. So IFC is better at that, but your designer needs to make sure that he knows how to export the data properly.

RQ: What rule of measurement do you use?

PR: NRM 1 for delivery, so we don't use NRM 2 and NRM3, we are currently looking at the whole lifecycle costing thing.

RQ: You don't use NRM 2?

PR: No.

RQ: You don't deal with the detail design?

PR: We do, but it's simply too much information and basically, no-one really cares about that much detail, NRM 1 is sufficient for the people that we work with for them to have, they're not looking for a Bill of Quantities which is way too detailed and does not give you much more than NRM 1, in our opinion and then theirs.

RQ: What about when the client you're working for has a cost specific document he wants you to use instead of NRM. How does that interplay with your classification rule?

PR: If the client has a specific way that he wants to cost his project with, we'll use that because that's his choice and the way we deal with it is we'll import his template into our CostX system, we'll do the whole costing estimate according to that template and then, once we're done with the project and we want to retain the information that we used on that project for our benefit in our database, we will translate the information using the client's template and translate that into NRM 1 because our own internal database of costs and rates and projects is NRM 1.

So we do the translating exercise, then we put it into our database which is on NRM 1 and we'll have on there all of the cost plans that we came up with along the project, so we've got three or four columns where we put in the NRM 1 equivalent for the projects.

RQ: And the client's happy with that?

PR: Well, yeah because we're using his cost report template the way that he wants and he never sees the NRM 1 equivalent because that's just for us.

RQ: Do you find any difficulty in quantification when you import a model and you want to get a Bill of Quantities? Are there issues around it?

PR: Yeah, definitely because one ... I've actually go a list of issues around that that's going to be in the second edition of that paper, so we've got issues around designers using the wrong object in their 3D models. So for example, a simple column is sometimes drawn on the 3D model as a wall, so instead of having a square column, the designer will just put a very small wall in order to represent that column.

Now, if he sends me the file and I open it on CostX and I simply, without looking at the model, export or do my quantity export, I will have a wall instead of a column, but it should be a column, so it should go in to two different sections in the NRM 1 cost estimate.

There are issues when something is modelled using the wrong tool, for example, a flat roof, sometimes it will simply be modelled as a slab, so obviously, in the NRM 1 cost estimate, you've got two different lines for the roof and all the slabs and if I'm not careful and I just run the system automatically, the roof will go into the slab line, so we've got to be careful around the designer's information because sometimes it's simply wrong, so that's one issue.

Design Optimization

There are issues around, for example, excavation for civils works. For example, drainage, you've got pipes below the ground and the NRM 1 will ask you information around the excavation volume of earth and mud that you need to dig out and put in your drainage and put back in - that information is not strictly intra object property - so simply having the pipe modelled does not give me any information around excavation volumes, so that's something that we need to work out and that's not based on the object itself, it's based on where it's based, if you see what I mean, so that's something that we cannot do automatically, we have to do some clever coding around that, so that's two issues.

Design Optimization

We've got issues around, for example, if it's a refurbishment project, there's obviously a big difference between the wall that you have to build and the wall that's been there all along and you don't have to touch. So in your Revit model, or whatever software you use, in the line ... I don't know what it's called, but you've got to make sure that it says 'new construction' when it's a new object and like 'present,' or 'is already there,' etc., so we've got to make sure that we don't count objects that were there all along, that we don't have to touch, so that's an issue. So that's three major issues, I've got some others, but ... yeah.

RQ: So than means NRM 1 has some deficiencies as well, it doesn't cover everything.

PR: No, NRM 1 does cover everything ...

RQ: Like the issue of the volume of earth you talked about.

PR: So NRM 1 requires that information and it's not an information that you can get strictly by looking at the objects in the model. So if we go back to that example, you've got your drainage which is below ground level, having the slab at ground level and the pipe below ground level does not give you the information that you need of volume 'cos yeah, I've got my drainage pipe information, I know how long it is, so I can put that in the proper NRM 1 line for the drainage information. I've got the slabs, so I know where to put that in my NRM 1 estimate, but the excavation volume is not given to me strictly by having those two objects, the excavation volume is not an object in itself, it's a dimension between objects, if you see what I'm saying. So NRM 1 is asking for that information and I don't simply get it by the objects themselves, it's a property between objects, so we've got to do some clever coding to capture that information.

RQ: Beside those problems, generating Bill of Quantities digitally, it's quicker. How can you compare that with the traditional?

PR: It's incredibly quicker. We actually ran a test in the office, we were on a specific project, we were given the usual 2D drawings and the 3D model. Now, the QS that was on the project came to us and said 'guys, I've got the model, I've got the drawings, how about I do the usual exercise that I'm required to do on the drawings, I'll take off whatever I can from the drawings, you do it with your 3D model the way that you do it with your CostX thing and we'll compare the results and how long it took us.'

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So at that point, it was just a steel structure for some shop, but big, steel structure, plenty of different beams and columns to take off. It took him half a day to take off all the steel structure and I can't remember the numbers, but he got to somewhere like 1,000tons of steel, something like that, in half a day. He gave us the BIM model, it took us 15 minutes to take off the information and we arrived at maybe 1,150 tons, so because our system is strictly based on the quantities within the model, as such, we can't be wrong, so we for sure have the right result for the steel structure and he was close, but he was not there, he was wrong by 15 per cent and we did it, again, in 15 minutes instead of half a day, so that gives you good information there.

RQ: And the rate is still being added on a spreadsheet?

PR: Yes, but there's actually a clever way of doing it, so if you have a client that builds multiple assets and you see the same objects coming up over and over again, from project to project, you can set up some sort of clever template within the system to recognise which object it's already seen and attach a rate to it.

So again, if you're clever, project 1, you'll just do it manually, put the rates in manually and then if you know that that project ... another project, but using the same objects, will come over and over again over time, you can set up a template that will recognise the name of the object and automatically attach the rate to it.

So over time, as you build your library of objects with the rates attached to it, you've gained an incredible amount of time because you don't have to do the rating up any more, manually.

RQ: So it's just a prototype object?

PR: Yeah. So the first time manually and then if it comes up again, it's automatic.

RQ: Okay, but that's not in existence and the moment, it's still being worked out.

PR: Here's the thing, it entirely relies on the information given to us by the designers, so if it's the same designer working on the different projects and he uses always the same naming convention for his objects, then we can set up our template on it. If he changes the name, it's gonna change the links, the clever links that we've put inside of our system to put in the rate which is why it's incredibly frustrating for us to work with designers who do not have a naming convention in place because it will screw up our automatic rate up system.

RQ: Do they have to name all the objects?

PR: It's already named. If you go on Revit and you want to put a table in that room and you've used always the same table, it's got a name, but sometimes because they choose to be annoying, or because they don't know what they're doing, they will change the name; so sometimes it will be called a wooden table and the next project, it's going to be called table 1 and the next time around, it's going to be called table 001 etc., so we rely on the naming convention of Revit, or whatever system. So whatever comes in, that's the name, that's what we rely on; it might be the same table, or if it's not, if it doesn't have the same name, then we lose the clever link, so we can re-establish it, but that's a waste of time. So for us, the critical thing for the design of information in models is the naming convention, it's got to be one and it's got to be respected.

RQ: So the BEP has to take care of that from the outset.

PR: Yes, absolutely. So the BIM library has to be in place and a new convention has to be respected.

RQ: The NBS Object Library, is it useful at all, or do they have a different naming convention ...?

PR: A different naming convention ... for us, it doesn't matter as long as there's one, then we can rely on it and again, the first project is going to be manually, then we rely on that naming convention - whatever it is - as long as there's one, it's okay for us.

RQ: How do you consider cost data management within BIM environment, or process?

PR: I mean, hubs, it should solve the problem if it was done properly. I'm aware of a software that we will probably purchase for the office who has access to the online BCIS Rate Library and ...

RQ: ... which one has the access?

PR: It's CostOS. So that has access to the BCIS library online, so basically that's taken care of, you don't have to worry about it, that's done. Now, if it doesn't have that information, you need to create it, relying on your own experience as a QS.

RQ: So using CostX, do you have to create that?

PR: Yes, that's the issue. That's, basically, the biggest reason why I'm lobbying my boss to switch from CostX to CostOS because it's not good enough, in my opinion, for dealing with the cost database. It's good enough from one project to the next, if we're talking the same client with always the same objects coming in, then that's fine and as I was saying before, you rely on those clever links.

If you go to an entirely new client with similar objects, then you lose your database and it's simply not good enough, you can go back to the previous thing and do some copy paste thing, but that's not efficient, or reliable. If you add access to the online thing of the BCIS and you get all online information, then suddenly it becomes more reliable, but currently, CostX, in my opinion, is not good enough with that, CostOS is better.

RQ: Are there any other online cost data at the moment or just BCIS?

PR: Not that I'm aware of, just BCIS.

RQ: What are the suggested ways you feel, in your years of practice, can support incorporating cost data within BIM environment? I understand, currently, it's an external link, it's isolated at the moment, you have to create the link to get it in.

PR: Well in a sense, yeah. I wouldn't call it outside, I would call it inside, but not linked. So it's in the system, but you have to manually go and grab it and link it to your system, or to your objects, specifically.

RQ: Is there a way to incorporate that cost data into the BIM environment?

PR: It goes back to what I was saying earlier, if you have a naming convention in place, admittedly, you've got to have ... if you've got two pieces of information and they've got to be linked somehow, you need to have a common denominator that attaches this to that, A to B, there's got to be a point that says 'well, actually, you're linked into it

That, to us, at the moment is the naming convention. So if A has a proper name, then B is automatically attached to it because it recognises that name, therefore it's that rate. So right now, we rely entirely on the naming convention which BIM addresses, so theoretically, that works. In practice, when the naming convention is butchered by the designers, we lose the link, but BIM should have that link in place.

RQ: Any other way?

PR: No, I think that's it.

RQ: What would you say regarding construction cost efficiency using BIM costing software, in contrast to ...? I know you've talked a little about it, but if you can go deeper regarding construction cost efficiencies in BIM costing software in contrast to the traditional costing approach.

PR: Something I haven't touched on yet is the revisions. If you go traditional as in 2D drawing... During the life of the project, during the design phase, you'll get ... again, if you follow the RIBA stages and the

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way that you've set up your BIM Execution Plan, you will get data drops which means that at stage 2, you'll receive your model and at stage 3 again, at stage 4 again, so we have to conduct our cost exercise three times, in theory which means that if it was a traditional project, we'll have to do the whole thing manually every time, so that means re-doing the exact same exercise on the exact same objects to make sure that they're still there and they're still the same dimension. The level of information increases, but some objects will be exactly the same because the designer chose to put that wall there, it's 15 metres long and that may not change from data drop 1 to 2, to 3.

If it's traditional, the guy with the ruler will go in and say 'that's 15 metres.' The second time around, 'yeah, that's still 15 metres.' If it's BIM, we don't have to do that because again, if it's the same wall and it's got the naming convention in place and it stays consistent from data drop 1 to the next, the next, the quantities will change automatically, so we don't have to go in manually and say 'oh yeah, still 15,' etc. The system will tell us 'it's still 15,' or the system will tell us 'no, it's 17,' so we don't have to waste time re-taking the same information; we'll only worry what's new. What's new, we worry about and we take care of it; what's old and hasn't changed, or has changed, but was already treated by the system, that's automated, that's gonna take care of it, so the revisions in BIM are much more efficient , so in terms of cost for us, that's great 'cos we don't have to spend that much time on it.

RQ: How do you handle variations and level of detail and level of information from different disciplines? It's a question outside my box now, but a few things you said just brought me into that thought; how do you handle variations in the level of detail and level of information, considering individual disciplines and looking at the RIBA stages?

PR: The way we see things is that you'll get your data drops at stage 2, 3 and 4. Level of detail and information, like you were saying, will increase from 2 to 3 to 4. One of the main reasons why we use NRM 1, rather than NRM 2 is because NRM 1 has the versatility to deal with different levels of detail and information.

If you look at NRM 1, towards the end in the appendix, it basically describes to you three different formal cost plans level of detail. You've got FCP 1, 2 and 3, so you go into more and more detail as you go. Now, if everything goes according to plan, at stage 2, you get your spatial model - it's very high level of detail, it's just gonna be some spaces here, whatever, place holders there for the next guys who come along and do some work etc - so at stage 2, we'll have a very high level cost estimate, only the big categories, we can't go into too much detail because the detail is not there and we'll mostly base our cost information on the area of those spaces, so that's at stage 2.

At stage 4, when the full detail is there, we will have our cost based on the objects, rather than the area. At stage 3, it's sort of an in between where some things will be fully designed and some will not, so it's a mix between area rates and object based rates. NRM1 has the flexibility to deal with changing level of detail, that's why we use it. We'll go from area based to object based as the detail comes in, if you see what I mean.

RQ: Looking at the contractor, the procurement strategies and cost activities, we've got a triangle and you have each on the note ... so that's contractor, procurement and costing on each of those notes. What would you say your experience would be expected in BIM impact at each of these notes, in the present and in the future?

PR: Between contractor and procurement, it goes back to what I was saying earlier, BIM allows the contractor to come in earlier into the project, so at earlier stages than 5. So he comes in earlier, he can quickly set up his supply chain, so that's all the sub-contractors etc., and that's going to be very clear in his BIM Execution Plan, so you've got that information earlier ... I think that's pretty much it for contractor procurement.

Contractor costs is his costs will be based on as much information as possible, rather than before where some information was hidden and he could, potentially, bid too low, or too high based on that lack of information, but because now it's there, he knows exactly what's going on, therefore his cost is more accurate and you deliver better projects where everyone is happy along the supply chain ... and in terms of cost and procurement, what can I say about that? I think I sort of touched on it between having more accurate costing information earlier, or more often I should say and more accurate, allows for, I guess, the ... I'm losing my trend of thought ... the procurement method of having the guys earlier involved in the project allows for a better, more accurate cost information and that does not necessarily mean that the cost of the project will go down, but it is more accurate and reliable, I would say.

RQ: What is the best practice, in your experience, costing experience specifically, to follow in order to achieve contractors' cost effectiveness using BIM and what are the risks that you perceive relating to cost output?

PR: I would go to the BIM Execution Plan. To me, to have the most accurate cost information - which is I think what you are touching on - you need to have a very, very clear and defined picture of what the information will look like at the different data drops. So if it is incredibly clear in the BIM Execution Plan, what detail will be delivered at each data drop, us as QS's, we know what's going to come in and we can prepare for it and we can immediately see whether some information is lacking and we therefore can't do our job properly, or there's too much information which is not a big issue, it means that they've already moved on, but we can disregard that information and just focus on what we need for the purpose of our exercise at the different data drops.

RQ: Specifically, I'm just wondering if you have an idea of what the best practice could be to achieve cost effectiveness, or contractors' cost efficiency using BIM?

PR: Well, to me, that's the BIM Execution Plan because you've got the BIM Execution Plan for the designers and you've got one for the contractor in his supply chain of contractors and sub-contractors.

RQ: What are the perceived risks, negative or positive?

PR: Positive because your sub-contractors will be involved early and know exactly what to deliver, therefore the cost information is more accurate, so that's very positive and negative, I'm not sure there is any.

RQ: Finally, what would you say is the future direction of 5D BIM costing and what do you envisage are the challenges, as much as the benefits?

Automated quantification & integration of process information

PR: The challenge goes back to what I was saying earlier - the fact that 5D BIM relies on 3D BIM which is the information produced by the designers - in a sense, what I always say is, as QS's, we are the first users of the data that's been produced, therefore our work relies on other people doing their job properly and within that category, we have the naming convention that I was talking about earlier, if that is not respected by the designers, then we are falling behind on our work, so as first users of the data, if the data is not right, we have a problem, so that's a problem for the 5D BIM element.

In terms of the benefits, that is basically it's faster, more accurate and it's only going to get better and better in my opinion because as much as I hate to rely on technology and software, they are getting better and I guess the competition between the software providers is something that drives that technology to improve more and more. So 5D is going to get better and the cost consultants will not, in my opinion, be threatened by 5D BIM becoming more accurate and better in general, you will still need your cost consultant to do the 5D BIM exercise, even though it gets better and more automated.

RQ: Finally, I just want to know if the scope of costing activities using BIM on a project, does BIM shrink it, or does it expand it or causing scope gap?

PR: To me, the scope is much wider because now we actually have the time to spend on things that we maybe in the past did not cost. I know that we're talking about 5D BIM specifically, but BIM, in general, is now allowing us to do lifecycle costing which is 6D BIM earlier than it's been done, traditionally. So the scope is, in that sense, doubled because before you only worried about the CAPEX delivery of the project and now you can also worry about the OPEX cost, so CAPEX, OPEX, TOTEX, you can now worry about all of these things, rather than just CAPEX, so in that sense, the scope has more than doubled.

RQ: Which one is TOTEX?

PR: TOTEX is total expenditure, so it's CAPEX plus OPEX equals TOTEX.

RQ: Thank you very much.

APPENDIX H

Qualitative Interview Questions

Qualitative Interview Questions

Research Instrument (Semi-Structured open-ended interview questions)

1) Participants' background
- What is your experience and knowledge working in a Building Information Modelling (BIM) cost related projects?
- what experience do you have working in CAD, 2D, 3D, 4D, and 5D BIM environment?
- What professional membership do you hold?

2) It is not clear at what phase of design model development the contractor's knowledge or involvement is needed using Building Information Modelling (BIM), in your experience what is your opinion?

3) Does procurement strategy adopted or decided by client affect contractors point of entry or involvement into model/project development and to what extent considering RIBA Plan of Work 2013?

4) What would be the perceived cost implication of a chosen procurement strategy in 5D BIM implementation - design and build (stage 1 & 2), traditional method etc?

5) From the contractor's perspective, how has BIM been able to integrate the value of the contractor's knowledge during the model development phase from the cost angle - improving communication, mitigating contingencies, with possible reduction of construction sequence conflicts and errors passed to the subcontractor?

6) Presently, to what extent are the contractor's engaging BIM in their project costing related activities?

7) How do you consider cost data management within the BIM environment/process? What are the suggested ways you feel in your years of practice can support to incorporating cost data within the BIM modelling environment? - (issues of cost data incorporation within the design model)?

8) What would you say regarding construction cost efficiency using BIM costing software in contrast to traditional costing method?

9) Looking at the contractor, the procurement strategies, and the costing activities - what would you say in your experience will be the expected impact of BIM processes at each of these nodes (i.e contractor, procurement strategies and costing activities) both in the present and the future?

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10) What is the best practice in your costing experience to follow in order to achieve contractor's cost effectiveness using BIM and what are the risks (negative or positive) involved relative to cost output while engaging BIM process?

11) What would you say is the future direction of 5D costing within the BIM environment and what do you envision will be the challenges (immediate/future) as well as the benefits for engaging such process?